'FOR THE POOR TO DRINK AND THE RICH TO DRESS THEIR MEAT': THE FIRST LONDON WATER CONDUIT

David Lewis

SUMMARY

This paper traces the history of London's first piped water supply that operated for at least four hundred years from c.1260. The London water supply system or 'conduit' was a complex and expensive piece of infrastructure — construction costs were probably equivalent to those of a cathedral — yet it has undeservedly been omitted from many accounts of the urban history of the city. This paper contends that an appreciation of medieval water transportation technology not only demonstrates the true scale of the enterprise that conceived of the London conduit in the first instance, but also explains the subsequent difficulties in building and developing the system.

Although there are few documentary sources on which to construct a comprehensive account of the medieval London conduit, the recent excavation of a small section of the original pipe-work (Paternoster Square, 2001) has provided important new evidence on how the system was built, its capacity, and the likely reasons for the incorporation of ever more remote sources of supply. The development of the system is tracked from a single public fountain in the City (Cheapside) in the 13th century, to a network of elaborate fountains by the 15th century that used only the forces of gravity to transport water (eventually) more than 6km through underground pipes, from springs near the modern site of Paddington Station to the fountain heads. Although the physical remains of London's first water conduit are now almost entirely lost, this paper seeks to reappraise this important part of the medieval City and to rediscover why the conduit was the subject of such celebration at the time, attracting financial donations from the City's wealthiest medieval merchants.

In his book on the history of water supply in England, Norman Smith notes that 'before 1600 London had made little attempt to pipe or channel water supplies from clean sources outside the City' (Smith 1975, 96). Whilst this opinion is at the very least contentious, it reflects the fact that most narratives on the history of medieval London pay scant attention to the availability of clean water; a surprising omission considering the fundamental importance of water for many facets of life. In mitigation perhaps it might be contended that as the City is located on the Thames — and a number of other river systems — water would have been readily available. Moreover, given the maritime climate of the British Isles and the geological basin that forms London's underlying rock strata, rainwater would have filled the many City wells that are known to have existed. The supply of water should therefore have been the least of the problems facing the medieval City authorities.

Whilst it is undoubtedly true that there was no shortage of water, the real issue was not availability, but purity. As early as the mid-13th century many of the London water sources were becoming heavily polluted, and the City authorities perceived that they needed to take action to provide clean water; well and river water might have been suitable for washing, but were rapidly becoming unsuitable for personal consumption. The pressure of population growth, including industrial activity within the City, was poisoning the local environment. Although the exact date is unclear, probably by 1260 the City had built, at considerable expense, an underground piped water system that brought spring water from about 5km to the west of the City, a system known as the London conduit or later the Great Conduit. The system used only the forces of gravity to move water through the pipes that ascended Ludgate Hill — apparently contradicting the forces of nature — to reach an elaborate conduit fountain at the eastern end of Cheapside. Although the development of the system was tentative at first, it was gradually extended, so that by the 15th century it represented a significant distribution network that stretched from Fleet Street to Gracechurch Street (Schofield & Vince 1994, 52). Regrettably, this early public utility, incorporating a complex of water filtering devices, pipes and cisterns, was largely destroyed in the Great Fire or in the subsequent reordering of the City infrastructure. In addition, and probably at the same time, it seems that the primary records of the system, most likely consisting of wardens' accounts, journals, and plans, were comprehensively destroyed. Although the London conduit was probably the first purely urban water system in England, the paucity of either direct documentary or archaeological evidence has consigned it to a minor footnote in the history of the City. It is not known, for example, who designed and built the system, although undoubtedly the application of complex hydraulic technology within an established city environment would have required considerable expertise.

Evidence of the London conduit however is not entirely lost. Most significantly, the recent archaeological discoveries of the undercroft of Great Conduit house or fountain (1994) and a section of the conduit pipe (2001) allow the London conduit to be reassessed and compared to other conduit water systems that are better preserved and even, in some cases, documented (Birch *et al* forthcoming; Rowsome 2000, 61). The relatively few documentary references to the conduit that have survived, such as the City letter books, property deeds, and wills, add further detail, together providing sufficient information to piece together the likely history of the system.

From a review of the available source material and considering the likely existing knowledge of conduit technology, the construction of the London conduit was an extremely bold project. There could have been little certainty at the outset that the system would work, although its construction consumed large quantities of raw materials (particularly lead and timber) and required a substantial labour force, of both skilled and unskilled workers. It represented a considerable financial risk. The fact that it subsequently operated for three hundred years until the Great Fire represents a major achievement that should be ranked in importance beside the building of London Bridge or the Guildhall. Clearly it deserves to be better understood.

THE DEVELOPMENT OF THE LONDON CONDUIT

The availability of drinking water from springs and streams was one of the principal reasons why the Romans decided to site London on the terraces above the marshy north bank of the Thames. Geologically, London sits on a basin of chalk approximately 200m thick, with a northern rim coming to the surface at the Chilterns and a southern rim at the North Downs. Overlaying this deposit of chalk are relatively thin beds of tertiary sands and pebbles, which themselves are overlaid first with a thick layer of London clay and then with a clay and sand mixture known as Bagshot sand. The water-bearing strata for London are found in the tertiary deposits and where these levels are exposed or cut, fresh water springs form. The dissection of these levels in the London basin by the Thames accounts for the number of fresh water springs found close to its banks, such as the St Clements well spring near Fleet Street. The cutting action of the Thames is not consistent however, and particularly in the area occupied by the western part of the City, the number of natural springs is limited. With the growth in the population of London from the 11th century and the parallel increase in demand for fresh water, there was an ever mounting pressure to access new convenient sources of water.

At first this demand was met through digging wells, but for these to be certain of reaching the tertiary levels that held pure, filtered water they would need to be, in most cases, greater than 16m deep. These wells were thus known as 'deep wells'. To be sure of only containing pure water, these wells would additionally require an interior lining of stone to prevent the ingress of surface and ground water that could be polluted with soakage from stables and cess pits, decaying matter from burial grounds, and the residue from water intensive industries such as tanning and metal working (Foord 1910, 250). Inevitably such wells were expensive to construct and were consequently infrequently built. A more common type of City well was the insubstantial 'shallow well'; this appeared to provide clear water, in exactly the same way as a deep well, but with the significant advantage of being both quick and cheap to build. One 13th-century description notes their rudimentary construction: that the well wall bracings consisted of knocked-through wine barrels stacked one on another 'five or six barrels deep', making the well perhaps 6m deep in total (Keene 2001, 173). With insufficient depth to reach clean water, no protection from contaminated surface water, and the minimum filtering of ground water from other levels, the water in such wells was inevitably impure. 'Shallow well' water might have been clear and possibly palatable but it was poisonous, and at worst could have brought 'death in the cup' (Foord 1910, 250). The impurity of City water was dramatically underlined in the 1860s when it was noted that once mains drainage was installed, the City wells comprehensively dried up (Church 1877, 16). The water contained in these wells, from the Middle Ages onward, was nothing more than what we would now classify as drain water.

The connection between clean water and health was appreciated by London citizens, Stow notes that citizens were 'forced to seeke sweete waters abroad' — City water was known not to be wholesome (Stow 1908, I, 16). For direct consumption or for the preparation of food the preference was for water obtained from unpolluted sources such as spring water from Clerkenwell, Skinner's well, or one of the other perpetual springs close to the City. But as water is heavy to carry — a typical three-gallon wooden pipe would have weighed approximately 30lb — the personal transport of water from these sources must have been at best inconvenient, and at worst rendered pure water inaccessible for many households. The temptation to use an impure, but more convenient source, such as a 'shallow well' shared between tenements, must have prevailed in many cases. As an alternative, water could be purchased from one of the City water-bearers who made a trade of supplying Thames river water from horse drawn delivery wagons. Presumably such water was considered of better quality than simple well water, although the purity was entirely dependent upon which part of the river the water was taken from. Thames water could be variously polluted, with sea salt, due to the tidal action of the river, or contaminated by the poisonous water of the Fleet and Walbrook tributaries that were effectively open drains running through the City. Equally river bank water was rendered unfit for consumption by mixing with groundwater and other floating debris (Riley 1868, 223). Clean Thames water could be taken from a central section of the river on an ebb tide, but as this part of the river was also subject to dangerous currents, some skill was required in correctly collecting the water. There could be no guarantees, however, that a water-bearer had necessarily taken the trouble to ensure a pure supply. In recognition of the hazards of collecting water, and in an attempt to control the quality of the water-bearers' product, the water-bearers became the object of 'craft' designation, with their charges being standardised by the City authorities in 1350 (Keene 2001, 169).

It would have been impossible to ensure that Thames water (however it was collected) was consistently of any better quality than well water, as fundamentally London rivers served a conflicting dual purpose. They were both a source of water for consumption and also the primary means of waste disposal for the City — this duality becoming increasingly untenable as the City population expanded in the 13th century (Keene 2001, 162). One solution might have been to simply specify the use of water resources: Worcester, for example, regulated that waste had to be thrown into the River Severn downstream from the town, allowing clean water to be taken from the river upstream. However, such a solution was not viable in London because of the city's size and the potential difficulty of enforcement (Holt 2000, 97).

The concern to obtain clean — and preferably 'sweet' — water was not limited to the demand for drinking water, as plain water was only regularly consumed by the poor. Good quality water was also needed to brew ale — the drink consumed by the majority of the City's population. Whilst ale was (mostly) rendered safe to drink through a production process that required malted grains to be boiled with water, poor quality water would produce inferior tasting ale. Where ale was brewed for commercial purposes the importance of 'taste' and a finished product that would readily sell could be appreciated. But the concern for taste would not have been restricted to commercial brewers; ale was widely brewed and consumed domestically, being a major part of the medieval diet. A household of five people, for example, could require one-and-a-quarter gallons per day or eight-and-a-quarter gallons per week (Bennett 1996, 17–19). Barbara Harvey notes that 19% of the energy in a monk's diet at Westminster Abbey was supplied through the consumption of ale, compared to *c*.5% from this source in the general population today (Harvey 1993, 58).

Clearly the pressures of a growing London population (possibly *c*.80,000 by 1300) and industrial expansion were contaminating water sources, and some action was necessary to ensure public access to pure supplies. Uniquely amongst English cities in the 13th century, the London government turned to technology to create a new source of piped water within the City.

WATER TRANSPORTATION TECHNOLOGY

The diversion of naturally occurring water sources to centres of population was not a new technology; since the 12th century the monastic communities in England had used either stone lined open trenches or closed lead pipes to obtain a supply of running water within their domestic buildings. Of the two methods of transporting water, stone lined trenches had the advantage of being technically unsophisticated, but the disadvantage of being expensive and potentially difficult to construct. They depended on having both a conveniently situated and geographically aligned source and destination point, given that water would only flow along a trench if there was a downward slope between the two points. Without the construction of expensive aqueducts to overcome river valleys or other geographic features, stone lined trenches were in most cases not a viable means of transporting water over substantial distances. The Romans, who are associated most with this method of water transportation, were only able to construct their urban water systems with an army of slave labour, a resource unavailable to medieval urban government. Occasionally medieval trench conduits were built, but in these cases the diversion of water was over a relatively short distance and in a location where geography allowed a trench to be constructed without the requirement to build water tunnels or aqueducts. Exceptionally, there are also examples of a trench system being used in conjunction with a piped supply, such as at St Mary Spital, London (Thomas *et al* 1997, 43).

Closed lead pipes or 'conduit' systems on the other hand were considerably more flexible; the source could be several miles from the destination and the underground pipe could rise and fall as the local topography required — the pressure within the pipe providing the energy to make water flow uphill, if necessary. The critical requirement for these systems to work was the creation and preservation of 'head' water pressure within the system, by tapping a source spring that was at an elevation above that of both the intermediate pipe and the destination fountain. Typically water would be collected at a source spring (or springs) into a receipt tank (or head cistern) that provided both a reservoir against intermittent supply from the spring(s) and also a source of consistent pressure within the pipe. The greater the difference in height between the source and the destination, the greater the head pressure within the pipe and thus the greater the volume of water that could be transported. The disadvantage with lead conduits, however, was that they entailed the resolution of a range of construction issues that did not apply in open trench conduits, and, in addition, post-construction they required a considerable amount of continuous maintenance. Take for example the lead pipes. The pipes had to be perfectly sealed to preserve pressure within the system; any imperfection in manufacture or subsequent damage could result in local flooding and a complete loss of water at the destination fountain. Not only was the production of perfectly sealed pipes difficult, but the buried pipes could be accidentally damaged by inadvertent excavation, excessive surface pressure from urban traffic, or frost damage in the winter. These dangers could be minimised by burying the pipe in a deep trench, but if the pipe needed to be accessed for maintenance work, a deep trench would incur excessive location and re-excavation costs. A balancing of opposing technical issues was not limited to the pipes, a range of other operational aspects of the system also required careful balancing. Without the correct resolution of these issues, lead pipe conduits would either perform poorly, or not at all.

The manufacture of robust water pipes was the initial technical difficulty in implementing a conduit system. Although some early conduits in towns outside London used earthenware and wooden pipes, all the contemporary descriptions of the first London conduit indicate that the pipes were made of lead. This metal was chosen because it is very malleable and has a relatively low melting point, a necessary condition if the joints between the sections of pipe were to be sealed with molten metal as the pipe was laid. The method of making lead pipes was first to cast a flat sheet of lead on a sand-bed approximately 4m by 22cm, in a similar method to making lead roofing sheets. Next, the partly cooled sheet would be pressed around a circular wooden mandrel, forming a tube with a pear-shaped oval cross-section. Finally the upper seam joint would be sealed by either casting additional metal along the seam or soldering between the two sides of the formed sheet (Homer 1991, 64; Hodge 2002, 313–15). The casting method was used for the Waltham Abbey conduit pipes (built in 1220–22) and is described in British Library Harley ms 391 (Skelton & Harvey 1986, 66). The manuscript describes how this involved packing the pipe with sand and then building a clay mould along the horizontal seam into which molten metal was poured. The finished pipe would have a distinctive ridge along the seam joint. As this production process required a number of additional steps to simply soldering the joint, it would have been a slower, and therefore more expensive, method of pipe production. Although cast joints appear on the earlier conduit systems, there is no clear evidence that there was necessarily a switch to soldered joints at a later period (Magnusson 2001, 67–9).

Making conduit pipes was deemed to be an especially skilled task. The plumbers ordinances of 1365 state that working 'a clove of lead for gutters or roofs of houses take only one halfpenny, for working a clove of lead for belfries and conduit pipes, one penny' (Waldo 1923, 22–3). The section of London conduit pipe excavated at Paternoster Square in 2001 appears to have been produced with a cast joint, as there is a clear ridge of metal on the upper surface of the pipe that seems to indicate the use of a clay mould. The almost circular appearance of this pipe, compared to the likely pear-shaped cross-section when it was originally fabricated, probably resulted from the internal pressures when it was in use (Hodge 2002, 311). Lead pipes would have been placed in the ground with the seam joint uppermost, to facilitate repairs, if and when they were necessary. The 1350 London conduit warden accounts covering two years record 'one fozer (fodder) of lead for repairs, 8 marks 12 pence'. This is almost a ton of lead, a considerable quantity for simple maintenance of the system, suggesting that repairs to leaking joints were made by pouring substantial quantities of molten lead onto the leaking section in the hope of reinforcing the pipe by the quantity of metal used. There is no mention of lead-tin solder in these accounts (Riley 1868, 264–6). The installation in 1447 of conduit pipes to provide a Westminster 'town' water supply as an extension of the Palace of Westminster system used soldered pipes, as the clerk of the King's works sold 46lb of solder for the project (Magnusson 2001, 68). Recording repairs to the Aldermanbury conduit in 1585/86, the Chamberlain's accounts refer to money paid to John Martin (plumber) for 'burnt pipes' (soldered pipes) and solder 'at 56/- the hundred' (Masters 1984, 78). It would also seem that the flat sheet of lead used to make conduit pipes was, in some cases, shaped rather than being formed around a mandrel. The 1588 grant of arms to the Plumbers Company states 'on a chevron sable towe soodring irons in saultor with a cutting knife and a shaver argent'. The cutting knife was sufficiently important an instrument in the plumber craft that it was included on their arms. The text notes that 'a cutting knife is a tool for shaving and making pipes hollow' (Waldo 1923, 14).

The London plumbers were located in Candlewick Street, which 'for many years past had been let to men of the trade' (Homer 1991, 65). In 1371 the smoke from their furnaces was deemed a danger to the local population and they were enjoined to maintain sufficiently high chimneys (Riley 1868, 355). Presumably the plumbers would have been engaged in maintaining the lead roof of St Paul's and in making conduit pipes, in a similar arrangement to that of the plumbers who built the Exeter Cathedral conduit (Magnusson 2001, 74). The plumbers' premises would have been relatively substantial to accommodate not only the furnaces but also the casting tables and workshops required to form the finished pipes. Lead sheets had to be cast indoors in order to carefully control the cooling process, otherwise the castings had a tendency to crack whilst being formed and were then useless for making sealed pipes (Rodwell 1981, 116). The typical dimensions of a medieval water pipe would be between 2cm and 10cm in diameter. The pipes excavated at Paternoster Square were well within the typical range of medieval water pipes and their location is reported as:

> The pipe was laid *c.*2m below contemporary ground level, parallel to the south side of Paternoster Row. Survived in two truncated sections measuring three metres and four metres in length respectively. The lead was between 4mm and 6mm in thickness, and

> the pipe had a diameter of 95mm. Recorded at the west end at 12.26 mod and at the east end at 12.22 mod. (Birch *et al* forthcoming)

Although there appears to be no standardisation of pipe dimensions between different conduits, presumably within a single system the dimensions of the pipes were fixed, to aid both construction and repair.

Sections of pipe would be transported to the installation site and joined either by simple butt joints or by flaring one pipe end and inserting the next pipe (male/female joints). The joints between sections would then be sealed by wiping molten metal across the joint. The use of molten metal to provide the seal would have required a mobile furnace to be built close to the installation site and the construction of an elementary mould around the pipe joint, probably in the base of the protective trench, to guide the flow of the molten metal. Clearly the construction of the conduit pipe would have been a slow process as the furnace and its fuel was moved from site to site. Of the possible methods of joining pipes, simple butt joints may have been less demanding to make, but they were weak and ideally needed additional protection. Pipes could be encased within a further stone or brick housing, but such arrangements added further expense and were omitted where either finance was tight or it was considered that the pipe was safe from damage. The Dover conduit, for example, was constructed with butt joints protected in a stone lined conduit channel one foot square (McPherson & Amos 1931, 170). Whereas the Windsor Castle conduit was buried unprotected in land outside the castle, only being given a brick 'paving' once it entered the busy upper ward of the castle, close to the distribution fountain (Tighe & Davis 1858, I, 602). A common improvement to medieval conduit systems was the subsequent installation of a protective housing for the pipe, to reduce the incidence of maintenance and consequently improve the reliability of the supply. The Exeter conduit was relaid in a stone lined channel in the mid-14th century to protect the pipe, with the new channel being wide enough to gain access for repairs (Holt 2000, 92–3). If the pipe was not to be provided with a housing throughout its length, then typically critical components would be provided with some protection. The London Greyfriars conduit trench incorporated a marble stone, to mark both the position of underground taps and to afford some protection (Norman 1899, 259). Flared joints between sections of pipe may have been stronger and thus required less protection, but they suffered from the disadvantage of not producing a smooth interior surface to the pipe. This would have made cleaning more difficult and probably also encouraged the development of additional internal deposits that could eventually create a blockage (Hodge 2002, 98).

Conduit pipes thus incorporated two joints — a horizontal seam joint along the pipe and an end joint between pipe sections. The seam joint would have been subject to the greatest internal pressure from the operation of the pipe, whilst the joint between sections, although under less stress, was potentially weak as it had to be made *in situ* (Hodge 2002, 314–15). Of the two joints, it would appear that the quality of the joint between sections was the most critical in ensuring that the conduit system remained 'closed' and therefore operated effectively. It is not known how the London conduit pipes were joined or if other external protection was provided when the pipe was first installed. Unfortunately, the pipes excavated at Paternoster Square did not include a joint between two sections of pipe, although one piece was approximately 4m long and it might have been anticipated that such a substantial section would have had at least one joint. A possible explanation might relate to the common practice of recovering (valuable) 'old' pipes to reuse the lead for other purposes. When the pipe was removed it is likely to have been crudely pulled from the soil fracturing it at the weak joint between pipe sections, resulting in only complete pipe sections remaining buried and unrecovered — perhaps locked in place because of other obstructions built on top of the pipe. The recently excavated pipe therefore represented a section that for some reason could not be recovered and was simply left in the ground, after the pipe sections on either side had been extracted.

Clearly, a calculation had to be made between casting longer pipes that would have been heavy and difficult to transport intact to the installation point without damaging the seam joint, and shorter pipes that would have been easier to transport but required more joints between sections. It seems that the conduit builders preferred longer pipes, on average 3–4m long (Magnusson 2001, 70).

The standard method of construction was to lay the pipe from the source to the destination, so that a check could be made as the pipe was laid that the water continued to flow. Although the pipe did not have to continuously slope downwards, if possible, the trench followed a downward path, to avoid any sudden change in gradient that might give rise to maintenance difficulties when the pipe was in use. As already noted, the depth of the trench in which the pipe was buried was a further important consideration to avoid freezing in the winter or mechanical damage from, for example, passing heavy carts. Too deep a trench, however, would subject the pipe to pressure from the weight of soil above, leading to potential fracture. The London Greyfriars conduit, built in 1432, seems to have been buried in a 1–1.5m trench that provided a satisfactory combination of protection from damage and reasonable accessibility (Norman 1899, 259, 265). The pipe was said 'in the depth of winter never to fail', yet the succession of cocks that were used to close the system for maintenance were accessible from ground level. However, this system passed mostly through open fields with little likelihood of surface mechanical damage and could therefore safely operate with a shallow trench. The London conduit passed along busy urban streets, probably at a depth of 2m (Birch *et al* forthcoming). Stow refers to the poor quality of the road between the City and Westminster (Fleet Street/Strand), 'being very ruinous and the pavement broken, to the hurt and mischiefe of the subjects' (Stow 1908, I, 265). It is likely that the conduit pipe laid under this road suffered from surface pressure which, combined with the increased internal pressure in the pipe from the gradient towards the Fleet river, would account for the persistent complaints of leaking conduit pipes in the locality. Certainly, later London conduits, such as the conduit built in 1535 at Aldgate (known as the Dalston conduit), buried the pipe much deeper, at depths between 2.6 and 6m (Foord 1910, 269).

Although a conduit pipe could simply be buried unprotected, normally the trench was crudely lined with either stone or clay which would serve a double function — stability whilst the pipes were joined and a rudimentary foundation once the pipe was buried. The conduit pipes found at Paternoster Square were described as being laid in a foundation of clay and this would fit with the construction techniques in other conduit systems (Birch *et al* forthcoming; Magnusson 2001, 83). A clay lining, however, was likely to be of mixed benefit. It would certainly have held the pipe in position as molten metal was poured to join sections of pipe, but, if the clay subsequently hardened, it could assist in fracturing the pipe. There are no references in the London letter books to the construction techniques used in the London conduit and equally the one set of surviving warden's accounts for 1350 makes no mention of stones or tiles purchased to line the trench or lay over the conduit pipe for protection. However, 16th-century London Chamberlain accounts do mention stones purchased to 'pave over the pipe that leads from Ludgate to Old Bailey', including gravel, presumably used to line the trench; this indicates that at least part of the pipe was provided with better protection at a later date (Masters 1984, 77). It seems that the London conduit, at least initially, was of relatively basic construction, presumably to minimise cost on what was a highly speculative venture.

Although the principles of conduit technology would at first sight appear to be quite straightforward, the practical execution of a system required an experienced conduit builder, who understood the difficulties of converting theory into practice. Each conduit site had different local geography and construction must have involved a good deal of trial and error. Where records have survived of early conduit systems, the architect of the system is often mentioned, such as Master Lawrence of Stratford, who built the Waltham Abbey conduit (Magnusson 2001, 65). The concentration of the first systems within monastic communities is probably explained by the requirement of these institutions for large quantities of running water, particularly under the Benedictine rule governing personal hygiene. This demand was exacerbated by the regulation of monastic life that resulted in 'peak period' consumption between offices. To meet this requirement the monasteries invested in water transport, storage, and distribution systems, which were initially based on Roman designs found in the revived stone buildings used as early monastic institutions (Magnusson 2001, 6). In addition, it appears that the monasteries took a longer term view of the substantial investment required to implement new water systems, certainly in comparison to temporal authorities, further concentrating the initial development of water technology in these institutions (Holt 2000, 88). The closely connected continental monastic communities disseminated their knowledge of water systems through their network of related houses, and thus the first conduit systems came to England through the monasteries. Personal connections between institutions accounted for their further development (Magnusson 2001, 20). The Lichfield Cathedral conduit, for example, can be traced to Walter Durden who was appointed bishop in 1166, having previously been prior of Christ Church Canterbury, where he initiated the installation of a conduit, completed under Prior Wilbert in 1167 (Holt 2000, 91). Some of the early civic water supplies resulted from these monastic systems, such as at Westminster, Exeter, and Canterbury, where a pipe was extended outside the monastic buildings for public use or, alternatively, where the overflow from an internal fountain was used as a basic civic supply (Brown *et al* 1963, I, 550).

Despite the difficulties in building conduit systems, they provided the significant advantage of flexibility over other means of transporting water in both the path of the pipe and the location of the distribution fountain. The Christ Church Canterbury plans (Fig 1) show this exact scheme, with the water moving from the source to a network of distribution points within the monastic buildings — some of these clearly requiring the water to move 'uphill'. Also clearly visible on the Canterbury plan are

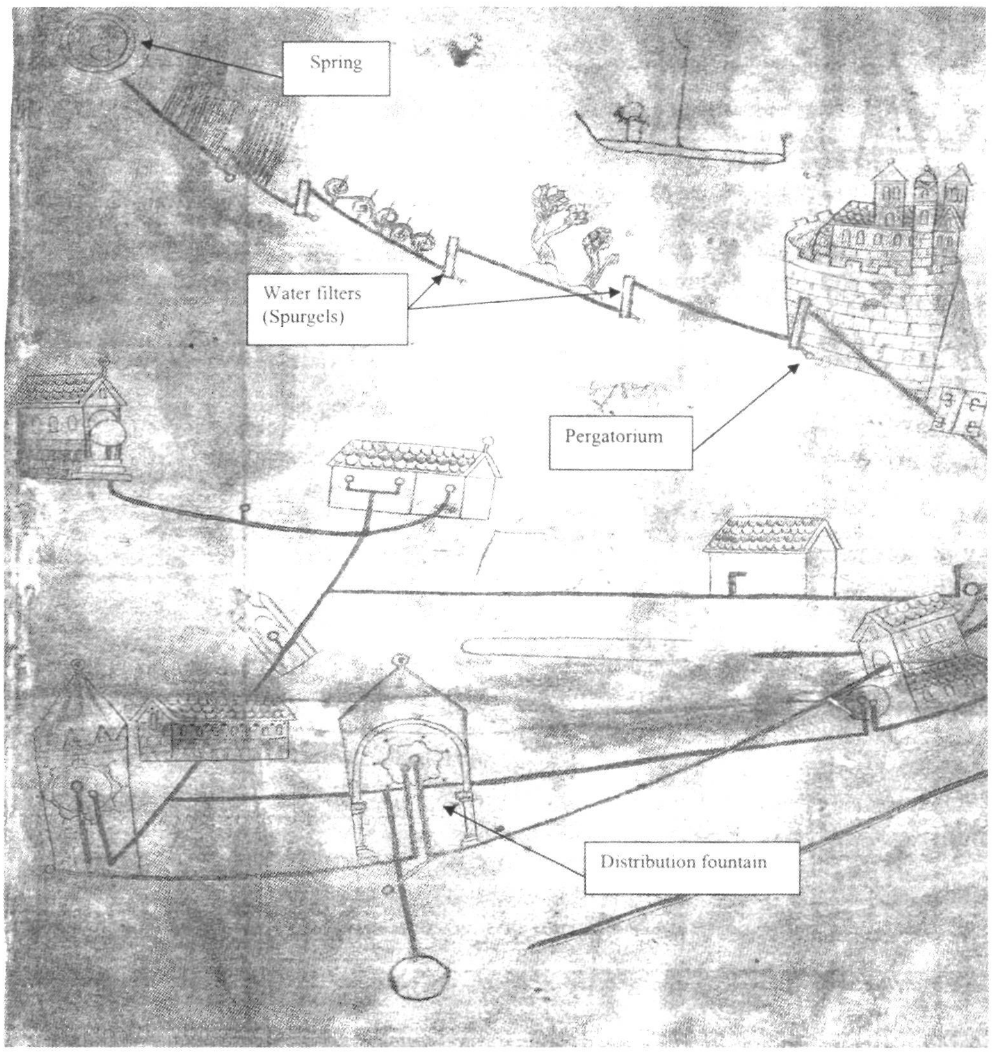


Fig 1. Christ Church Canterbury, conduit plan, 1153–61 (Trinity College Cambridge, ms R. 17.1, fols 284v–285r) (By permission of the Master and Fellows of Trinity College, Cambridge)

the succession of water filtering devices, known as 'spurgels', located between the source and the first distribution point; mostly located in field settings. As conduit water was collected from field springs, it generally contained a substantial quantity of suspended matter, such as fine grit or sand, that had to be removed both for the purity of the water and to prevent its accumulation within the pipe, leading to pipe blockage. The first level of filtration was a simple mesh covering the source pipe that removed any larger pieces of debris. The plan of the Waltham Abbey conduit clearly shows this feature (Fig 2). Finer suspended matter would then be removed

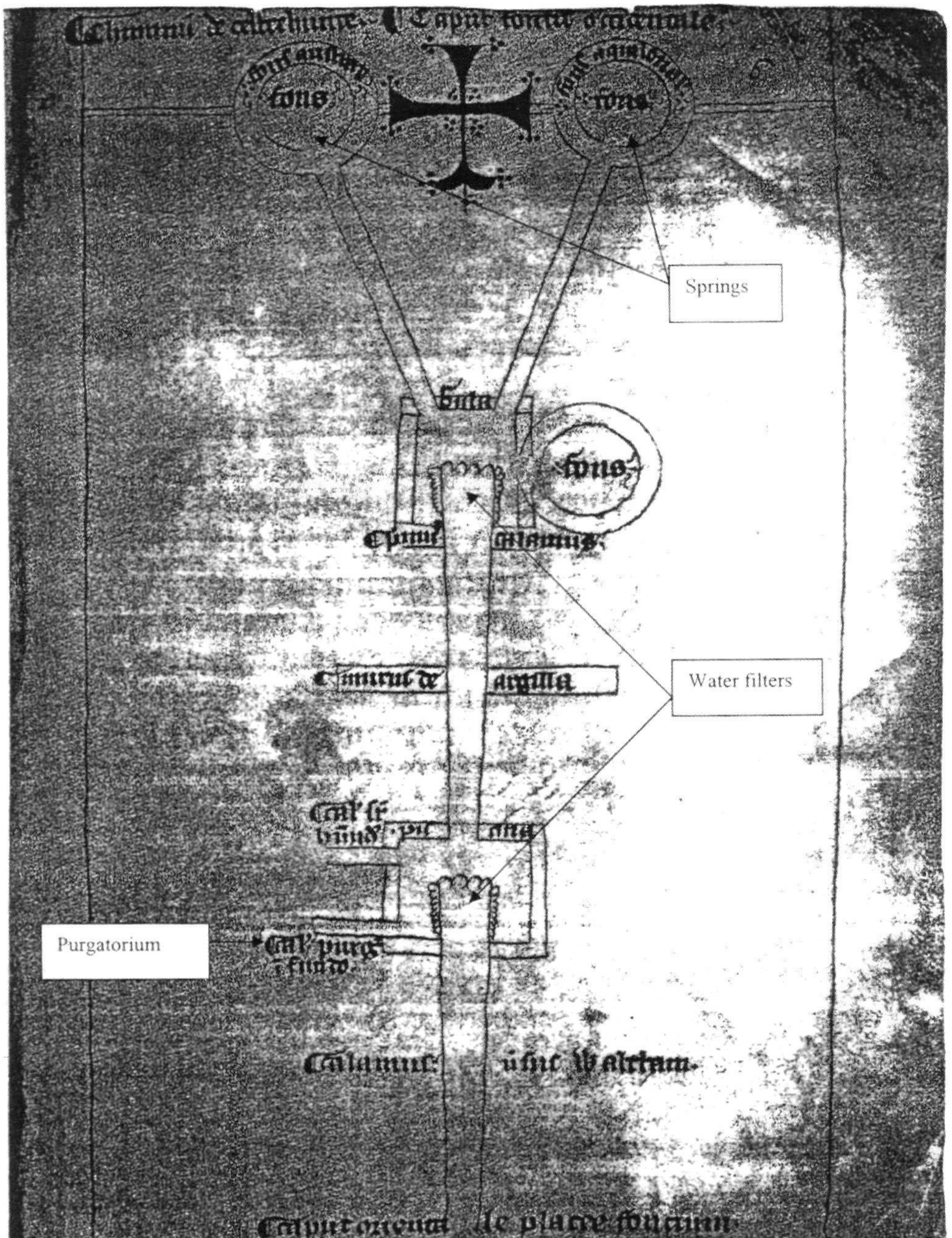


Fig 2. Waltham Abbey conduit plan (Harley ms 391, Co 6r) (By permission of the British Library)

through a succession of sealed separation tanks or 'spurgels'.

Spurgels operated by allowing unfiltered water to enter a tank through a pipe set approximately in the centre of one side of the tank. As the tank filled, 'cleaned' water would be drawn from a pipe set at the top of the opposite side of the tank; any suspended debris falling to the bottom (Fig 3). The tank was cleaned by draining off the collected sediment through a tap in the base; these are clearly visible on the Canterbury and Waltham Abbey conduit plans, marked as *purgatorium*. A succession of spurgels could be linked together to increase the effectiveness of the cleaning process. The cleaning tanks were referred to under a number of different names in medieval documents, such as *expurgatorium*, *spurgellum*, *suspiral*, or *separall* — although often called *spurgels* (Magnusson 2001, 85). Despite filtering water through several spurgels, some sediment could still enter the pipe and over time create a blockage, particularly if the water pressure was low. Any sediment needed to be removed by regular maintenance and cleaning of the pipes. In addition, the water would deposit dissolved calcium salts, known as 'sinter', inside the pipe, especially if the water was 'hard', also potentially accumulating and creating a blockage. A layer of sinter, however, did have some beneficial effect, as it provided protection against the leaching of poisonous lead into the water, but excessive accumulations had to be removed. It seems that the method of cleaning the pipes was to scour them with the aid of a heavy gauge wire, access to the pipe normally being gained at the spurgel. A reference is made in the 16th-century London Chamberlain's accounts to 'seventy-seven feet of great wire' delivered to the conduit head by John Frenche, girdler, and a payment to William Palmer of £4 1s 10d, for 'scouring the City's latten squirts' (cleaning the conduit taps) (Masters 1984, 27).

A further maintenance requirement was the prompt repair of any leaks to the pipe or spurgels, as the operation of the system depended on the careful preservation of water pressure within

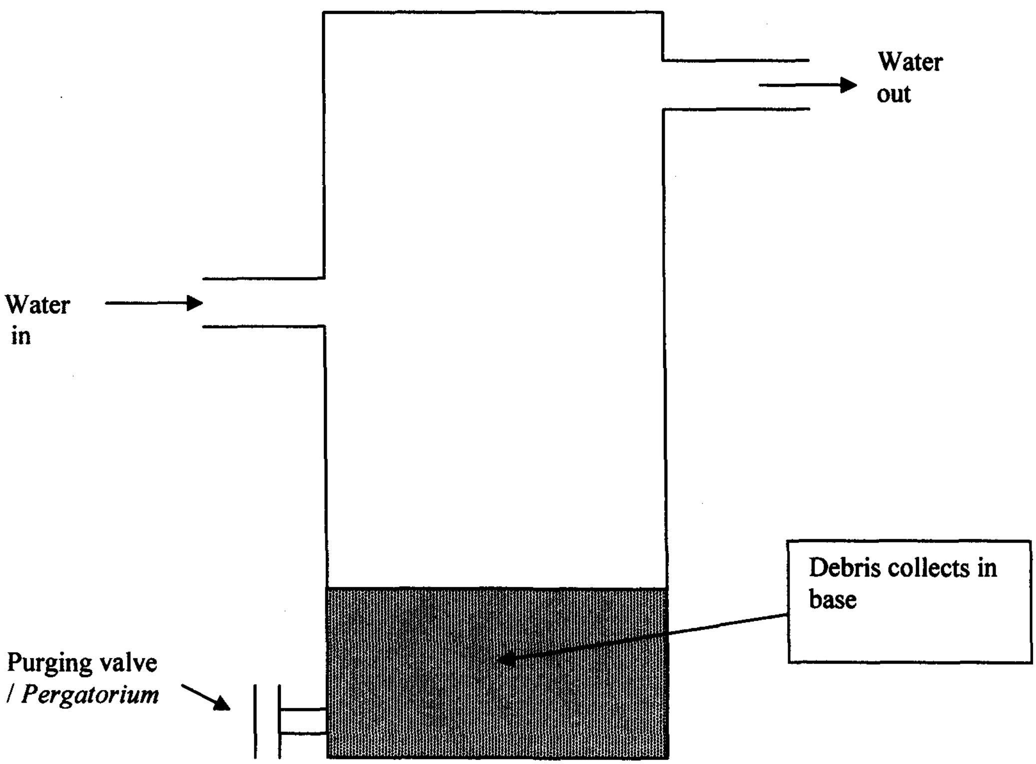


Fig 3. Schematic operation of a medieval conduit water filter or spurgel

the pipe. Leaks could most obviously be caused by damage to the pipe from external forces, such as physical movement of the soil or other mechanical damage. Perhaps less obviously, excessive water pressure within the pipe could also give rise to pipe failure. The water pressure in closed pipe systems varies over the length of the pipe, being at a maximum where the difference in elevation of the pipe from the source is at its greatest. Typically this would occur in sections of pipe that passed through a valley floor. Excessive internal pressure could give rise to premature failure of joints between sections of pipe or substantial leaks from areas of minor damage to the pipe. Low lying sections of conduit pipe could therefore require disproportionate amounts of maintenance. To guard against this problem the designers of conduit systems turned to a secondary feature of the 'spurgel' separation tank. Spurgels have the effect of dissipating water pressure due to their dimensions, and by inserting additional spurgels in a low lying section of pipe the internal pressure can be reduced, creating an artificial new 'head' within the system. In Fig 4, the pressure in the pipe between System A and B is halved by inserting an intermediate tank.

The medieval designers of the London conduit were well aware of this aspect of conduit technology, as in 1388 the City ordered that a conduit 'penthouse' be built in Fleet Street. This was the section of lowest elevation of the London conduit and therefore the part most likely to suffer pressure leakage (Appendix 1). The objective of the additional 'penthouse' was to avoid the regular inundations of local properties from burst conduit pipes 'in order that it might be seen whether the damage could by such means be averted' (CLBH, 503). The word 'penthouse' is Riley's translation of the Latin word *aventum*, a term that implies some function of venting the pipe — an operation that it was believed a spurgel performed (Riley 1868, 503). The concept of water pressure is a modern notion. To the medieval mind a pipe failed because of excessive quantities of trapped and compressed air within the pipe that needed to be released and spurgels were thought to provide this venting function (Hope 1902, 301). Presumably the belief that compressed gasses were the source of pipe failure arose from the observation that air bubbles could be seen rising from falling water and that these needed to be dissipated, as they would have been if the water was not trapped within the pipe.

The design of the Charterhouse conduit, installed in 1430, provides an interesting case study of how spurgels were used for pressure regulation. This conduit had a drop of 21m over the course of a 1.2km pipe and included a succession of eleven spurgels. This can be compared to the London conduit that originally contained only three spurgels (two in the original design and an additional one added at Fleet Bridge) in a drop of 15m over a 4.8km pipe. The insertion of spurgels into the system was therefore a further feature of conduit design that required the balancing of opposing requirements. A greater number of spurgels would allow the water to be better filtered and avoid the potential problem of debris being deposited in the inaccessible underground pipe,

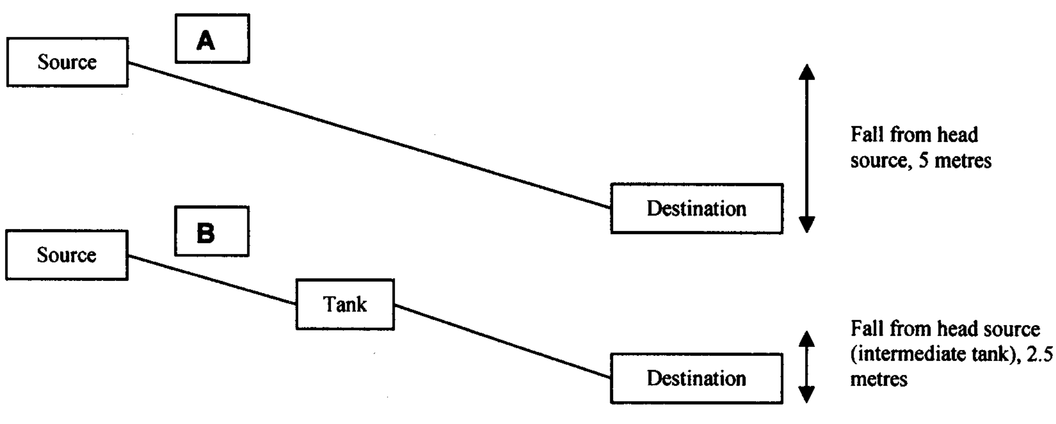


Fig 4. Schematic diagram to show the reduction in pipe pressure, by inserting an intermediate tank

but, on the other hand, the greater the number of spurgels, the lower the pressure in the system. A lower pressure system would deliver less water and be less capable of successfully crossing steep river valleys. It could be deduced from the apparent design of the London conduit, with the limited number of spurgels, that the preservation of pressure took precedence over the requirement to filter the water, probably because of the unknown forces required to lift water from the Fleet valley to Cheapside. Whether this would have represented a risky decision would in part depend on the soil surrounding the field springs, as inevitably some of this soil would be carried by the water and would need to be removed. Very fine, light, or sandy soil would require more filtering than other types. If insufficient spurgels were included in the London system, the conduit risked failure from blocked pipes. The incorrect balancing of filtering versus preservation of pressure appears to have been the problem with the extremely expensive Windsor Castle conduit (costing over £3,000 in 1552–59) which operated for little over fifty years, being reported as 'broken' as early as 1609. It operated in an area of very fine soil, but only incorporated three spurgels, the water pressure being preserved to power an elaborate fountain inside the castle (Hope 1917, I, 290). The criteria for selection of the appropriate springs to feed a conduit system therefore had to include a combination of elevation above the intended site of the distribution fountain, year-round productivity, and the absence of suspended matter in the spring water or, alternatively, sufficient additional elevation to allow it to be removed. It would seem that there were few potentially useful spring sites to feed the London conduit.

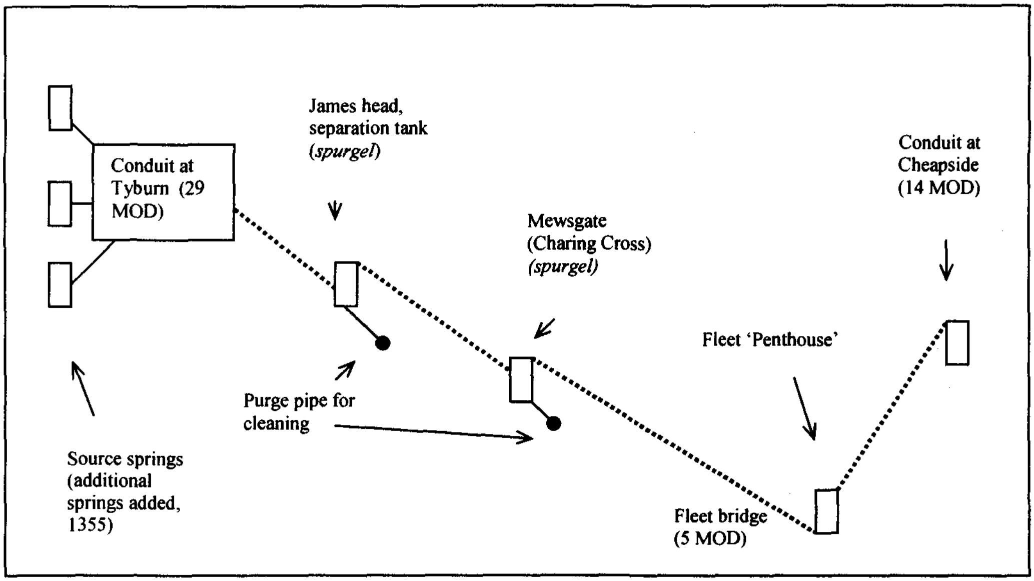
Perhaps the most critical issue in constructing the London conduit was the location of the source spring at Tyburn, to the west of the City. This site would require a conduit pipe 4.8km long to connect to a conduit house in Cheapside, probably longer than any other English system. It would have been unknown at the outset whether such a pipe could be made and installed, whilst remaining perfectly sealed. Monastic systems generally had a short run from source to destination, involving fewer pipe sections and consequently less loss of pressure from leaks at the temperamental joints between sections. The Canterbury and Charterhouse systems, for example, ran for less than 1.5km. It would have been difficult to predict the effective pressure within a long pipe, such as the London conduit, and ultimately whether there was sufficient pressure to transport the water over the intended route. The existing experience of building monastic conduits, where these were built in an urban setting, had only installed pipes under streets that sustained the pressures of a much lower population density than London. Moreover, monastic conduit systems could often be optimised by avoiding difficult topographic features such as river valleys or steep inclines by routing the pipes through open fields. The pipe for the London conduit had to follow the existing street pattern — there was no flexibility to avoid such difficult features as the Fleet Valley. Clearly there were significant differences between the installation of a monastic system and the London conduit that would stretch the existing knowledge and experience of conduit building.

Despite the practical problems, conduit systems had been successfully installed in a number of continental European cities, in some cases initially sharing resources with the monastic communities or in other cases reviving systems originally developed by the Romans. Early systems were installed in Essen (1039–58), Magdeburg (1125–60), Paris (before 1119), and Salzburg (1136) (Magnusson 2001, 6). Whilst the motivation for installing a conduit system in London was most likely the improvement of City health, particularly for the poor, there must also have been some pressure on the City authorities to demonstrate the status of London by emulating continental developments. Although there are no surviving plans of the London conduit, the plans of the Canterbury (1153–67), Waltham Abbey (1220–22), and London Charterhouse (1430) conduits give an indication of how the London conduit might have worked.

The grant of land to the City for a conduit source was made by Gilbert de Sanford in 1236, and the first reference to the, presumably operating, conduit in Cheapside was made in 1261. From these dates it would seem that the system took approximately twenty-five years to plan and build (CCR ii, 38). The conduit head at Tyburn (opposite the modern Bond Street tube station) probably gathered water from several very close springs, that together made a sufficient supply, into a collection reservoir tank or cistern. The original grant states '...all those springs and waters arising from those springs which they have made to unite into one place' (CLBA, 14). The cistern fed a single lead pipe that was laid, for the most part underground, to the conduit head in Cheapside. The exact course of the pipe is unknown, but four sections of pipe have subsequently been found and these give an indication of the likely route. Two sections were found in Fleet Street (1743) and St Clement's church (1765) during building work, and a further two sections close to the northern boundary wall of St Paul's Cathedral in Paternoster Square (2001) (Foord 1910, 266). The conduit warden accounts refer to mending the pipe between the Mews (Charing Cross) and the mill in the field (Windmill Street), suggesting a course of the pipe to the north of the modern day Strand. The pipe is assumed to have initially followed the course of the Tyburn valley, south towards the Thames, as using the valley would have provided a ready made gradient for the pipe and have saved the cost of digging new trenches. On reaching the brow of a hill known as 'James head' (St James's), the pipe entered an inspection tank or 'spurgel'. The pipe then turned sharply east, following a path beneath the road to the King's mews at Charing Cross, where there was a further spurgel, and then north of present day Strand and Fleet Street to the Fleet valley (Morley Davies 1910, 47). The Fleet would have been crossed at Fleet Bridge, as there are references in the letter books in 1350 to 'mending the spurgail broken at Flete bridge 6s.3½ d., for mending the pipes there 6s.8½d.' (Riley 1868, 265). The pipe would then have ascended Ludgate Hill and passed around the precinct of St Paul's to Cheapside. The conduit 'house' was located outside the church of St Mary Colechurch, at the extreme eastern end of Cheapside, on land close to the birthplace of Thomas Becket. The technical design of the conduit head or fountain, apart from its elaborate decoration, was likely to have been an elevated lead cistern that received water from the conduit pipe and in turn delivered water through brass or latten taps at street level. Users would fill portable vessels from these taps, with a stone basin beneath to collect any spilled or wasted water. The water collected in the stone basin could also be used by those without access to the taps.

The volume of water passing through the conduit is thought to have been relatively insubstantial, Keene has suggested that it was only sufficient to support 45 households or about 1% of the City population in 1350 (Keene 2001, 178). However, calculations based on the dimensions of a section of pipe excavated at Paternoster Square would indicate that the pressure at the Cheapside conduit head would be *c.*20 psi or equivalent to a delivery of 1.25 gallons per second, given the location of the source spring, the likely elevation of Cheapside in the mid-14th century, and assuming the conduit pipe was entirely 'closed'. Engineering calculations would, therefore, indicate that the problem with the London conduit was not insufficient water pressure, but excess (Appendix 1). There would have been some difficulty in containing the pressure within the pipe, especially in the spurgel at Fleet Bridge. The assumption that a medieval pipe, especially one almost 5km long, could be completely 'closed', is certainly unrealistic, but even assuming that 20% of the pressure was lost at the point of highest pressure in the system, the Fleet valley, the water pressure at Cheapside would still have been *c.*13.4 psi or equivalent to a delivery of 0.84 gallons per second (Fig 5). This volume of water is significantly more than was required to support 45 households, especially given the relatively restricted use of fresh water. As the contemporary records imply that there was a shortage of water at the conduit head, there must have been some other factors accounting for the poor quantities delivered. This could have been either that the Tyburn source did not provide a sufficiently regular supply; that the pipe was partially blocked in places and did not run freely; or that the pipes leaked significantly more than 20%; or possibly a combination of all these factors. Whatever the cause, there appeared to be an excess of demand over supply.

Despite the apparent deficiency in water supply, the conduit buildings played a special role in civic and royal pageants when the City reaffirmed its loyalty to the monarch. The conduit head was elaborately decorated, becoming one of the regular stopping points of the celebrations — running with wine in 1273 for the coronation of Edward I and being decorated for the passing procession of Henry V on his return from Agincourt in 1415 (Foord 1910, 253, 259). Although there are several references in the City record to the conduit 'flowing with wine', it is uncertain how this was achieved. There is no indication on the monastic plans of a 'master tap' to close the system at the source, allowing wine to be poured into the



Water pressure (psi) in the pipe. *Appendix 1.		5.5		33		20

* using a factor of 4.3 psi, per 10 feet of fall.

Fig 5. Schematic London conduit map based on Stow's description

conduit in substitution for water. Simply closing the pipe at the conduit head would have caused extreme pressure elsewhere in the system. The most likely means of stopping the flow would have been to entirely divert the Tyburn source, emptying the system of water and, having closed the pipe between Cheapside and the Fleet valley so that the wine did not flow backwards down the pipe, simply pour wine into the top cistern of the conduit building. Wine would then issue from the taps below, appearing to make the entire conduit 'flow with wine'.

The attitude of the City to public infrastructure projects, such as the conduit, was that they should 'live of their own', be self-financing and managed by dedicated officials (Tucker 1995, 244). Conduit wardens, elected by householders in the vicinity of the conduit, were responsible for the maintenance of the conduit, regulation of the conduit head, and the collection of any fees for the use of conduit water (Keene 2001, 176). The London conduit wardens appear to have also had some function with regard to maintaining the pipes, as their names indicate they were drawn from the non-ferrous metal trade, such as William le Latoner (1325), Geofery de Gedelstone (1325), Thomas le Peautrer (1333–35), Robert le Foundour (1350, 1352–53), and Arnold le Peautrer (1353) (Magnusson 2001, 119; CLBC, 11). Unfortunately, other than the 1350 accounts that were presented by a warden who was subsequently judged dishonest and are therefore recorded in the City letter books, no other conduit accounts survive to confirm this arrangement.

The undercroft of the conduit head in West Cheap was accidentally discovered in 1994 under the current road junction of Poultry and Cheapside, close to the Tesco supermarket (Birch *et al* forthcoming). Although a full excavation was not carried out, a significant amount of additional information was gathered on the building. The internal dimensions are 1.6m high, 2m wide, and 6.5m long. Curiously the walls on three sides are

2m thick, compared to an expected thickness of approximately 1m for a building of these dimensions. Possibly the additional structural strength was thought necessary to support the various lead cisterns that were enclosed within the building; it perhaps also points to a degree of over-engineering, reflecting the uncertainty of the required tolerances in a conduit building project that was itself at the margins of existing knowledge. An unusual feature of the excavated remains was evidence of water damage within the undercroft. The excavation team speculated that the undercroft also acted as some form of reservoir in addition to the cistern above road level. However, if this was the case, there must also have been some mechanism to raise the water from the undercroft to the above ground cistern. There was no evidence of such a device. The street level at the time the building was in use could be accurately estimated as 14m above sea-level.

The conduit seems to have operated effectively, albeit that the volume of water was insufficient. Complaints recorded in the letter books refer to wasting the conduit water or its inappropriate use for industrial purposes, underlining the problems of supply (CLBF, 200; Riley 1868, 77–8). Unsurprisingly, one of the industrial uses for conduit water specifically mentioned, and apparently a cause of local friction, was the commercial production of ale and beer, near Saint Paul's Cathedral — the producers competing with the local inhabitants for access to the water (Bennett 1996, 20). The first attempt to improve the level of water supply was made in 1355, when additional springs close to the existing Tyburn source were connected to the head cistern. This would have had a potentially double effect. Firstly, by increasing the head pressure, more water would have flowed through the existing pipes and secondly, by increasing the rate of flow, any underground blockages in the pipe would have been cleared, making the pipes more efficient. It seems that the 1355 improvements did increase the supply of water, as an additional destination fountain was tentatively approved in 1390 for the 'substantial men of Farringdon' (CLBH, 521). Such an extension would not have been contemplated if the supplies to the existing conduit head were still considered inadequate. By the close of the 14th century, therefore, the London conduit system consisted of a number of enclosed springs in the vicinity of the original Tyburn source, a single lead pipe, laid mostly underground from Tyburn to Cheapside, with an extension to Farringdon made close to the church of St Michael le Quern, and an elaborate, castellated conduit fountain at the eastern end of Cheapside.

LAW AND FINANCE

The legal issues associated with the construction of a conduit system can be analysed into three parts; firstly, obtaining property rights over the source spring and permission to construct a collection cistern; secondly, permission to lay pipes between the source and destination either from private landlords or from the King (if the pipe was laid beneath the King's highway); and finally, property rights to construct a conduit house to distribute the water to the public.

The 1236 grant by Gilbert de Stanford of the lands at Tyburn allowed springs on the site to be enclosed and a collection cistern built. The construction of a cistern would have taken relatively little space and presumably the rest of the land at Tyburn could continue to be used as it had been previously, provided that the springs were not contaminated or otherwise compromised. Clearly, once the collection cistern had been built to gather water from a group of adjacent springs, it was important that the same springs were not diverted for another purpose, leaving insufficient water for the conduit to operate. This concern was specifically mentioned with regard to the 1420 extension of the London conduit, that was planned to enclose springs also used by the Westminster Abbey water conduit. The Abbot had the right, by charter, to disconnect the London conduit if it proved detrimental to the Westminster supply.

The wording of the grant by Gilbert de Stanford implies that royal permission to build the conduit had been obtained, as a clause states (referring to the king) 'for his honour and reverence' that the conduit should be built 'for the common benefit of the City and citizens of London' (CLBA, 14). The charter, however, appears to be deliberately vague about the likely course of the conduit pipe and the arrangements for collecting water, presumably to give a free hand to those building the system. Equally the 1355 extension to the Tyburn source to incorporate additional springs on the same site, granted by Alice Chobham, was similarly vague — 'to have a plot of land twenty-four feet square for a spring, wherever they might choose' (CLBG, 210).

The right to lay the pipes under private property would have required a documented way-leave from the property owner, whereas the right to lay pipes under the highway required a royal licence that would normally have been recorded in the national record. Royal grants would be subject to an option to order an inquisition '*ad quod damnum*' to determine if there was likely to be any damage to royal interests by granting permission to construct a conduit. It seems, however, that not all royal authorisations were recorded, as there is no grant for the construction of the London conduit. The grant for the Chester conduit provided a considerable degree of latitude 'to open and pierce and reclose the said land, the City wall and the highways where necessary' — presumably, as in the construction of the collection cistern, to give the conduit builders some flexibility in their work (CPR (1272–81), 165).

Once the pipe had been laid, there was always the danger that new buildings would encroach on the site of the conduit pipe, rendering subsequent maintenance of the pipe — or indeed, its replacement — either difficult or impossible. This point was specifically mentioned in the 1443 grant for the extension of the London conduit, 'whereas both our land of Mews and others', over and under which the water pipes are situated, are lately enclosed by walls and other edifices, so that the Mayor, Alderman and Citizens cannot examine or repair them without much trouble and difficulty...' (CPR (1441–46), 198).

Land for building the conduit fountain on Cheapside was donated by the City in *c.*1240. There had been an earlier plan to construct a basilica on this site, dedicated to the birthplace of Thomas Becket, but this plan had not come to fruition and a much smaller scale church was built instead, leaving a vacant plot for the conduit house (Keene 2001, 178). The location of the conduit house, with its flowing water, had obvious religious symbolism, enhanced by the association with Saint Thomas.

Maintenance income

The financial arrangements to pay for the maintenance of the London conduit can at best be described as haphazard. It seems that no serious consideration was given to the requirement to establish a source of funds for this work. Whether this was the result of ignorance — that the conduit once built would operate without substantial additional expense — or design — that water charges were assumed to be sufficient to cover maintenance costs — is not known. One financing scheme after another was tried, found to be inadequate, and replaced. The result was that a system, which probably operated below expectation from the start, slowly deteriorated during the 14th century, albeit that the source springs were enhanced in 1355. Repairs to the system were carried out as and when the funds became available; if there were insufficient resources, then the conduit was allowed to decay. By the early 15th century, it was reported 'whereas the fountain heads and conduits serving the City ... diminish and dry-up' (CPR (1441–46), 198). The inadequacy of routine maintenance eventually threatened the system with complete collapse.

In striking contrast to London Bridge, the other major piece of City infrastructure, the conduit had virtually no fixed source of income, although they had economic features in common — namely, the requirement for a high level of continuous expensive maintenance, to be funded through the collection of a large volume of relatively insignificant usage charges. London Bridge was endowed with a substantial portfolio of London properties, donated by citizens wishing to be associated with the cult of Saint Thomas, to whom the Bridge chapel was dedicated. Bridges were often seen as objects of pious offering, but this does not appear to have applied to the conduit, notwithstanding the fact that the poor were seen as major beneficiaries of clean water and that such associations normally elicited giving (Webb 2000, 230). The location of the conduit head, outside the birthplace of Saint Thomas, also appears not to have gathered many bequests, although the possibility of such a source of income was surely contemplated. The substantial value of properties attached to the Bridge did result in the rather unexpected outcome that the Bridge wardens were almost as much involved with managing and exploiting the landed endowment as they were with maintaining the fabric of the Bridge (Harding & Wright 1995, 11). Rental income from Bridge properties located near St Paul's accounted for at least three-quarters of the Bridge's total revenue of £796 per annum between 1404 and 1537, whilst the income from crossing charges at 2d per cart and 1d per ship passing under the Bridge amounted to only £7 in 1420 (Harding & Wright 1995, 17). If the Bridge wardens had only to rely on the insecure usage charges to fund the repairs, then the Bridge would soon have fallen into disrepair, as they were simply inadequate.

The conduit wardens, like the Bridge wardens, were also responsible for substantial repair costs, but were expected to maintain the system with usage charges and a small number of relatively low value endowments established in the late 14th century. The majority of water charges were levied on brewers, fishmongers, and cooks who took conduit water in connection with their businesses. The difficulty with relying on variable usage charges was that they varied in an exact contrary pattern to the incidence of maintenance expense. When the system failed and needed substantial repair, income to meet the repair costs declined because of a reduction in the available water on which to levy charges. The concept of building a reserve or contingency fund within conduit finances to pay for exceptional costs appears not to have been considered. In the one set of surviving conduit warden's accounts, for 1350, although a surplus was declared, it was not allocated to a reserve to meet repair costs in later years but appears to have been available for distribution. In common with other public works, the accounts for the conduit were prepared on a simple cash receipt and payment basis.

The first reference to conduit finances occurs in 1310, when the conduit warden, William Hardy, was enjoined not to sell water on pain of losing his freedom (CLBD, 237). The clear intention was that conduit water was supposed to be supplied without charge and that there had been some attempt, presumably by the conduit warden, to profit from water sale. This policy was changed in 1312, when the cooks, brewers, and fishmongers were granted an 'easement' to use conduit water in exchange for an unspecified fee; the money was to be used to repair and maintain the conduit (CLBD, 107). The next reference in 1333–35 notes that £6 18d had been received by the conduit wardens for tankard 'quitrent', with the implication that, whilst the water from the conduit was free, the use of tankards to transport the water incurred a charge (CLBD, 237). By 1350 when the conduit warden's accounts are recorded in the letter books, two years revenue from tankard quitrents amounted to £11 15s 4d.

Despite these charges, it was thought necessary about this time to implement a new revenue stream to support the maintenance costs; properties in the vicinity of the conduit head in Cheapside and Poultry were charged half a mark per year as a fixed fee (Riley 1868, 264–5). This source of income appears, however, to have been either judged inequitable, as those who used the conduit waters lived outside the vicinity of the conduit head, or uncollectable, as a meticulous list of those who had not paid was kept by the wardens. There is no further reference to this method of collecting revenue.

The next solution to the problem of matching conduit income and expenditure was to lease out the entire conduit pipe for twenty marks a year for ten years from 1367, with the lessee enjoying 'the profits and advantages' above ground. This presumably included routine maintenance tasks such as cleaning the conduit heads, with the lessors (the City) retaining the repair costs of the underground pipe, 'provided the Sheriff, Aldermen and commonalty could take water without charge, as old accustomed' (CLBG, 223). It seems this scheme also failed to solve the financial problems of the conduit, as it was not renewed after the initial term expired. The underground repair costs must have been greater than the twenty marks lease income received by the City and the conduit was therefore taken back into public control at the end of the lease.

The next reported solution, in 1378, was an attempt to increase revenue through voluntary donations. The City tried to persuade the 'good men of each ward to make a free gift according to their wealth and zeal for the City' to support the cost of the conduit. Where such moral pressure was insufficient to raise funds from those who were thought capable of paying, an assessment was to be made against those who 'maliciously refused' (CLBH, 116). In addition, perhaps recognising the real problem, it was noted that an inquiry was to be held to achieve some better method of raising money for the conduit. The exact result of the inquiry is not known, but in the following year each resident of the City wards was asked to supply one day's free labour during a five week period between 16 May and 21 June, to work on the City conduit and ditches (CLBH, 127–8). Presumably the idea was the reverse of the 1378 'solution', that if revenue could not be increased, perhaps costs could be reduced, by substituting free labour for paid. Labour costs, based on the 16th-century Chamberlain's accounts, represented the only substantial element of cost that was not related to raw materials, such as lead and timber, and therefore seeking to reduce this element of the conduit's maintenance costs would seem to be a reasonable means of achieving some saving (Masters 1984, 78). Again, the exact outcome of this experiment is not known, although it seems not to have resolved the problem, as there are further references to the pressing need for maintenance expenditure. In 1383 the rooms and walls over Cripplegate were reported as being 'ruinous and infirm' but could only be repaired if there was any surplus 'over and above reasonable outlay on the conduit' (CLBH, 477). The conduit was to receive preferential access to City's resources.

The lack of conduit warden accounts makes it difficult to draw any definitive conclusions on the effectiveness of the financial administration of the conduit. Accounts for public utilities were normally rendered following the end of the responsible warden's term of office and were not necessarily produced annually (Harding & Wright 1995, 10). It seems that in the late 14th century the urgent need for more funds to support the conduit was partly met from bequests. An examination of the wills proved in the Court of Husting shows that of nine bequests made to the conduit between 1259 and 1499, five were made in the period 1380–1400 (McEwan 2000, 38). The repeated changes in gathering revenue, the call in 1379 for free labour to work on the conduit, and the later reliance on bequests and other donations suggest that the conduit was not covering its costs (CLBH, 127–8). The City records specifically note that modifications to the conduit were to be at the cost of the local inhabitants, as if the conduit wardens had no available reserves or surplus funds (CLBH, 326).

In 1415 there is reference to a different charging mechanism — the collection of additional revenue from 'industrial' users of the conduit. Brewers were to 'rent' the upper pipe of the conduit, for both malting and brewing, with the lower tap (*ie* the waste water) being allowed for the 'common people' without charge (CLBI, 617). After 1420 the conduit was subject to substantial renovation and presumably the issue of maintenance expenditure was then less pressing and this would account for the silence on this topic in the letter books, until the 1470s. It would appear that later in the 15th century routine conduit maintenance costs were being paid by the City authorities, as there is reference in the City journal to a fourth part of the fifteenth being collected in 1471, a further fifteenth in 1472, and a quarter of a fifteenth in 1475, for 'the repair' of the conduit (Journ. 8, fo 23,27,101).

CONSTRUCTION FINANCE

The total cost of constructing the first conduit is not recorded, but it would probably have been *c.*£1,900, based on the known costs for the conduit extension in 1442 (Appendix 2). The major part of the capital construction cost must have been raised from pious donations, possibly, as with London Bridge, associating the donor with the cult of Saint Thomas (Barron 2004, 256). The contribution of £100 recorded from the merchants of Amiens, Corby, and Nele in Picardy for a licence to offload and warehouse woad within the City, represented a relatively small drop in the financial ocean of the overall project (Keene & Harding 1987, 612). This is the only reference to the construction costs of the first conduit in the letter books.

The finance and control of the London water conduit changed significantly in the 15th century, switching from a mixture of City and private funds to, almost exclusively, wealthy merchants, most of whom were at some time either aldermen, sheriffs, or mayors of London. This change begs two questions: why was there a switch from public funds to private donation and why was the provision of water selected as a worthy project for charitable giving?

The answer to the first question is complex. The Cheapside conduit head was a very symbolic building; it demonstrated the modernity of the City in the application of technology and the generous provision made for the poor; its importance was acknowledged in City pageants. Early 15th-century London was a boom town that had made a number of leading merchants extremely wealthy. Key amongst these were perhaps Whittington (Mercer), Estfield (Mercer), and Eyre (Draper). These merchants wished to leave their mark on the City, both as an act of piety and as a gesture of civic pride. Estfield, in particular, is associated with the development of the London conduit, although there is no obvious reason why he selected 'water' as a suitable vehicle for donation, other than the obvious religious associations and the benefits clean water brought to public health. Perhaps, in the often mixed motivations of 15th-century public giving, it was the position of the conduit on Cheapside, located immediately outside the Mercer's Hall, an area in which many mercers lived, that would act as a visual reminder to his business associates for post-mortem prayer. Undoubtedly Estfield would have seen the daily competition for water at the conduit taps and he must have decided that an improvement to the City water supply would be a worthwhile act of charity. Estfield appears to have become increasingly involved with water-related projects during the early years of the 15th century, eventually becoming directly involved in financing the expansion of the conduit — paying in 1443 for new source springs, located in Paddington, to be incorporated into the system. He left bequests in his will in 1446 for the completion of a new conduit to the church of St Mary Aldermanbury, where he was to be buried. His executors subsequently built the new conduit by 1471 (Cal Wills II, 509–11).

By the 15th century it seems that the City understood the necessity for sound finances to support public works. The 'new work' of the Guildhall, in 1413, demonstrated the new thinking, as it was funded by a collection of 'pious alms of citizens and helping hands of divers generous and benevolent persons' and a further hundred marks of the City's profits from London Bridge (Riley 1868, 589). Significantly, public funds were used to supplement private donation. The City did not commission new civic amenities until a means of financial support had been agreed.

EXPANSION OF THE CONDUIT SYSTEM

The early 15th-century conduit system, although increased in capacity in 1355 through the addition of new source springs at Tyburn, was almost two hundred years old by 1440 and would surely have appeared to be a very tired piece of City infrastructure. The cumulative effects of inadequate maintenance, probably resulting in silted and leaking pipes, would have significantly reduced the flow of water through the conduit. The inadequacy of supply was leading to disputes between tradesmen and ordinary consumers as each group competed for access to the water; in 1415 some of these disagreements were recorded in the letter books (CLBI, 617). The convenience of the conduit had stimulated its own demand and whilst increasing numbers of people wanted access to the water, at the same time the supply diminished and became more unreliable. The system was in need of a complete overhaul.

The difficulty with increasing the supply through the existing conduit pipe was that the source at Tyburn had already been fully exploited and the option of simply linking in more springs in the immediate vicinity of the head cistern was not available. In addition, the existing pipe was in need of substantial repair that would require its excavation, recasting, and relaying. The system needed to be completely renewed. At this point it is not known whether a radical solution to the failing conduit was contemplated, such as finding a completely new source that might have been available to the north of the City. Any new system, however, would have involved investing in a new pipe and trench, with the implicit risk that the new source would not provide the necessary pressure to ensure an improved supply. It seems that a two stage improvement was planned: firstly to incorporate new source springs — these would simply consist of tapping the Westminster Abbey supply in Oxlease, 2 km west of Tyburn, close to the modern site of Paddington station; and secondly, to excavate and relay the problematic section of pipe in Fleet Street (CLBK, 233). In order to minimise the amount of pipe and trench that was required to connect Oxlease to the existing conduit system, a new pipe would need to be laid south of Oxlease (probably partly following an existing river bank) to link with the spurgel at Charing Cross. By 1430 negotiations had been concluded with the Abbot and Prior of Westminster, but conditions were attached. Firstly, that 'should the ancient supply of water to the Abbey of Westminster from the manor of Hyde be interfered with, the granters shall be entitled to resume possession of the head and springs now granted' (Morley Davies 1910, 26). In addition, it was established that any water extracted for use in the London conduit incurred a charge. Presumably this condition was included as double protection, that if the London conduit refused to resite their conduit having diminished the Abbey supply, the Abbey could then charge a usage fee, sufficient to pay for the construction of a new Abbey supply. The initial charge was set at an immaterial two peppercorns per year (Foord 1910, 269).

A second condition was that any new pipes were not to cross the manor of Hyde — the reason for this is not known, presumably it was not just a question of the disruption that laying new pipes might cause. However, this condition was problematic as the most direct route to the spurgel at Charing Cross was through the manor

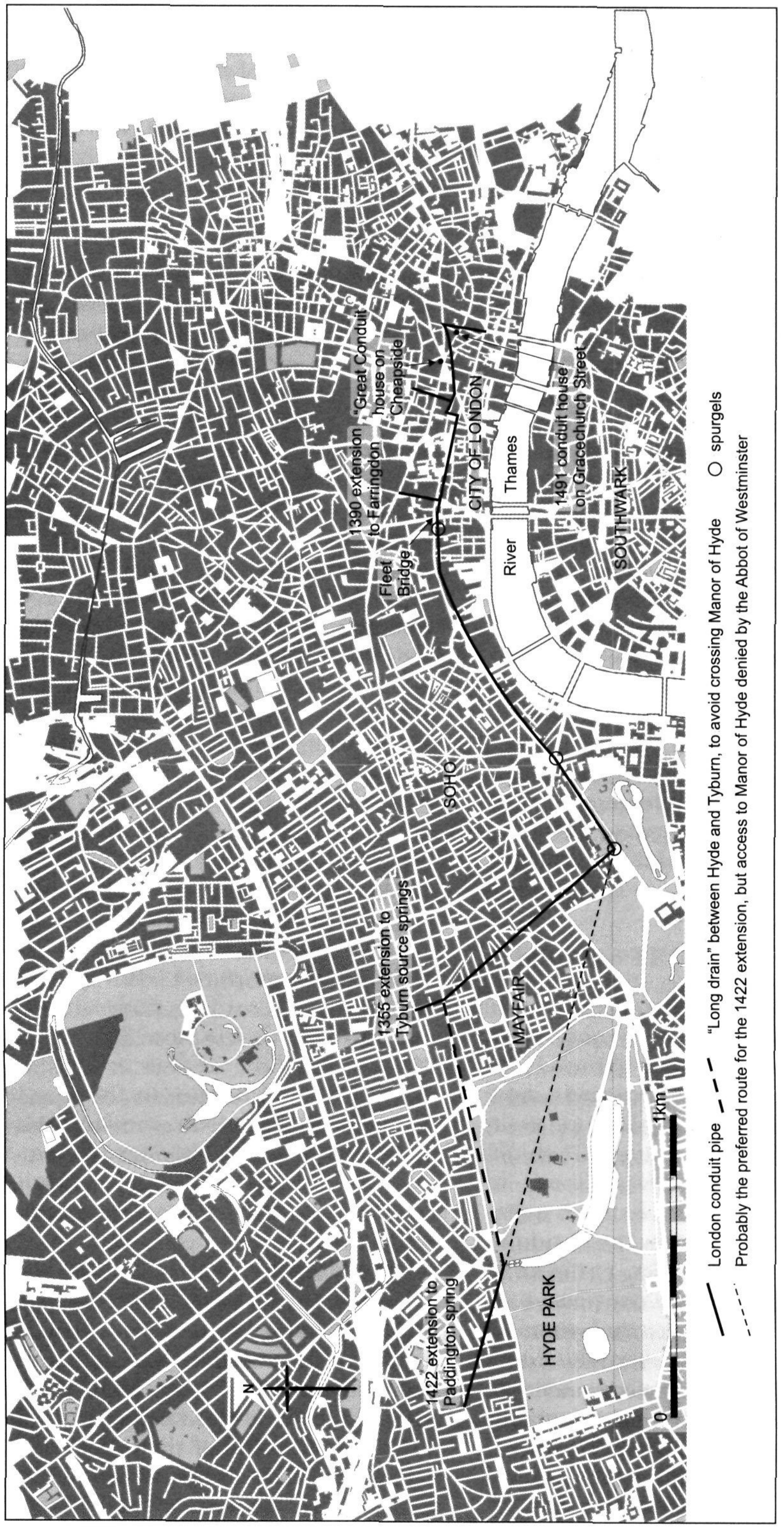


Fig 6. Map of the probable line of the first London Conduit, overlaid on a modern map of the city.

of Hyde (Fig 6). The alternative of laying a pipe to the cistern at Tyburn, to link in with the existing system, would have involved the pipe mounting the high ground at the junction of the manors of Hyde and Tyburn (present day Hyde Park corner). As the difference in elevation between Oxlease and Tyburn was only about 3m, a closed pipe in this location would not have transported a sufficient quantity of water over the intervening high ground to significantly increase the total capacity of the system (Morley Davies 1910, 24–8).

To solve this problem a 'long drain' (an open trench conduit) was to be built between Oxlease and Tyburn with sufficient capacity to increase the head pressure at Tyburn. This 'solution' was not without technical difficulties; the drain would have to operate within a very shallow gradient, over a relatively long course, and, given the crude instrumentation available to the builders, construction would have involved a considerable amount of trial and error. A committee had been formed by 1439 to plan the new works and raise the required finance; investment in the conduit was clearly seen at this point as a project to be managed by the City authorities (Barron 1971, 270). Estfield was chosen to supervise the work and this appears to be his first recorded involvement with 'water' projects. The new work on the conduit is not mentioned in the City journal for a two year period at this time, and it could be speculated that the construction of the 'long drain' accounts for the apparent delay (CLBK, 243, 249).

At the same time it seems that the pipes in Fleet Street and Strand were being repaired on the basis that the new conduit would extend from Tyburn to the Charing Cross spurgel and from there to the City using the repaired 'old' conduit pipes (Barron 1971, 270). Stow refers to 'water conveighed ... in pypes of lead into a pype begunne to bee laide besides the greate Conduit heade at Maribone [Tyburn], which strecheth from there unto a separall ....made against the Chappell of Rounsevall by Charing Cross, and no further' (Stow 1908, II, 41). In 1442, William Cliff (the City building surveyor) promised to account for his work on the Fleet Street conduit, but was unwilling to estimate the likely future expenditure (Barron 1971, 270). It could be that the construction work was more costly than anticipated, as the 1,000 marks tax revenue raised by the wards in 1440 seems to have been exhausted by 1442. Conventionally, the project is thought to have ground to a halt at this time.

An alternative explanation might be that new plans were drawn up to radically increase the capacity of the conduit by laying additional lead pipes from Tyburn to the City, including intermediate spurgels (Barron 1971, 271). The reason to suppose that there might have been such a plan is two fold. Firstly the 16th-century drawing of the conduit by Treswell clearly shows the system in the vicinity of western Cheapside comprised of a number of supply pipes and not the single pipe of the original system. Secondly, the 1443 royal grant for the construction work, including laying pipes under the King's highway, (*ie* after the initial project appears to have stopped in 1442) records 200 fodders (*c.*190 tons) of lead being purchased for the project. As the standard practice was to recover lead from the old pipes in making the new, this amount of lead is far in excess of the amount required to repair a single pipe. For the repairs to the Windsor Castle conduit in 1603, that used a pipe of similar dimensions to the London conduit, 56 tons of new lead were required to recast two miles of pipe, two thirds of the total lead required being met from melting the old pipe (Hope 1917, 230). Even if it is assumed that there was little or no recovery from removing the 'old' London conduit pipe, the lead ordered in 1443 would have been sufficient to install a double pipe from Tyburn to Cheapside, based on the dimensions and weight of the recently excavated section of conduit pipe (Appendix 2). As no accounts of the extension to the conduit exist, what exactly was installed in the early 15th century has to remain speculative; however as the technology of pipe manufacture only allowed pipes of a *c.*10cm diameter to be made, the only way of increasing the capacity of the system would have been to lay a double pipe. The evidence of the Treswell drawings and the purchase of substantial quantities of new lead would support this conclusion.

Initial financing of the extension to the conduit appears not to have been resolved until 1446 when it consisted of a mixture of City funds, private loans (including 250 marks from Estfield), and bequests (Barron 1971, 274). The element of public finance in the project was to be deferred and collected over the period 1446–50, presumably to meet the planned construction costs as they arose (CLBK, 318). However, with the exception of the inhabitants of Cheap ward, who had a vested interest in completion of the project, the funding was either not collected by the aldermen or appears to have been diverted to other purposes. It has been speculated that Estfield, who had died some time before 29 April 1446, provided funds for the completion of the conduit project by a verbal codicil to his will and, knowing this, the wards diverted funds to other priorities (Barron 1971, 275). Certainly, however, the executors of Estfield adopted the management of the project from 1453 after lengthy negotiations with the City, including permission to lay new pipes between Fleet Street and Cheap (Journ. 5, fo.185). Stow notes that this work was completed in 1471 (Stow 1908, I, 17; CLBK, 355–7; CLBL, 158, 207). The transfer of the conduit project from the City authorities to private hands points towards a changed attitude in the management of public works programmes. A development also reflected in a number of other projects, such as the grain store at Leadenhall built by Simon Eyre (1445) or Whittington rebuilding Newgate prison (1431) (CLBK, 49–52).

The extension of the conduit to incorporate the source springs at Oxlease took over thirty years to complete and cost between a phenomenal £3,200, and possibly as much as £5,000, but dramatically increased the supply of conduit water to the City (Barron 1971, 277). The new conduit was over 6.5km long from Paddington to Cheapside and was efficient enough not only to supply the original conduit in Cheapside, but also a number of new distribution points.

Little Conduit on Cheapside

Although Stow attributes the building of the Little Conduit 'close to Powles gate' to Estfield in the 'ninth of Henrie the sixth' (September 1430–August 1431), this point is not clear from other City records (Stow 1908, I, 268). The letter books refer to the Little Conduit being built at the same time as an extension to the church of St Michael le Quern 'half on the common soil' and the Little Conduit being 'repaired' at the City's expense in 1430, implying that it was built some time before this date — previously the repair costs being met by local inhabitants (CLBK, 110; CLBL, 106). A possible earlier construction date might be 1390 when the 'substantial men of Farringdon, near St Michael le Quern' were granted permission to construct a conduit — the Little Conduit forming part of this development. Undoubtedly, however, the Little Conduit was located at the extreme western end of Cheapside and was fed from the same pipe as the first conduit house at the eastern end of Cheapside, that became known as the 'Great Conduit' following the construction of the Little Conduit.

The Little Conduit was drawn by Ralph Treswell in 1585, in one of his earliest drawings of London (Fig 7). The dimensions on this plan show the Little Conduit as being approximately 32ft long, compared to the Great Conduit (excavated in 1994) that was approximately 34ft long — the 'Little' Conduit was, therefore, only a slightly smaller building than the Great Conduit (Schofield 1987, 56–7). The Treswell plan also shows that three pipes were laid under Cheapside, one of which enters the Little Conduit with the other two passing (presumably) to other distribution points on Cheapside. Surprisingly the plan does not show the 1390 extension of the system to Farringdon, suggesting that Treswell was either not aware of the underground pipe or that the pipe was joined at some other point (CLBH, 521). The Treswell drawing of the Little Conduit and the church of Saint Michael le Quern is itself mysterious, as it was unrelated to other Treswell drawings of London streets and apparently was not part of a larger scheme. Equally it is not known who commissioned the drawing. It could have been made simply to note the path of London conduit pipes, avoiding confusion with any other pipes that may have been laid by 1585, allowing them to be located for repair. It has been suggested that early monastic water supply maps have survived for this same reason.

As the term 'little' did not refer to the size of the conduit building, it possibly referred to the quantity of water delivered there, as there are no references to disputes over access to the water; it may only have supplied 'domestic' quantities of water. Regulation of the volume of water was achieved by attaching a very narrow diameter pipe to the main supply, often referred to in the letter books as a 'quill' of water — the 'quill' referring to the thickness of the pipe that was probably no more than a swan or goose quill (8mm). The technology to restrict the flow of water by means of a valve did not exist (Magnusson 2001, 70). It would also probably have been symbolically important not to divert an excessive quantity of water into the 'Little' Conduit, in substitution for water delivered to the 'Great' Conduit, given the problems of supply being experienced in the early 15th century.

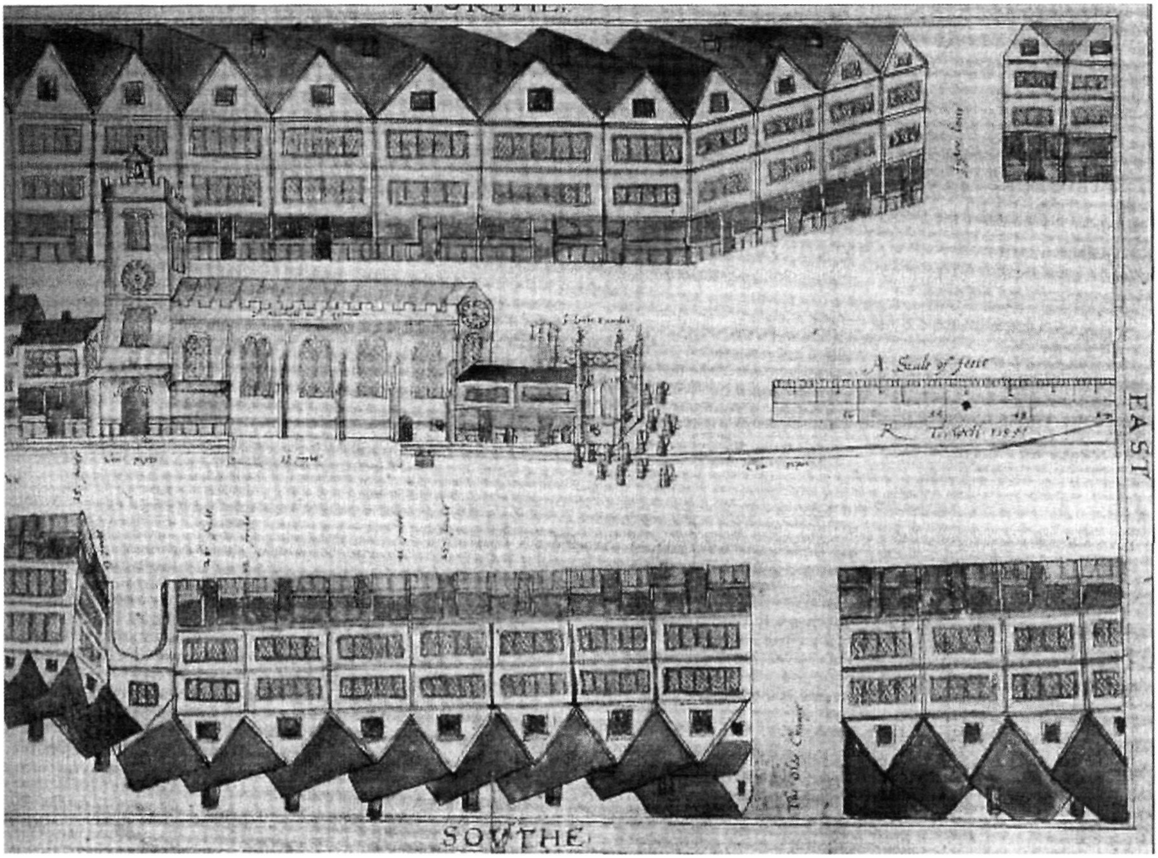


Fig 7. The Little Conduit at St Michael le Querne, Cheapside (BM Crace Collection 1880-11-13-3516) (By permission of the British Library)

Standard on Cheapside

The Standard was located in the centre of Cheapside, opposite Honey Lane, and was originally a place of public execution (Stow 1908, I, 265). It appears to have been built of wood and Stow refers to it first having 'water conveyed to it' in 1285, the same date he gives for the building of the Great Conduit, implying (improbably) that the Standard was part of the original conduit plan (Stow 1908, I, 17). How the Standard worked as both a place of execution and a water conduit is uncertain. Presumably, if Stow was correct, the Standard would not have included a lead cistern, but simply a succession of running taps that only flowed when there was sufficient pressure in the main pipe. Wooden framed conduits were not unknown, however; Stow mentions a wooden standard in 'Old Bayly' forming part of the supply to Ludgate prison '...delivering fayre spring water' (Stow 1908, II, 38).

The Standard on Cheapside therefore could have been initially a wooden structure rather like a scaffold, being (re)built with stone following a bequest from John Wells (ex-mayor) *c.*1442 (Stow 1908, I, 26). The new Standard was decorated with an image of Wells being embraced by angels and contained a small lead cistern 'having one small cock continually running, when the same was not turned or locked' (Foord 1910, 259). The regulation of water pressure at the Standard would have been achieved by using a narrow diameter 'quill' attached to the main pipe, in a similar arrangement to that at the Little Conduit. The rebuilding of the Standard in 1442 confirms that it formed part of the general improvement to the conduit that included the work being carried out on the Fleet Street/Strand section of the conduit pipe. Although there are no references indicating that the rebuilt Standard delivered greater quantities of water, the fact that work was simultaneously being carried out to increase the conduit's capacity might suggest that the 'new' Standard relied on the conduit's general improvement.

Cornhill conduit

Extending the conduit to Cornhill had been an ambition of the City fathers since the late 13th century, as Cornhill, in common with Cheapside, was on the traditional processional route through the City and the location of a market. The first reference to a conduit in Cornhill occurs in 1378 when 500 marks were given under the will of Adam Fraunceys (ex-mayor) for carrying conduit water to 'cross-ways on the top of Cornhill' (CLBH, 108). This gift presumably formed part of general improvements planned for the Cornhill market, which until 1394 had operated under relatively restricted opening hours, with the City granting permission after this date for the market to open in the evening on feast days (Archer *et al* 1988, 9).

The early references in the letter books to a conduit on Cornhill refer to the crossways junction of Gracechurch Street and Cornhill, but as this is the highest point in the City (*c.*20mod), there would have been insufficient water pressure within the system to operate a water fountain at this location, even allowing for the 1355 improvements to the head cistern at Tyburn (Appendix 1). It seems that at some point a compromise was reached and that an existing building, called the 'Tun' or 'Tonne', part way up Cornhill was to be modified and incorporated into the conduit system. As the Tun was at a lower elevation than the crossways, it accessed greater pressure from the pipe and therefore was more likely to provide a reliable supply. The Tun on Cornhill was built in 1282 by Henry Wales (Wallis), ex-mayor, as a prison for 'night walkers', prostitutes, and other offenders, obtaining its name from its barrel shape (Schofield 1984, 110). It was located close to Birchin Lane and Stow refers to it being 'cisterned' in 1401, presumably the installation of a lead cistern at some height above street level with exterior taps, in a similar arrangement to the Great Conduit (Stow 1908, I, 17, 188). The homecoming of Henry V from Agincourt in 1415 mentions the pageant at the conduit in Cornhill, and this gives the latest date for its conversion from a prison to a public utility. It is likely that it was either a relatively small fountain or that it ran intermittently, as it was fed from the same pipe as the Great Conduit, which at this time was suffering from a shortage of supply. Calculations suggest that it was operating below 5 psi, equivalent to delivering half a litre per second, at best (Appendix 1).

Stow notes that in 1475 the cistern of the Tun was enlarged together with an 'East end of stone, and castellated in (a) comely manner', the improvements being paid for by the ex-major Robert Drope (Stow 1908, I, 191). Again the enlargement of this fountain could only have been contemplated once the overall capacity of the system had been increased through the incorporation of the Oxlease source.

Gracechurch Street conduit

The conduit on Grasses Street (or Gracechurch Street) was located between the crossways intersection and Grace church. It was built following a bequest from Sir Thomas Hill, ex-mayor, in 1484, who left 'one hundred marks towards the conveyance of water to this place' (Stow 1908, I, 211). Dame Elizabeth Hill (Thomas Hill's widow) was granted permission by the City authorities to 'turn up the soil in Gracechurch Street for the purpose of the conduit' in 1491, and Stow reports that the building of the conduit head was apparently completed in the same year (CLBL, 280). Hill's executors also reported completing building it in 1491. In common with the Cornhill conduit, the Gracechurch Street fountain was located, significantly, on the main processional route for City ceremonials between London Bridge and Cheapside. It would appear that building conduit fountains had become a fashionable means of post-mortem commemoration for late 14th-century civic office holders.

The Gracechurch Street conduit was obviously a local landmark, as Stow notes that the City watch was directed to pass 'the Grasse Street conduit' on returning to Cheapside (Stow 1908, I, 102). It was connected to the Great Conduit via the Tun on Cornhill, but, due to its elevation, it appears to have had a poor or intermittent supply of water. In the case of this fountain, however, the cause of insufficient supply was not solely related to the capacity of the system. It seems that with the post-1470 improvement to the conduit, it was realised by Londoners that an underground pipe could as easily provide the convenience of a domestic supply as provide a public function. The practice of private, and probably illegal, tapping of conduit pipe became common in the late 15th century and clearly the City authorities disapproved. A case was recorded in the letter books in 1478 concerning a brewer, William Campion, who seems to have tapped into the conduit main below Fleet Street, probably by using a narrow diameter pipe or 'quill' that provided a ready supply of water for his business, saving the cost and effort of transporting water from his local public water fountain. As a discouragement to others, who may have contemplated emulating Campion, he was paraded through the streets on horseback, with a 'vessel like unto a conduit' on his head, that ran with water; the water being refilled as it was wasted (CLBL, 160).

Although an example was made of Campion, private tapping of the conduit was a more general problem. The licences granted in the mid-16th century to tap the conduit mostly concerned residences in the Strand, owned by aristocratic or wealthy merchants, and not simply the occasional resourceful artisan. The problem with taking private supplies from the 'high pressure' section of the system in the Fleet Street/Strand area was that public fountains further along the pipe, and at a higher elevation, would suffer an off-setting reduction in pressure and therefore an interrupted supply. By 1543 it was noted that water in the Cornhill, Aldermanbury, and Gracechurch Street conduits had stopped, due to the reduction in pressure caused by private tapping into the conduit pipe (Foord 1910, 276). The problem of regulating access to conduit water so as to provide an adequate public supply, whilst also granting some private supplies, concerned the City authorities into the 16th century.

The Standard on Fleet Street

The Fleet Street Standard, built in 1471, according to Stow, was located opposite Shoe Lane close to Fleet Bridge. In 1478 the local inhabitants had obtained a licence from the City authorities to install two new cisterns to be linked to the Fleet Street Standard. The first was to be decorated 'as a fayre tower of stone, garnished with images of St Christopher on the top, and angels round about lower down, with sweet sounding bells before them, whereupon by an Engine placed in the Tower, they, divers hours of the day and night chymed such Hymme as was appointed' (Stow 1908, II, 41). Clearly this conduit fountain was intended for display. The second cistern apparently collected the waste water, in a similar arrangement to the Great Conduit, and was located near Fleet Bridge. Stow does not mention whether the two cisterns were connected, although it is probably safe to assume that they were. The local inhabitants paid for the installation of the Fleet Standard, presumably the sounding of hours was associated with either the hours of prayer or the Inns of Court, located in the area. A conduit warden was appointed to maintain the Fleet Street conduit in 1485, together with a separate warden for the Aldermanbury conduit (CLBL, 228).

A further extension was made to the conduit at Fleet Bridge in 1475 to supply the nearby prisons at Ludgate and Newgate. William Cliff, the City building surveyor, and the aldermen William Hulyn and Hugh Middleton supervised the building of the extension. Although authorisation for the work was received in 1459, the Paddington source was not connected until 1471, and so the completion of the prison extension was not finished until 1475 (Barron 1971, 277). The City agreed to pay for the maintenance of the new pipes (CLBL, 130). Ludgate prison had been enlarged, improved, and endowed by Agnes Foster (widow of mayor Stephen Foster) in 1463, being reserved for Londoners, to save them from suffering the dirty and cramped conditions at Newgate prison. As part of the endowment to Ludgate, prisoners would not have to pay for either lodgings or water and Stow notes that the water to the prison was provided 'by certain verses grauven in Copper, and fixed on the side quadrant' (Stow 1908, I, 39–40; Archer *et al* 1988, 98).

CONCLUSION

Stow attributes the development of the London conduit system to the charitable objectives of providing good quality water to those who could not otherwise afford it. Although there is no specific mention of the motivation for such giving, inferences can be drawn from the way the conduit was developed that place it exactly within the pattern of pious donations seen elsewhere in the 15th century. In addition to constructing a funerary monument in a crowded London church that competed with many others, perhaps post-mortem prayer could be encouraged by making a unique contribution to the City infrastructure — especially eliciting the potent prayers of the poor. The placing of both the Little and Great Conduit heads next to the churches of St Michael le Quern and St Mary Colechurch respectively, and close to the birthplace of Saint Thomas, was surely intended to illicit remembrance.

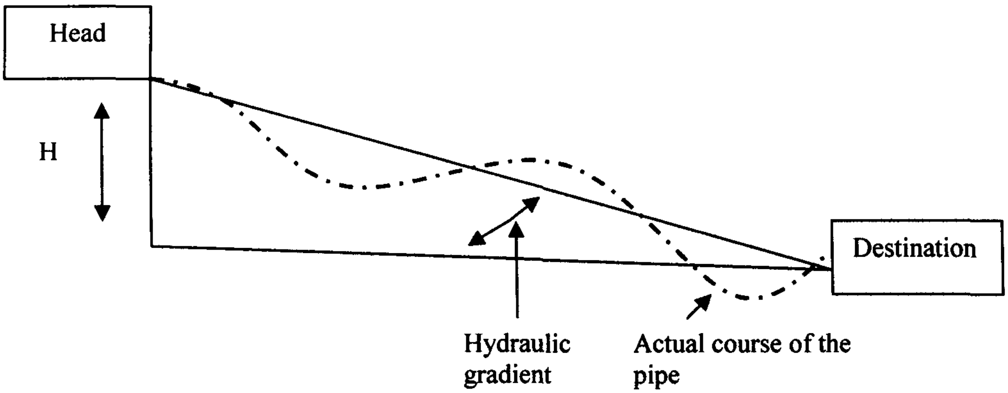
It is significant that the pattern of expansion of the conduit largely followed the processional route of those entering the City on special pageant days, providing the maximum opportunity to remind Londoners, and perhaps a wider circle from outside the City, of those responsible for providing the City infrastructure. This is not to imply that the pious provisioning was the only motivation. No doubt competition between wealthy merchants to out-do one another in their giving and an element of civic pride played their part.

During the course of the 15th century the attitude of the recipients of City infrastructure projects was seen to change. Profits from trade during the 13th and 14th centuries had been tainted with the possibility of containing an element of usury and were therefore thought 'distasteful'. The use of these same profits to finance the construction of public buildings and monuments potentially cast these projects in a similar light. By the 15th century, however, profits came to be seen differently; they were the means of performing good works and were therefore to be encouraged, or as Little states, 'philanthropy held one of the keys to the justification of profit-making' (Little 1978, 213). The London economy was fast growing in the early 15th century, overseas trade was increasing, and a number of individual merchants were becoming extremely wealthy. As much as anyone else, these individuals wished to shorten their time in purgatory and to achieve this, they constructed their monuments within the urban space from which they derived their wealth. Simon Eyre in building the grain store at Leadenhall, Whitington in numerous public buildings, including a college of priests, a library, and the Guildhall, William Estfield in augmenting the conduit system, Hill, Drope, and Foster all left their mark, amongst many others.

Setting aside the problems of finance and the possible motivations for its building, the London conduit represented a remarkable engineering achievement. It transported fresh, wholesome water through almost 7km of underground pipes, with some sections rising against the force of gravity. It represented the earliest English application of hydraulic technology to overcome the problems of pollution resulting from urban growth, yet seems to have undeservedly faded from the historic record since its physical removal. What was at one time a complex and unique technology has become as understated as Stow's simple description of the motivation for its installation: 'For the poor to drink and the rich to dress their meat'.

APPENDIX 1.
ENGINEERING CALCULATION OF THE CAPACITY OF THE CONDUIT PIPE

(Calculations kindly provided by Gordon Fitch, MSc(Eng))



Irrespective of the actual course of the pipe, the hydraulic gradient governs the head pressure and therefore the static pressure in the pipe at any point, calculated by the formula:

$$\text{Difference in height between source and destination} = \frac{2 \text{ X friction factor X length of pipe X velocity of flow}^2}{\text{gradient factor of the pipe X diameter of the pipe}}$$

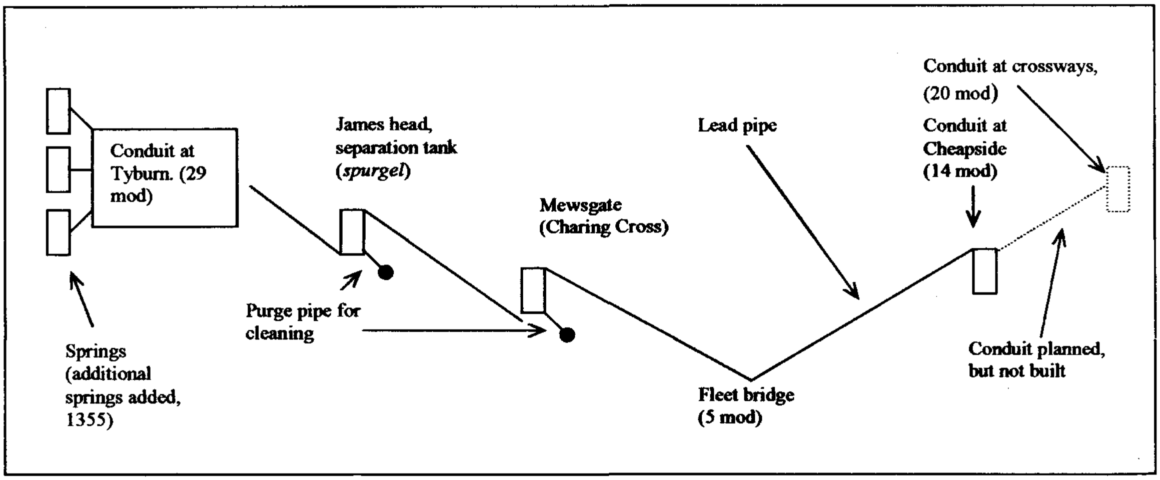
$$\text{or } \Delta H = \frac{2FLV^2}{GD}$$

$$\text{and } V = \sqrt{\frac{\Delta H\ GD}{2\ FL}} \text{ feet per second,}$$

$$V = \sqrt{\frac{48 \text{ X } 32.2 \text{ ft/sec}^2 \text{ X } 0.29 \text{ ft}}{2 \text{ X } 0.0075 \text{ X } 15{,}682 \text{ ft}}}$$

V = 4.3 psi per 10 feet of fall or 1.25 gallons per second

As a large part of the data within this formula is fixed, once the characteristics of the pipe are known, there is a direct trade-off of the difference in elevation between source and destination and the velocity of flow.



Pressure (psi), using a factor of 4.3 psi per 10 feet of fall, assuming no pipe leakage	0	5.5		33		20	3.8
Pipe pressure (psi), assuming 20% loss of pressure at Fleet Bridge				26.4		13.4	0

Fig 8. Schematic London conduit map based on Stow's description of the system, including the planned extension to the top of Cornhill

Conduit section	**Elevation**	**Information source**
Source springs, Tyburn	29 mod	Spence 2000, 24
Fleet Bridge	5 mod	*ibid*
Cheapside conduit head	14 mod	Birch *et al* (forthcoming),

APPENDIX 2
CALCULATION OF THE LENGTH OF THE LONDON CONDUIT

Stow's description of the length of the conduit: 'The water course from Padington to James hed hath 510 rods; James hed on the hil to the Mewsgate 102 rods; from the mewsgate to the crosse in Cheape 484 rods' (Stow 1908, I, 17). (NB The field next Oxlease was called 'Hill Field', suggesting that this was a local high point.) Total 1096 rods @ 20ft to a rod* = 21,920 feet, or 6.68km. As a deep trench, presumably in almost a direct line, would have been excavated from 'the close' at the Paddington spring to Tyburn of 1.9km, the 'old' conduit from Tyburn, was therefore 4.78km.

*The length of a rod varied by region; Morley Davies estimates Stow's rod as 19ft, although this assumes a direct measurement from Charing Cross to Cheapside. The conduit had to skirt St Paul's precinct and therefore Morley Davies's calculation may be a slight underestimate of the length of a 'rod' as used by Stow (Morley Davies 1910, 18, 46).

EXTENSION OF THE CONDUIT IN 1442 TO INCORPORATE SPRINGS AT PADDINGTON

200 fodders of lead ordered to be purchased 25 June 1442, by writ of privy seal (CPR Henry VI, 1441–46, 198). 200 fodders of lead are equivalent to approx-imately 190 tons.

Waste allowance in manufacture of the pipes approximately 7.7%. ('waste of a wey of lead when newly molten [he shall have an allowance of] two cloves, as has been the usage heretofore'.This is about 14 pounds in 180 (7.7%), the weight of clove and wey varying (Riley 1868, 322).)

Finished weight of pipe therefore 175.2 tons.
The recently excavated conduit pipe found at Paternoster Square weighed 19.5kg (43lbs) for a 1m (3.3ft) section. 175.2 tons (178,003 kg) of pipe would therefore have been approximately 9.128km (5.7 miles) long.

Two pipes from Tyburn to Cheapside would have required 9.56km of pipe, allowing for the inaccuracy in some of the weights and measures used. It seems reasonable to assume that the purchase of lead was sufficient to build a double pipe from Tyburn to Cheapside. This would accord with the drawing of the Great Conduit by Ralph Treswell, showing three pipes. One pipe being the original conduit and the other two relating to the 1442 extension.

Cost of one fodder of lead in the 1350 warden's accounts, 8 marks 12 pence (total 1,292d).
Cost of 200 fodders, 258,400d or £1,076 13s 4d.

The cost of the 1442 extension was *c.*£2,790 (Barron 1971, 277). Approximately £1,100 represented the cost of lead pipe and £1,870 other installation costs — mostly labour wages and timber.

The first conduit pipe was a single pipe with an approximate cost of £550 (50% of the 1442 pipe cost), assuming labour costs in 1250 were 30% lower than in 1442, the total cost of the first conduit would have been *c.*£1,900.

BIBLIOGRAPHY

Abbreviations
CCR: Calendar of Charter Rolls (1906)
CLBA, CLBB, *etc*: R R Sharpe (ed) *Calendar of Letter Books of the City of London* (1899–1912)
CPR: Calendar of Patent Rolls (1909)
Cal Wills: R R Sharpe (ed) *Calendar of Wills Proved and Enrolled in the Court of Husting, London 1258–1688* (1890)
Journ: Journals of the Court of Common Council

ARCHER *et al* (1988), I Archer, C Barron & V Harding *Hugh Alley's Caveat*
BARRON (1971), C M Barron *Government of London and its Relations with the Crown* unpub doctoral thesis, University of London
BARRON (2004), C M Barron *London in the Later Middle Ages: Government and People 1200–1500*
BENNETT (1996), J M Bennett *Ale, Beer and Brewsters in England*
BIRCH *et al* (forthcoming), M Birch *et al Excavations at 1 Poultry: The Late Saxon, Medieval and Post-Medieval Sequences*
BROWN *et al* (1963), R A Brown, H M Allen, H M Colvin & A J Taylor *The History of the King's Works*
CHURCH (1877), A H Church *Plain Words about Water*
FOORD (1910), A S Foord *Springs, Streams and Spas of London*
HARDING & WRIGHT (1995), V Harding & L Wright (eds) *London Bridge: Selected Accounts and Rentals, 1381–1538*
HARVEY (1993), B Harvey *Living and Dying in England 1100–1540*
HODGE (2002), A T Hodge *Roman Aqueducts and Water Supply*

HOMER (1991), R F Homer 'Tin, lead and pewter' in J Blair & N Ramsay (eds) *English Medieval Industries*, 57–80

HOLT (2000), R Holt 'Medieval English water related technologies' in P Squatriti (ed) *Working with Water in Medieval Europe: Technology and Resource Use*

HOPE (1902), W St John Hope 'The London Charterhouse and its old water supply' *Archaeologia* 8, 293–312

HOPE (1917), W St John Hope *Windsor Castle and Architectural History* (2 vols)

KEENE (2001), D Keene 'Issues of water in medieval London' *Urban History* 28, 161–79

KEENE & HARDING (1987), D Keene & V Harding 'The Great Conduit: St Mary Colechurch' in D Keene (ed) *Historical Gazetteer of London Before the Great Fire*, 36

LITTLE (1978), L K Little *Religious Poverty and the Profit Economy in Medieval Europe*

MAGNUSSON (2001), R J Magnusson *Water Technology in the Middle Ages*

MASTERS (1984), B R Masters (ed) *Chamberlains' Accounts of the Sixteenth Century*

McEWAN (2000), J McEwan *The Water Conduits of Medieval London* unpub MA thesis, University of London

McPHERSON & AMOS (1931), E R McPherson & E G J Amos 'The Norman waterworks in the keep of Dover Castle' *Arch Cant* 43, 166–72

MORLEY DAVIES (1910), A Morley Davies 'London's first conduit system: a topographical study' *Trans London Middlesex Archaeol Soc* 2, 9–58

NORMAN (1899), P Norman 'On an ancient conduit-head in Queen Street, Bloomsbury' *Archaeologia* 6, 257–66

RILEY (1868), H T Riley *Memorials of London and London Life in the XIIIth, XIVth and XVth Centuries*

RODWELL (1981), W Rodwell *Archaeology of the English Church*

ROWSOME (2000), P Rowsome *Heart of the City: Roman, Medieval and Modern London Revealed by Archaeology at 1 Poultry*

SCHOFIELD (1984), J Schofield *The Building of London*

SCHOFIELD (1987), J Schofield (ed) *The London Surveys of Ralph Treswell*

SCHOFIELD & VINCE (1994), J Schofield & A Vince *Medieval Towns*

SKELTON & HARVEY (1986), R A Skelton & P D A Harvey *Local Maps and Plans from Medieval England*

SMITH (1975), N Smith *Man and Water*

SPENCE (2000), C Spence *London in the 1690s, a Social Atlas*

STOW (1908), J Stow *A Survey of London* (ed C L Kingsford, 2 vols)

THOMAS *et al* (1997), C Thomas, B Sloane & C Phillpots *Excavations at the Priory and Hospital of St Mary Spital*

TIGHE & DAVIS (1858), R R Tighe & J E Davis *Annals of Windsor* (2 vols)

TUCKER (1995), P Tucker *Government and Politics: London 1461–83* unpub doctoral thesis, University of London

WALDO (1923), F J Waldo *History of the Worshipful Company of Plumbers*

WEBB (2000), D Webb *Pilgrimage in Medieval England*