School of Archaeology, Geography and Environmental Science

The River Walbrook and Roman London

PhD thesis

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November 2016

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Research Abstract

This thesis is concerned with the hydrology of the River Walbrook and its influence on Roman London. The Walbrook had a small catchment (4.7 km^2), most of which was rural in the Roman period, and flowed to the Thames through urban Roman London. The research is based upon data abstracted from reports, plans and sections of seventy archaeological investigations in the urban Roman Walbrook Valley, supplemented by archaeological literature, maps, boreholes and modern data. A methodology specifically developed for the research is described and hydrological descriptors of the Roman Walbrook and catchment are recreated, as they would have been 2,000 years ago, for a river that has not flowed for at least 400 years.

A mean base flow rate of the river in the Roman period of 87 litres/sec is derived by means of a surrogate river analysis. An analysis of geoarchaeological data using GIS (Geographic Information System) is used to re-create the pre-Roman and late Roman land surfaces and to define the course and bed slopes of the river through urban Roman London and hence its flow-full capacity. A storm flow regime is derived and used to assess flood frequency for key areas within urban Roman London for a range of 36 channel conditions. In the flat northern urban area, flooding would have occurred more than once a year and somewhat less frequently in the other areas. The effectiveness of Roman land-raising activity and river management to reduce flooding is assessed and indicates limited success until completion of the town wall in 220 CE that acted as a flood control device.

The counter-intuitive siting of industry in the northern suburbs, in spite of marshy conditions and frequent flooding, is examined. The beneficial use of the Walbrook, by industry, including milling, farming and for water supply and rituals, is also discussed in the context of its hydrology.

Declaration of Original Authorship

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Stephen D Myers

Acknowledgements

In the five and a half years that it took to undertake and complete this thesis, many people have provided support and assistance, unfortunately too many to acknowledge individually. However, the work could not have proceeded to a successful conclusion without the invaluable, wise and knowledgeable counsel of my two supervisors, Professor Michael G Fulford and Dr Nicholas P Branch, both with the Department of Archaeology, School of Archaeology, Geography and Environmental Science (SAGES) at the University of Reading. They patiently guided a water engineer through the research for the totality of its duration.

Early in the work, excellent advice was provided by both Professor Grenville G Astill and Professor Andrew J Wade, both also of SAGES and I am indebted to both of them for their contributions to the research. The work could not have progressed without access to the archaeological investigation reports, plans and sections at the London Archaeological Archive Research Centre of the Museum of London. The Archivist, Cath Maloney, gave her time unstintingly and her encyclopaedic knowledge of investigations in London proved invaluable, not least due to her involvement in reporting on sites relating to the urban Roman Upper Walbrook Valley. Geographic Information Software (GIS) proved an essential tool for the development of the research and to complement the course on its use run by the University of Reading, I was further instructed in its specific application to the research by Nathalie Marini of Quest and Gideon Simons both of whom have a profound knowledge of GIS software that proved invaluable. The work relied heavily on the results of numerous archaeological investigations and professional publications that provided input to re-creating the topography, landscape, environment and Roman activity of the urban Roman Walbrook Valley. My thanks are due to the investigators and authors of the reports and publications relating to these, too numerous to mention by name but who have been cited in the text, appendices and bibliography. I owe a debt of gratitude to Dr Angela Taylor who, having read the draft of my first book on the "hidden rivers" of London, suggested that I undertake PhD research and made the introduction to Professor Michael Fulford.

Last, but by no means least, I would like to thank my long-suffering wife, Marion, who has had to cope with my obsession with the lost rivers of London, in particular the Walbrook, over many more years than occupied by this research. The work isolated me from her company too often and for far too long and, hopefully, we will be granted the time to remedy this.

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Abbreviations Used in Text

AMC	Antecedent Moisture Condition
AOD	Above Ordnance Datum
BGS	British Geological Survey
BP	Before present (year)
CBA	Council of British Archaeology
CEH	Centre for Ecology and Hydrology
CN	Curve Number (as used in HydroCAD Software)
DEFRA	Department for Environment, Food and Rural Affairs
DGLA	Department of Greater London Archaeology
DUA	Department of Urban Archaeology
FSR	Flood Studies Report
FEH	Flood Estimation Handbook
GIS	Geographic Information System
GLAAS	Greater London Archaeology Advisory Service
GLHER	Greater London Historic Environment Record
GM	Guildhall Museum
GWV	Greater Walbrook Valley
HAT	Highest Astronomical Tide
HMSO	Her Majesty's Stationery Office
IOH	Institute of Hydrology
ka	thousand years from present
LAARC	London Archaeological Archive Research Centre
LAMAS	London and Middlesex Archaeological Society
MLWS	Mean Low Water Spring
MHWS	Mean High Water Spring
MOL	Museum of London
MOLA	Museum of London Archaeology
MoLAS	Museum of London Archaeological Service
NERC	Natural Environment Research Council
NRCS	Natural Resource Conservation Service (US)
OD	Ordnance Datum
OS	Ordnance Survey
ReFH	Revitalised Flood Hydrograph Model
RMLEC	Roman and Medieval London Excavation Council
SCS	Soil Conservation Service (US)
SI	Système Internationale (SI units of measurement)
T_c	Time of concentration
UK	United Kingdom
URWV	Urban Roman Walbrook Valley

Units of measurement

ha	hectare (10,000 m^2 = 2.47 acres)
kg	kilo (weight) (1 kg = 2.2046 pounds)
km	kilometre (1 km = 0.6215 miles)
km^2	square kilometre (1km^2 = 100 ha)
l	litre (1 litre = 0.22 Imperial gallons)
l/sec	litres per second
m	metre (1m= 3.2808 feet)
mm	millimetre (25.4mm = 1 inch)
m^2	square metre (1 m^2 = 10.76 square feet)
m^3	cubic metre (1 m^3 = 1,000 litres & weighs 1,000 kg or 1 tonne)
m/s	metres per second
m^3/s	cubic metres per second

Chapter 1

Research Context, Aims and Objectives and Report Structure

1.1 Research Context, Aims and Objectives and Report Structure

1.1.1 Research context

The City of London was founded at the confluence of two rivers, the Thames and the Walbrook. Whilst the Thames was - and remains - of primary importance to London, the Walbrook also played a role in the development of the Roman town that eventually evolved into one of the world's largest and most influential cities.

The location of the Study Area is shown on Figure 1.1. London is shown located in South-East England with the Thames flowing west to east with its estuary into the North Sea. The study Area is shown within the context of modern Greater London and the Walbrook's topographic and groundwater catchments, as defined by the current research are shown to a larger scale, together with the Ordnance Survey reference for the approximate centre of the Study Area, TQ 32750 82850. Roman London, as confined within its early 3rd C wall is also shown.

Hydrologically, the Walbrook was a minor tributary of the Thames. However, its north to south passage through the middle of what became the City of London ensured that its citizens were frequently made aware of its existence in their daily lives. The Walbrook may have been an unremarkable stream but there is evidence that it "punched above its weight" in its impact upon Roman London (see Chapters 7 and 8).

Unfortunately, apart from some fascinating insights into Roman life incised into wooden tablets found recently on the Bloomberg site (BZY10), no contemporary written record of life in Roman London has yet been found. Reliance must therefore be placed on interpretation of the findings of archaeological investigations to understand how the Walbrook impacted upon the daily lives of the townspeople of Roman London. From early in the development of the Roman town, as it expanded from Cornhill on to Ludgate Hill, the population would have been aware of the river as they crossed it by the bridges at

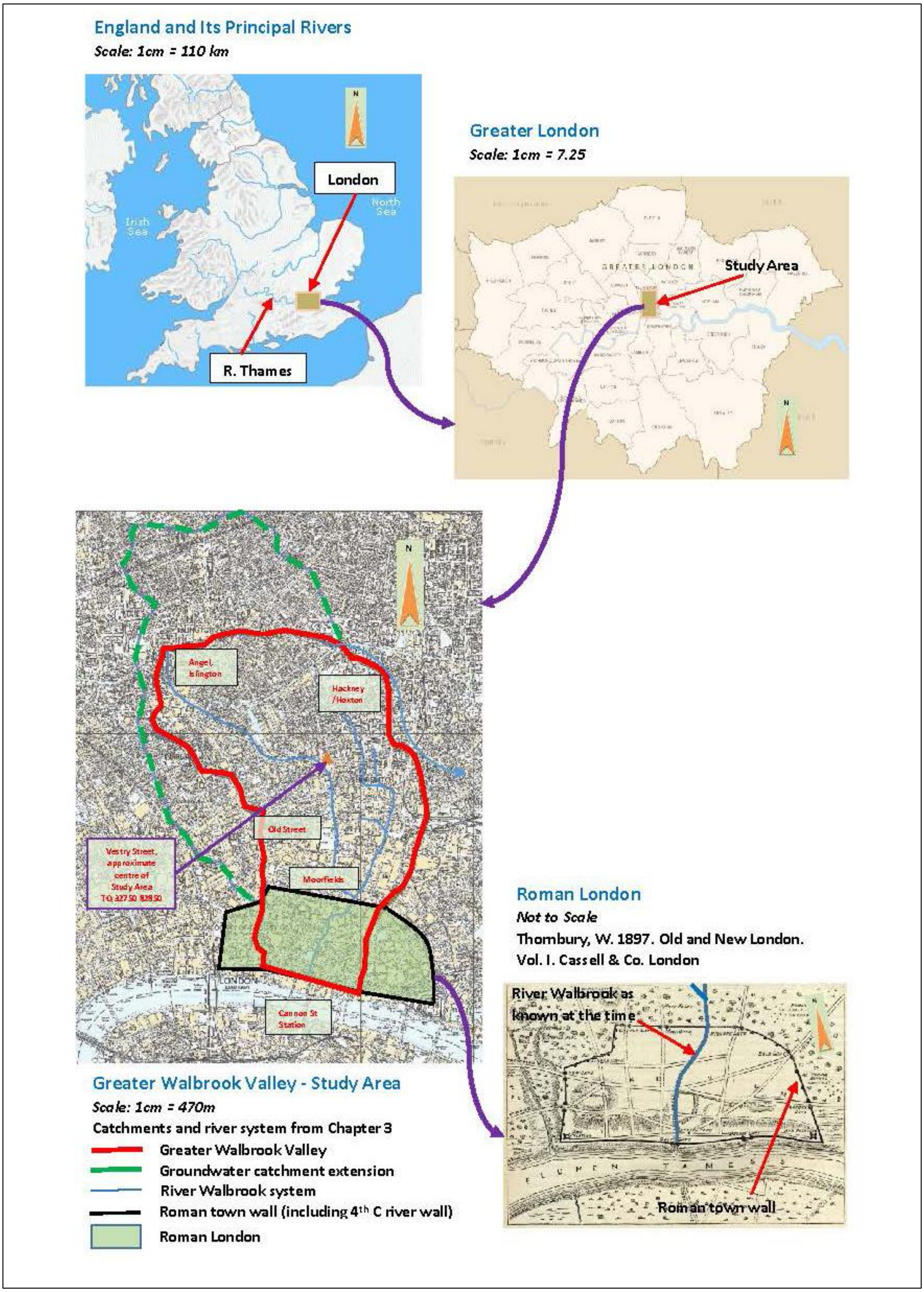


Figure 1-1 Study Area Location Plans

Bucklersbury and Cannon Street. Archaeological investigations have generated evidence of water-consuming crafts and industries established by or close to the banks of the urban Walbrook, particularly in the northern suburbs of the Roman town (see Chapter 8, Section 8.4). There are also indications that the river may have flooded parts of its urban valley, particularly in the northern suburbs but also, more rarely, its lower reaches. Investigations have also discovered evidence of river management and infrastructure that may have been attempts by the Romans to mitigate the effects of flooding (see Chapter 7, Section 7.3).

It has previously been difficult to place this evidence in its proper context with respect to the Walbrook as, prior to this research, the hydrology of the Roman Walbrook has not been studied. This present research therefore constructs a hydrological analysis of the Walbrook in the Roman period. Here, and throughout the thesis, the "Roman period" refers to their occupation of Britain from 43 to c410 CE. It also examines the archaeological evidence for river management and flood control in its urban Roman stretches and of the Roman's beneficial use of the river. In the course of developing the hydrology of the Walbrook, the research has had to deal with a number of problems not normally encountered with hydrological analysis of today's rivers, viz.

- a river that has not flowed at the surface for at least 400 years;
- a river that has never been accurately mapped;
- a catchment that would have been undeveloped prior to the arrival of the Romans and predominantly rural in the Roman period but that is today completely urbanised;
- a physical topography which, particularly in the lower reaches of the catchment, has undergone considerable restructuring; and
- absence of a contemporary description of the Roman catchment or of urban Roman London.

These problems have been addressed through examination and application of data drawn from different sources. These include archaeological investigations carried out by others in the urban Roman Walbrook Valley (URWV), publications describing conditions in catchments similar to those of the Roman Walbrook supplemented by data drawn from modern sources, including flow records of surrogate rivers having similar catchment descriptors and hydrological character to those of the Roman Walbrook.

1.1.2 Water, Rivers and Society – The Historical Context

Water is an essential requisite for all living organisms. The human body can survive without food for 3 to 4 weeks, however, lacking water to drink, the limit is between 3 and 10 days depending upon age, health and climatic factors (Packer, 2002). Access to a potable source of water is therefore vital to life. As today with primitive hunter-gatherer peoples, e.g. the San people of the Kalahari (Silberbauer and Logan, 2016), settlements have been attracted to establish themselves close to sources of water, whether waterholes or running water at the surface or over reservoirs of groundwater into which wells may be dug. The settlements that have grown into towns and cities have access to water resources sufficient to satisfy their increased demand. The sources may be local or remote, a river, lake, an upland catchment or an aquifer but if remote, acquiring the source has to be affordable and sustainable. For hundreds of millennia, rivers have been the favoured routes by which populations migrated. The migration of *homo sapiens* out of Africa took place along two main routes, maritime and riverine. The former encouraged movement along the east coast of the continent and into the Arabian peninsula through the Red Sea (Lawler, 2011, 387). The latter saw migration along "green corridors", fed by rivers, such as from Ethiopia into Egypt along the Nile and the rivers of the Sahara desert, now underground, such as the Irharhar (Vianello, 2015, 7-22). Before farming, rivers were important as communication waterways, safer and easier to travel than overland trackways. They were also important sources of food through fishing and of clay for pottery (Vianello, 2015, 32).

So ingrained into human consciousness is the fundamental importance of water that many cultures, both past and present, imbue rivers with sacred status and properties. The ancient Chinese system which governs the siting of structures and burial grounds and the well-being of those using them, Feng Shui (wind-water), is heavily reliant upon the spatial arrangement and orientation of material things to bodies of water, large and small (Bruun, 2008). The Ganges, or Ganga is a sacred river for the Hindu religion in which believers bathe and to which they make offerings but, pragmatically, many millions depend upon it for irrigation, drinking water and waste disposal (Alter, 2001). The religious practice of Japanese Shinto has an abundance of gods individually devoted to aspects of water - rain, irrigation, wells and all types of flowing water often linked to agriculture. Under Shinto, a river is a purifying force carrying sins for dispersal in the sea (Vianello, 2015, 14-18).

The purifying and cleansing power of water, often in the form of a river is a common concept in various religions, including the ritual of Baptism in Christianity. Water used in rituals has also been linked to hygienic practices. Although almost certainly not the origin of ritual use of water for cleansing, the many requirements set out in the Old Testament are witness to the recognition of the importance of personal hygiene (Leviticus 14: 8-9; 15:5, 6, 8, 10, 11, 13, 16, 18, 21 and 22; 16: 4, 24, 26 and 28). This lead to the development and regular use in Judaism of the mikvah, a ritual bath, a practice that continues today.

The cultivation of cereals and other foodstuffs from their wild origins beginning approximately 22,000 years BP (Hillman, 1996, 159-203). The later domestication of animals led to a much greater demand for both quantity and reliability of water sources either through natural inundation or through artificial irrigation, both requiring river sources when practised at a large scale (Macklin and Lewin, 2015, 228-244). Water is considered so important that possession of the means to conduct it to fields under cultivation was considered as valuable a possession as cattle by at least one Kenyan tribe, the Marakwet, “When water comes home, it is a marriage. Whoever has a furrow (channel) has a wife” (Ostberg, 2004, 36). The Khmer Empire constructed an extensive network of channels around and within Angkor Wat for irrigation to counter dry periods and to act as waterways over an area in excess of 1,000 km^2 that would not have been possible without local access to the waters of the great Mekong River system and Tonle Sap Lake (Evans et al., 2007, 14277-14282).

The control of water resources for the purpose of irrigation and potable supply through reservoirs, channel networks and rudimentary lifting devices had been practised prior to the Roman era. Siphons and tunnelling were introduced to water supply techniques in the Hellenistic period. However, it was the Romans who built on the limited understanding by the Greeks of civil engineering, mastered hydraulics (White, 1984, 161-172) and who applied its principles and their sophisticated use of surveying wherever they established their colonies (Hodge, 2011, 31-32). One of their major innovations was the use of arched bridges, viaducts, to maintain a constant grade to their aqueducts (Tolle-Kastenbein, 1993, 78-99). They constructed a complex system of aqueducts to supply Rome, including the Acqua Appia, the Aniene Vecchio, the Acqua Marcia and the Acqua Vergine that continues to feed the fountain in the Piazza di Spagna. Flowing water has the potential to be used as a source of energy. The potential energy of running water was used by the Romans as a source of power to drive milling, fulling and hammering machinery (Lewis, 1997, 89-109). Many examples of rivers used by the Romans to power mills have been unearthed, dating from early in the 1st C, in the Near East, continental Europe and in Britain (Spain, 2008, 13-67) (Moritz, 1958, Spain, 2008) (see Appendix 8B for details of milling in the Roman period).

By the time that the Romans invaded and occupied Britain, their understanding and use of water resources was advanced and sophisticated and their attitude to it ranged from the practical to the spiritual. Their encampment on Cornhill on the north bank of the Thames was probably chosen for its strategic benefits. The low hill provided an overview of an otherwise flat, low-lying area, the Thames was tidal to that point assisting the movement of shipping to and from the open sea but was shallow enough to be bridged. In addition, a tributary of the Thames marked a defensible western boundary and, were it to prove necessary, could provide a source of potable water, as the Thames was semi-saline. The encampment was destined to grow quickly into a town, Londinium or London, the principal trading and administrative centre of the Province. The tributary of the Thames was the Walbook, itself destined to flow through the centre of the town as it expanded onto Ludgate Hill to its west.

1.1.3 The Walbrook in Literature

It is difficult to pinpoint precisely the first literary reference to the Walbrook and when the first map showing the Walbrook was produced. The river is mentioned in a confirmatory Charter granted by William I in 1068 to the church of St Martins-le-Grand in Cheapside where it is referred to as “wylrithe”, a generic Old English term for “spring rivulet”, i.e. it appeared to have no name (Kemp, 1825). This has been corrupted by some to “Well brook”, hence Wallbrook or Walbrook (Foord, 1910, 29). However, the Norman drafters of the Charter may just have been in ignorance of a local name. In the mid-12th C, in the Ramsey Chronicles, the river is referred to as the Wealhbroc, “Wealha” being the Saxon name for Wales. The basis for this is the suggestion that in the early Saxon period the Walbrook was the border between the Welsh and the Saxons. William FitzStephen, writing in the last quarter of the 12th C (Riley, 1860, 2-15), does not name the river but describes how apprentices skated on a frozen Moorfields, a marsh fed by the Walbrook. John Stow in his book describing London in the greatest detail towards the end of the 16th C (Stow, 1603 (reprinted 1908), 13-14) states that *"The running water so called by William Conquerour ……… entered the wall, and was truly of the wall called Walbrooke, not of Gualo, as some haue farre fetched"*. He also says that the Walbrook had by his time become so covered that it was hidden *"…… and therby hardly knowne."*.

Without being named as such, the mouth of the Walbrook was shown on a number of the pictorial, "birds-eye view" maps that were the norm prior to the mid-17th C, e.g. Giles Codet (1560), William Smith (1588) and, perhaps most accurately by Wencelas Hollar in 1647 (Barber, 2012). The Copperplate map of c 1555, by an unknown draughtsman, copied a few years later by Ralph Agas, shows the Walbrook, possibly both an eastern and western streams, flowing through Moorfields and forming the moat outside the city wall. This map is referred to in Chapter 3 as it shows clothing laid out on the moor to dry, indicating that the flow from the Walbrook no longer flooded the area. Two-dimensional maps of London produced to scale were first produced from the beginning of the 17th C but, unfortunately, the Walbrook was already covered and is therefore not shown on any map from that date.

Possibly the first map showing the Walbrook and named as such was a 1722 engraving by William Stukeley, included in the first edition of his book (Stukeley, 1724), reproduced as Figure 1-2. The river is shown petering out less than a kilometre north of the Roman town wall. This map has no basis in fact outside of the town wall and is the origin of the misunderstanding that continues to the present day – viz. that the Walbrook consisted of only a single stream fed from five short extra-mural tributaries. These sources were considered to be the wells and springs at Holywell and others a short distance further north at Hoxton and Shoreditch. This research has demonstrated that this stream was not the only source for the Walbrook but that another longer stream flowed from the Angel, Islington and that the source of the Hoxton/Shoreditch stream were the springs on the Islington ridge at

Canonbury and Highbury. This error, that the Walbrook had a single source stream, has been perpetuated by a number of authors in the 20th C, amongst which Foord is one of the earliest (Foord, 1910, 25-39) and another two and a half decades later (Whitaker-Wilson, 1935). The book contains many errors, another being one first written about in the 19th C (Tite, 1848) that the Walbrook was *"300 feet broad at its mouth……. narrowing to about 120 feet at Moorfields"*.

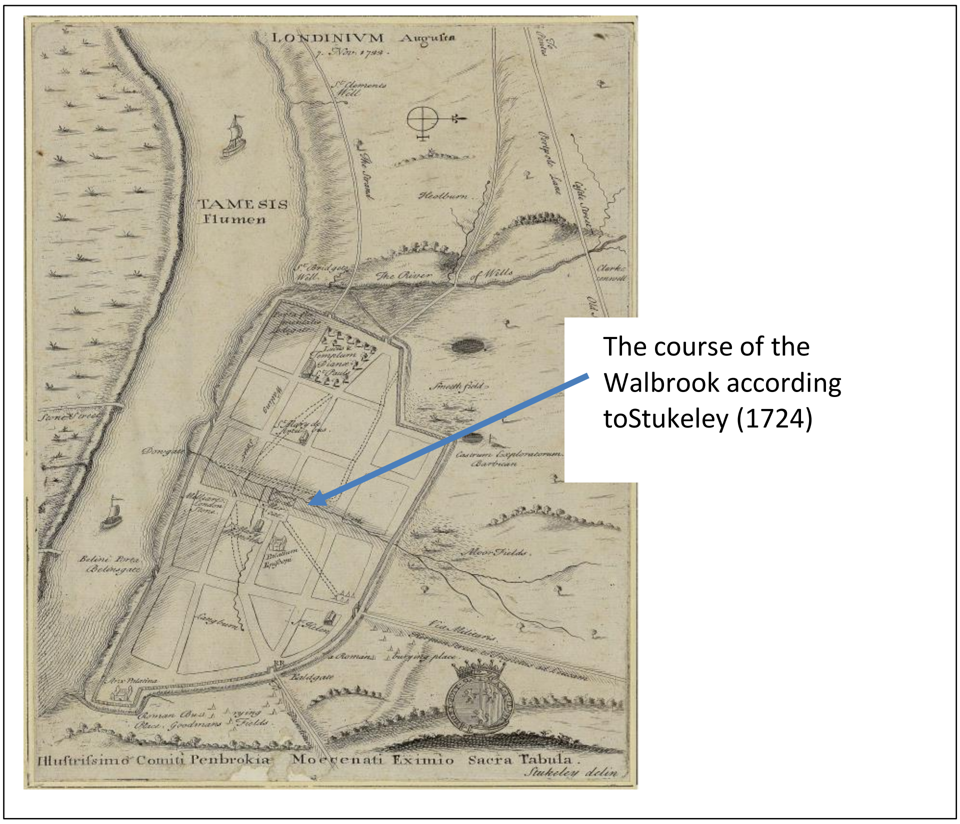


Figure 1-2 1722 map of Roman London, an engraving by Dr William Stukeley

Foord was confusing the river's floodplain with its channel. An otherwise excellent book, (Barton, 1962, 21-25), perpetuates Stukeley's mistaken understanding of the origin of the Walbrook and Tite's as to its width. This source is unique in mentioning a western tributary but it relates to the stream that rises at the Barbican and passes through the wall at Moorgate. The river being sourced solely in the Hoxton area is also found in otherwise excellent books on London's lost or hidden rivers [(Clayton, 2010); (Talling, 2011); (Bolton, 2011)] . A modern book (Trench and Hillman, 1993) makes the first reference to the Walbrook having two source streams, an eastern one fed from springs in Hoxton and a western stream fed from Islington, however the authors give no reference for this statement. The existence of a significant western stream of the Walbrook was further researched in 2009-10 (Myers, 2011, 126-130). This led to the formulation of the concept for this current research.

As an example of how this limited view of the extent of the Walbrook has manifested itself in the work of archaeologists, reports [*St Margaret Lothbury church*. MAR76; (Leary and Butler, 2012)] and monographs [(Maloney and De Moulins, 1990); (Wilmott, 1991); (Merrifield and Hall, 2008, 127)] have made reference to the Lower, Middle and Upper Walbrook, in order to define stretches of the river between the Thames and these sources of the Walbrook. Based on an interpretation of these sources, as measured from the Thames, "Lower Walbrook" has generally referred to the first 400 metres (to Bucklersbury), "Middle Walbrook" to the stretch between 400 and 800 metres from the Thames (from Bucklersbury to just short of the Roman wall) and "Upper Walbrook", the remaining stretch from the wall to Hoxton.

The Walbrook is referred to in many publications dealing with London Archaeology. The Royal Commission on Historical Monuments (Royal Commission on Historical Monuments, 1928, 14-16) in its volume on Roman London referred to the Walbrook as *"forming the central landmark of the ancient city"*. The Royal Commissioners promote the Hoxton and Shoreditch sources for the river and hence a single (eastern) stream. They raise the subject of the many skulls found in the Walbrook just outside and inside the wall, without offering an explanation. This and other finds noted in the RHCM work, particularly the culverts conveying the Walbrook and its tributaries through the Roman wall into the town, are referred to in appropriate points in the thesis.

An author with considerable experience of the archaeology and history of Roman London also refers to the importance of the river

> *"The Walbrook remained a dominant feature of Londinium throughout the Roman period ……… forming the western limit of the earliest settlement, and dividing the fully developed city in two almost equal parts.* (Merrifield, 1969, 91-95)*"*

Archaeological investigations in the urban Roman Walbrook Valley have made important contributions to the general understanding of life and culture in the Roman period, far beyond what would have been expected of a minor town in a remote Province. The reason for this is environmental. The water table being high in the area, contexts at the level of the Roman river are normally waterlogged and have been so throughout the intervening years. Anaerobic conditions are created in the groundwater and soils are often gleyed. Metal and wooden objects are therefore well preserved when normally they would have decomposed. Apart from finds in normal everyday situations, being a relatively densely populated area, waste pits and middens were dug into these contexts and contain a variety of objects. These objects are therefore found in good condition when otherwise no trace would remain.

Merrifield describes the route of Walbrook from the Thames at Dowgate north through the City of London to the Roman wall. This route is the one determined from excavations over a long period and has remained the accepted course of the river to today, Figure 1-3. Principal place names mentioned in this section have been added to the original map in Figure 1-3. The author debunks the idea of a wide river noting that this mistaken view arose from deposits of black silt that were the results of flooding, not stream bed deposits. Merrifield suggests that the land between Bucklersbury and Cannon Street was full of market stalls, a suggestion that recent work would support, although the area also accommodated craft workshops and small industries. He is a promoter of the idea that the Walbrook was considered sacred, at least along this stretch where market stalls and industry gave way to a major temple and some significant shrines from the second half of the 2nd C. He cites the many coins found in the Walbrook and broken stylii and other tools as votive offerings made to the river from its banks and the Bucklersbury Bridge.

It should be noted that none of the three public baths shown in Figure 1-3 was fed from the Walbrook. It has been claimed that the demand for water by Roman London’s bath-houses would have required water resources remote from the town to have been tapped, e.g. from the Bagshot Sands aquifer in Highgate and Hampstead (Wacher, 1978, 104-108). There is no evidence of extra-mural aqueducts, and only short lengths within the town. It is more probable that the population relied on local wells and, where necessary, used pumping machinery, to supply their water (Wilmott, 1984, 5-10).

The “Palace”, also shown on Figure 1-3, was sited on a low promontory overlooking the lower Walbrook and The Thames, was named as such by Merrifield (Merrifield, 1983, 72-77). However, the structure is now considered to have been an imposing building probably associated with the administration of the Roman town or the Province [(Milne, 1996, 49-56); (Taylor, 2010)] and not the “Governor’s Palace” as previously known. In another book by the same author, he provides an extremely useful Gazeteer summarising hundreds of excavations, a number of which have contributed to the research (Merrifield, 1965, 189-325).

Between Caesar’s invasions of Pretannia (Britannia) in the 1st C BCE and the invasion in 43 CE, Strabo, in *Geographica* 5.2 The Keltic Islands, noted that the island

> *“……….. produces grain, cattle, gold, silver and iron. These are exported from there, as well as hides, slaves and dogs suitable for hunting …… and imports, which include ivory chains, necklaces, lyngourina* (sometimes interpreted as tourmaline)*, prepared glass, and other such minor objects ….” (Roller, 2014).*

These products provided cargo for transport by water. Substantial port facilities were constructed along the north bank of the Roman Thames around the bridge and were used by both maritime and riverine vessels (Milne and Richardson, 1985, 96-102) (Miller, 1986, 88-93). The former were employed in import and export trade and the latter for transporting ragstone and other building materials, agricultural produce and minerals (Jones, 2012).

Sir John Soane, architect of the Bank of England, noted that during construction of the building in the 1820s the Walbrook was uncovered running in a curve from a southerly direction to a western orientation, from Lothbury to Princes Street, beneath the Bank. In constructing the National Safe Deposit Company’s premises, now the City of London’s Magistrates Court, opposite the Mansion House, in the early 1870s, excavations uncovered the stream of the Walbrook in Bucklersbury and a

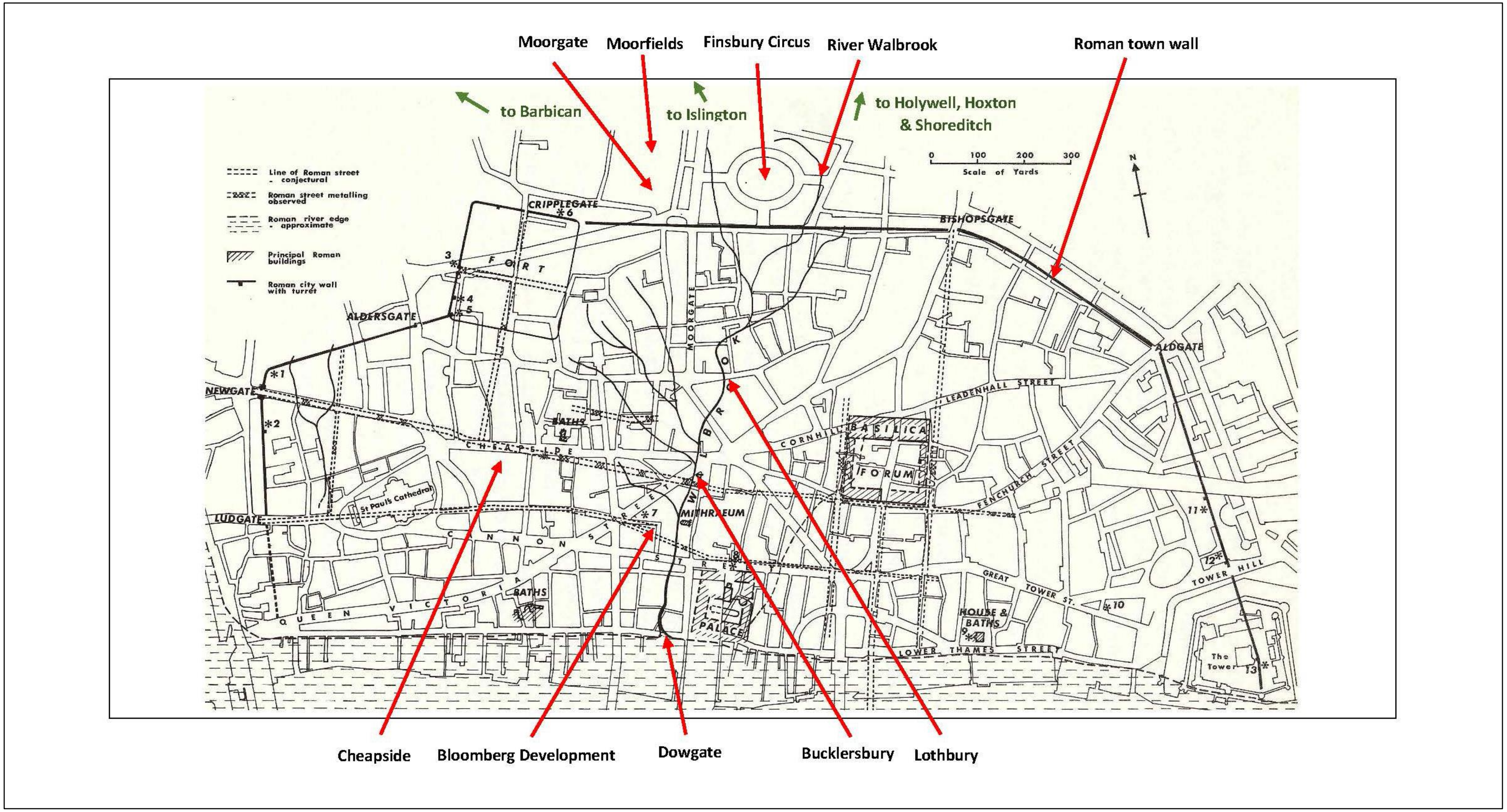


Figure 1-3 **Map of Roman London and the Walbrook superimposed onto a modern street map of the city of London (Merrifield, 1969, 99 - Fig 24)**

substantial wooden platform on its east bank (Puleston, 1873, 55-56). This may be related to the recent finds thought to be those of a mill found on the Bloomberg Development site (BZY10). In 1912, Lambert found a substantial river channel oriented from the north curving to the east across Finsbury Circus (Lambert, 1921, 55-112), identified in this research as the western stream of the Walbrook shortly before its confluence with the eastern stream at Blomfield Street.

From 1951 to 1954, Professor W F Grimes excavated a large, roughly triangular-shaped bomb-site with its apex at Bucklersbury and its base at Cannon Street (WFG44/45), today known as the Bloomberg Development (BZY10). The Walbrook ran from north to south through the site. Although he is best known for the disinterment of the Temple of Mithras situated on the east bank of the Walbrook, near the south-eastern end of the site, he describes how the initial, primary aim of the work was to study the valley of the Walbrook (Grimes, 1968, 92-98). He shows an east-west cross-section through the site, the first published for the Walbrook Valley. His record drawings are referred to and depicted in Section 7.3.1 of the thesis with respect to revetments found lining the channel.

The first publication to discuss the archaeology of the Walbrook Valley by analysing a group of sites had the title “The Upper Walbrook in the Roman Period” (Maloney and De Moulins, 1990). That study was based about the detailed analysis of four investigations at the corner of Copthall Avenue with London Wall, OPT81, LDW84, LWA84 and KEY83, all grouped under the latter reference. It also drew upon the findings of 36 other investigations in the vicinity. It demonstrated that the KEY83 area was traversed by a number of meandering channels in the Roman era, none definitively claimed as the main Walbrook stream. This is an important observation and is referred to in the thesis, Sections 4.6.1 and 4.6.2. However, the points at which significant channels had been noted in the broader investigations was shown on a diagram and related to the Walbrook streams as then known. This is reproduced here as Figure 1-4. Apart from its contribution to the understanding of stratigraphy of the area close to the wall, it noted the wide range of industries found there and described the area as industrial.

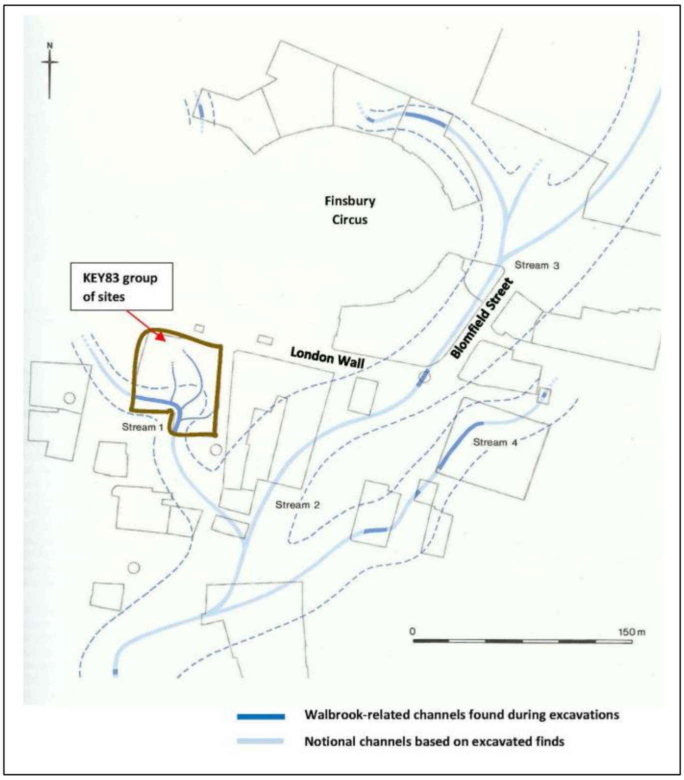


Figure 1-4 Walbrook channels discovered during excavations and notional channel routes inferred from them (adapted from Figure 25, (Maloney and De Moulins, 1990))

Publications on major investigations carried out in the last fifteen years have included more data on environmental finds and analyses than was formerly was the case. These have assisted the research to develop an understanding of the landscape and vegetation of the Greater Walbrook Valley. Reports contributing archaeological environmental evidence to the research have been referred to in Section 4.8 of the thesis, viz. 6-8 Tokenhouse Yard (Branch et al., 2012, 60-75), No 1 Poultry (Hill and Rowsome, 2011), Moorgate Telephone Exchange (Lewis, 2016, 171-177); Crossrail at Moorgate Station and Finsbury Circus (Pfizenmaier, 2016, 211-216) and the Bloomberg Development [(Scaife, 2014, 123-130, Stewart and Smith, 2014, 152-157)].

Another publication followed which referred to a “region” within the urban area, “Excavations in the Middle Walbook Valley” (Wilmott, 1991) and these two publication cemented the impression that the Walbrook Valley was restricted to the urban Roman area and its immediate vicinity. As this is not the case, a terminology which builds on this has been formulated for this research. Other publications describe specific aspects of Roman activity in the urban Roman Walbrook Valley e.g. pottery (Seeley and Drummond-Murray, 2005), life around the Bucklersbury Bridge crossing (Hill and Rowsome, 2011) and cemeteries (Harward et al., 2015). These are drawn upon in the thesis wherever appropriate.

The research has drawn upon numerous reports and publications of archaeological investigations and interpretations of their discoveries. These are referred to in their appropriate context throughout the thesis. Two guides to archaeological investigations in the City of London have been published [(Shepherd, 1988, 71-75); (Schofield and Maloney, 1998)], the former listing the excavations overseen by Professor W F Grimes from 1946 to 1972 and the latter a guide to excavations carried out by the Museum of London Archaeology and its predecessor organisations from 1907 to 1991. The subject of each excavation is described in the guides and the principal findings summarised. 110 of these sites were chosen from the guides as having potential to inform the present research and, after a process of prioritisation, approximately half of these have been included and their reports and plans studied at the London Archaeological Archive Research Centre (LAARC). In addition, reports on 20 investigations were accessed at the Greater London Historic Environment Record (GLHER). London and Middlesex Archaeological Society (LAMAS) Transactions from 1968 to 2014 have been reviewed in the literature search for this study and nineteen papers were found to have covered subjects relating to the Walbrook. Monographs, conference proceedings and professional articles have either provided data on further sites or elaborated upon those accessed at LAARC and GLHER. Notes on many of these can be found in Appendices 2A and 2B (LAARC), 2D (GLHER), 2F (publications and papers consulted early in the research) and 2G (LAMAS).

Archaeological investigations on a number of sites over the last four decades or so, e.g. 35-45 New Broad Street (NEB87); 1-8 Angel Court (ACW76), Draper's Gardens (DGT06) and the Bloomberg Development (BZY10), have produced evidence that demonstrates that the Walbrook would, on occasion, flood land close to its banks in the northern suburbs and lower districts of the town. However, it has been difficult to reconcile the relatively small catchment of the river, as formerly envisaged, with a potential to generate storm flows in the river sufficient to cause flooding. The prospect of a surface catchment more than double the size than formerly envisaged and, as suggested by geological maps, a groundwater catchment that extended over an even larger area, gives greater credence to the potential of the Walbrook to flood parts of urban Roman London.

A quantitative analysis of the hydrology prior to the arrival of the Romans and during the period of their settlement is essential to an assessment of both the probable frequency of flooding and the potential for beneficial uses of the river's waters.

In the course of the literature search, no published evidence was found that any hydrological analysis of the River Walbrook and its catchment had been undertaken prior to this present research. However, after this study was begun, a short duration study, lasting only a few months, of the hydrology of the Walbrook was carried out by the Museum of London and reported in the London Archaeologist, including the map of the Walbrook based on that produced by this researcher. However, the study carried out under limited funding did not include a detailed study of the catchment characteristics and did not assess the flood potential posed by the river (Taylor, 2012, 95-99).

Although the River Walbrook appears to have played a significant role in the development of Roman London – and would have been a notable topographic feature to the townspeople - it does not appear to have been previously studied as an entity in itself. The rationale for the current research is therefore to rectify this. Its overall objective is to provide a better understanding of the hydrology of the Roman Walbrook, its physical extent and flow regime, so that the findings from archaeological investigations in the Walbrook valley can be assessed in the context of an improved understanding of the river. The research has also examined Roman river and land management activity and infrastructure to control the river, mitigate the adverse effects of flooding and to facilitate beneficial use.

1.1.4 Research terminology relating to the Walbrook and its valley

As previously stated, there is an extensive body of published works and reports of archaeological investigations that refer to the Walbrook as having only a single stream, the one sourced from Canonbury, Shoreditch and Hoxton. This is typified in a recent article (Blackmore, 2015, 115-121) "*This part of Hoxton and Shoreditch is located at the head of the Walbrook valley ….".* Numerous references have also been made since the late 1980s to the Upper, Middle and Lower Walbrook, the first two areas referring to stretches of the river wholly within the town wall and the latter area both within and without the wall but closely straddling it. One of the early, authoritative publications to promote this nomenclature had "Upper Walbrook" in its title (Maloney and De Moulins, 1990).

To avoid confusion with terminology commonly employed by those working on London archaeology, this present research has coined the term Greater Walbrook Valley (GWV) to refer to the full extent of the catchment of the Walbrook. The terms Lower, Middle and Upper Walbrook Valley have been retained but with reference only to the urban Roman Walbrook, extending from the Thames to Finsbury Circus. The boundaries delineating these three areas within the urban Roman Walbrook Valley (URWV) have been altered a little to reflect the hydrological as well as archaeological findings of this research. The limits of these three areas are further defined and mapped in Section 3.4.

"Roman Walbrook" and "Urban Roman Walbrook", as used in the research and thesis, have the following meanings:

- **Roman Walbrook**

  The full extent of the River Walbrook in the Roman period from all its sources to the Thames, its main streams and tributaries, and fed by runoff and springs within its full topographic and groundwater catchments.
- **Urban Roman Walbrook**

  The River Walbrook in the Roman period from the general area of of Finsbury Circus, to the Thames, as described in Chapter 3, Section 3.4. In effect, this is the stretch of the Walbrook as it flowed through the urban Roman Walbrook Valley (URWV), i.e. from a point just outside the eventual town wall to the Thames.

1.1.5 The Need for the Study and its Broader Application

No contemporary description of the Walbrook in the Roman period exists and descriptions of the Walbrook in the medieval period are brief and qualitative. The extent of the literature on the Walbrook is evidence that the river was a significant topographical feature of London from the Roman period through to the 15th C. By the end of the 16th C, the river had been completely covered and had passed from public consciousness. In addition to a lack of a description of the Roman Walbrook, prior to this research, neither the Walbrook nor its catchment had been the subject of hydrological analysis. In absence of such analysis, the true extent of the river and its catchment were unknown and the flow regime of the river, the base flow regime or its storm flow based on runoff from a range of storm intensities and return periods, were undefined. This lack of hydrological data on the Walbrook meant that all interpretation based on findings of archaeological investigations within the urban Roman Walbrook Valley could only be interpreted qualitatively, not quantitatively.

Two examples illustrate the limits imposed on interpretation of the findings of archaeological investigations in the absence of hydrological data relating to the river:

- Artefacts relating to milling and a water-driven mill mechanism were found in a Roman context on the Bloomberg Development site (BZY10). As they could have been imported to the site for some reason unknown, archaeologists interpreting their finds were unable to decide whether the milling artefacts were evidence of a mill at that location or one remote from the site. In part, their doubts were based on an inability to respond to important related questions. Did the Roman Walbrook have the quantity and reliability of flow to drive a water mill? Further, had there been sufficient flow in the urban stretch of the river, was there an appropriate point of abstraction upstream to provide sufficient head to drive one or more mill wheels? Interpretation would have benefitted from a knowledge of the base flow regime of the urban Roman Walbrook and of the topography of its stream-bed through the urban area. Possession of such data may not have provided definitive proof but would have least demonstrated the viability or otherwise of a mill at that location.
- Several archaeological investigations in the northern middle urban Walbrook Valley found evidence that the Walbrook may have been capable of flooding parts of urban Roman London, e.g. THY01, DGT06, MGT87 and nine other sites as well as 4 sites in other parts of the urban area (see Section 7.2 for details). In general, evidence of what could be interpreted as flooding took the form of extremely thin layers of silt in what otherwise was a loam soil or fill material. The imperfect nature of these silt layers contributed doubt to their interpretation as due to flooding. A further doubt was related to whether the Walbrook would have been capable of flooding given the small area of its notional catchment related to the short length of the river as understood prior to this research. Interpretation of the findings would have benefitted from an understanding of the true extent of the Walbrook catchment and a flood frequency analysis of the Walbrook based upon its storm flows and channel carrying capacity in the area of the investigations.

The situation represented by the Walbrook is not an unusual one. As with Roman London, many ancient towns and cities throughout the world were founded by the banks of a river or stream. Such towns may have just evolved around a bridgehead but most will have been deliberately sited to take advantage of the river as a source of supply of water for drinking, for horticulture or for industry and crafts. The river may also have been viewed as a source of power and a safe means of transportation of people and goods. As a town expands, formerly rural areas are progressively urbanised and, in the process, it is common for streams and rivers to be covered and culverted for use as drains for both surface runoff and foul sewage. Conventional archaeological investigations may produce evidence by which the impact of the river on the town and, conversely, of society on the river may be inferred. However, in absence of contemporary writings or a hydrological analysis of the river's flow regime, it can be difficult to discern the full potential for beneficial use of the river and to determine whether and to what extent the river may have flooded the urban area. The methodology as developed for the hydrological study of the Walbrook in the course of this research should therefore have application elsewhere, although it will almost certainly need to be adapted to the specific conditions of each location.

1.2 Research Aims and Objectives

1.2.1 Research aims

Based upon the rationale for the research, as set out in Section 1.1.2, the principal aims of this research on the subject of the River Walbrook in the Roman period are:

1. to determine the full extent of the Greater Walbrook catchment and the courses of the principal streams which constituted the river from its main sources to the Thames;
2. to determine the hydrological regime of the River Walbrook, its base flow and storm flow regimes, during the Roman period;
3. to assess whether and to what extent the river posed a flood risk to urban Roman London and its potential for beneficial use; and
4. to identify the riverine infrastructure and land management activities employed by the Romans to manage the Walbrook, possibly to mitigate the adverse effects of flooding and to enable beneficial use of its waters.

1.2.2 Principal research objectives and questions

To achieve the aims of the research, its principal objectives are to:

1. re-create and model the Walbrook, its catchment and the landscape through which it flowed as it was in the Roman period, a river that has not flowed as such for at least 500 years;
2. establish the most probable flow regime for the River Walbrook over its urban Roman London stretch in the Roman period, including its base flow and peak flows at times of storm for a range of rainfall intensities, durations and return periods;
3. determine whether and to what extent the Walbrook posed a flood risk to urban Roman London;
4. identify river and land management measures taken by urban Roman society to cope with and benefit from the consequences of the Walbrook's flow regime; and
5. identify beneficial usage of the waters of the Walbrook by the inhabitants of Roman London, as demonstrated through archaeological evidence as well as conjectural.

Arising out of these principal objectives, the research also responds to the following specific questions relating to the River Walbrook in the Roman period:

Q1 What were the boundaries and extent of the surface water runoff catchment of the river and, if found to be different, its groundwater collection catchment?

Q2 Is there sufficient evidence to confirm that the Walbrook had a second, westerly stream in addition to the known easterly stream?

Q3 Given the existence of both a westerly and an easterly stream, at what location did the two streams combine?

Q4 What would have been the hydrological catchment descriptors and, where relevant, their numerical values?

Q5 What would have been the magnitude and reliability of the river's base flow in dry weather?

Q6 What magnitude of peak storm flows would have been generated in the river as it traversed the urbanised area of Roman London for rainfall intensities and durations relating to storm return periods ranging from 1 to 500 years?

Q7 What was the morphology of the urban Roman London land surface at the beginning and at the end of the Roman period of occupation and, as a surrogate for the longitudinal profile of the Walbrook's bed, the line of the thalweg through urban Roman London?

Q8 Were the Walbrook to have posed a flood risk to urban Roman London, which areas of the URWV were most at risk from flooding and to what extent?

Q9 Given the River Walbrook's flow regime and the nature of the superficial deposits within its catchment, could sediment transport have taken place and to what extent could such movement have contributed to an accumulation of superficial deposits within the river's floodplain and estuary?

Q10 In response to the derived hydrological regime of the Walbrook, what forms of land management and river management structures and operational management, as evidenced by the results of archaeological investigations, were employed to avoid or mitigate its detrimental impacts on Roman London and to optimise the potential uses of the river's flow?

Q11 What was the extent and magnitude of land raising and levelling activity in the Roman period within the urban Roman London Walbrook Valley?

1.3 Research Components and Report Structure

1.3.1 Research components

In order to satisfy the principal aims and objectives set out in Section 1.2, it is first necessary to determine the hydrological character of the Walbrook in that period. This entails definition of the full extent of its catchment and its river system and estimation of its flow regimes in dry weather (base flow) and at times of storm, viz. its palaeo-hydrology. The potential for the river to flood areas of urban Roman London at risk would depend upon the rate of flow in the river at times of storm compared with its flow-full capacity, i.e. the capacity of the river to carry flows before its banks are over-topped.

Flow-full capacity is, in turn, dependent upon the slope of its riverbed through the urban area, i.e. its longitudinal profile. This latter has altered significantly from the topography of today and a study of the stratigraphy of urban Roman London is therefore required in order to determine this, viz. a study of its palaeo-stratigraphy. The frequency of flooding will depend upon the frequency of return of storms that can cause over-topping of the river's banks. A flood-risk analysis can be produced by combining the outcomes of the palaeo-hydrological and palaeo-stratigraphic studies. Outputs from the foregoing work form the basis of a flood-risk analysis and the study of archaeological data for the urban Roman London Walbrook Valley to assess the employment of river management techniques.

The research therefore divides naturally into five constituent components, viz.:

1. **Palaeo-hydrology** - of the Greater Walbrook Valley catchment in the Roman Period

2. **Palaeo-stratigraphy** - of urban Roman London within the Greater Walbrook Valley

3. **Flood-risk analysis** - which draws upon outputs from the palaeo-hydrology and palaeo-stratigraphy components

4. **River management** - based upon the flood-risk analysis, archaeological records and water engineering.

5. **Beneficial use** - of the waters of the Walbrook, actual and conjectured.

The first three of these – palaeo-stratigraphy, palaeo-hydrology and flood-risk analysis - may be considered as service components, generating the context in which the data and background can be assessed with respect to river management and beneficial use. All five elements of the research draw upon the evidence of many archaeological investigations principally carried out in the URWV but also, in order to assist the palaeo-hydrological work, elsewhere on the gravel terraces of the Thames Valley.

Data collected were frequently of use to more than one of the five research components. Work on all components was carried out contemporaneously throughout the research and as the outputs from one component frequently impacted upon the work of another, the process proved an iterative one.

The palaeo-hydrological work went through a number of revisions, particularly once the results of the palaeo-stratigraphy component had been finalised. A literature review and data acquisition period preceded analytical work on all components.

1.3.2 Research and report structure

The overall structure of the research process is shown in Figure 1.3, which also shows the main points of interaction between the components and Chapter numbering.

1.3.3 DVD – main text of thesis and appendices

A DVD has been attached to the inside back cover of the thesis. The DVD contains files of the following:

- The main text of the thesis (in pdf format). This enables complex tables, with small font that may be difficult to read in the printed volume, to be more readily accessed.
- The Appendices to the main text, some of which are in pdf format and some of the larger tables in Excel.

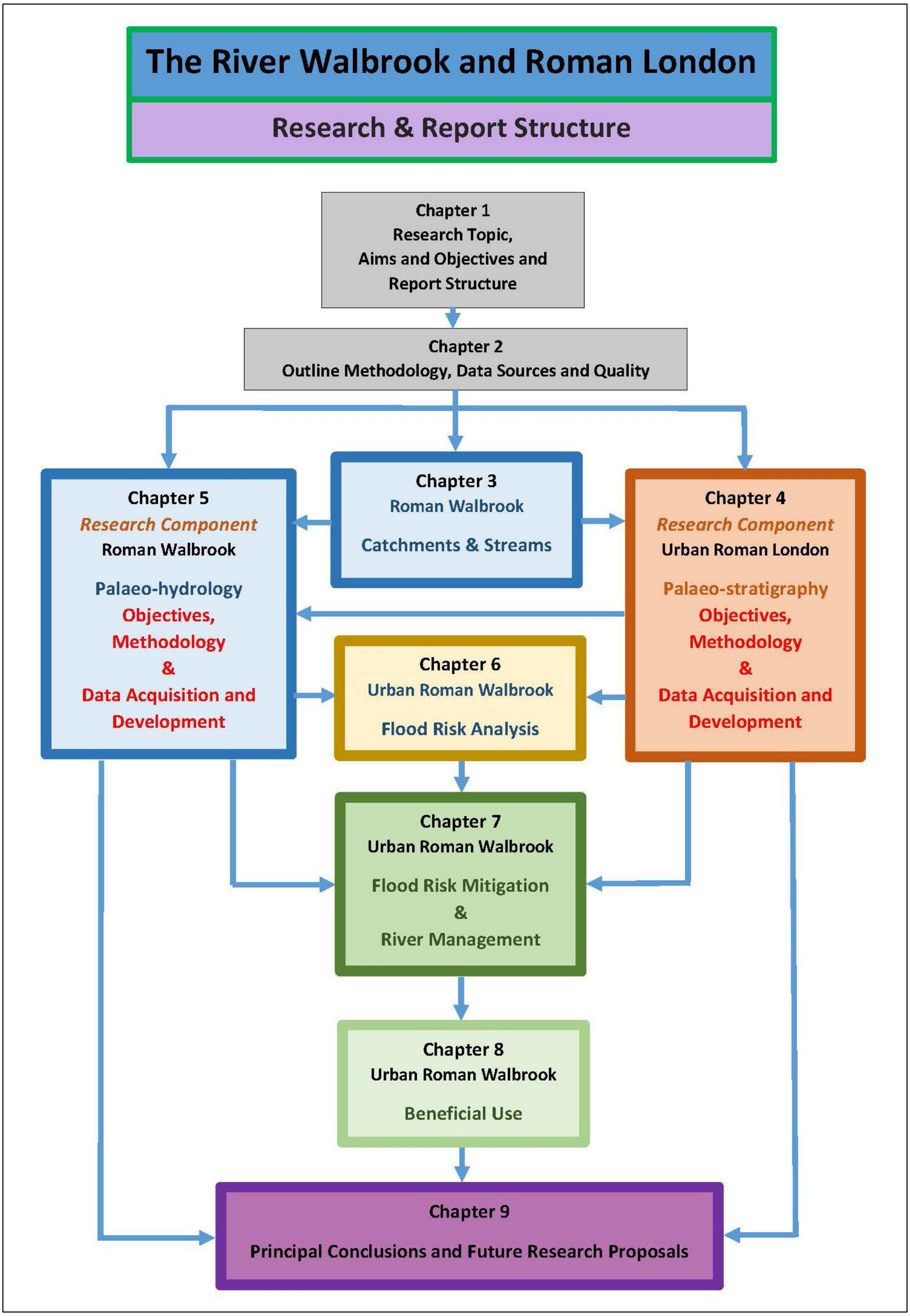


Figure 1-4 Research and Report Structure

Chapter 2

Outline Methodology, Data Sources and Quality

2.1 Introduction

The research is based principally upon the records of archaeological investigations and archaeological publications related to the Walbrook. This has been supplemented by data, relating to both ancient and modern conditions, wherever possible drawn from other parts of the Thames region founded on gravel terraces similar to those of the Greater Walbrook Valley. Hydrological software and a geographical information system (GIS), using data gathered from these sources, have been used to respectively model the hydrological regime of the river and its stratigraphy in the Roman period.

This chapter acts as an introduction to the subject of data sources, acquisition and development. The data for the research has been derived from archaeological investigation reports and plans, from maps dating from the 16th century through to modern, historical and archaeological publications and borehole logs.

The sources of data have included:

1. London Archaeological Archive Resource Centre (LAARC)
2. Greater London Historic Environment Record (GLHER)
3. British Geological Service (BGS)
4. Ordnance Survey – printed and digitised maps
5. Museum of London – publications and maps
6. Archaeological and historical publications – monographs; research reports; books; papers in professional journals and magazines, including the London and Middlesex Archaeological Society Transactions (LAMAS)

The primary data acquired from these sources for each of the palaeo-hydrology, palaeo-stratigraphy, flood mitigation/river management and beneficial use components are reported in their respective chapters, viz.

- Chapters 3 and 5 Palaeo-hydrology

- Chapter 4 Palaeo-stratigraphy
- Chapter 6 Flood Frequency Analysis
- Chapter 7 Flood Mitigation and River Management
- Chapter 8 Beneficial Use

2.2 Research Methodology

The structure of the research has been set out in Section 1.3 and illustrated in Figure 1-2. The following is an outline of the methodology used in the research. A detailed methodology is presented for each of the main components of the research in the chapter dealing with the respective topic as indicated below.

1. **Literature Search – Chapter 1.**

   A Literature search was carried out. References that proved useful in the research are reported throughout the thesis under their appropriate research component. Notes on the most relevant of these references are also reported in Appendices 2B, 2D, 2F and 2G.

2. **Data sources – Chapter 2**

   Sources of data for each of the five research components were identified and, as necessary, prioritised with respect to their relevance to the Roman Walbrook. A programme of data collection was established and completed.

3. **The Roman Walbrook its catchment and streams – Chapter 3**

   The full extent of the Walbrook's topographic catchment and its principal streams and tributaries were determined; the geology of the catchment was identified and hence the full extent of the Walbrook's groundwater catchment was determined.

4. **Palaeo-stratigraphy component objectives, methodology, data acquisition and development – Chapter 4**

   A full methodology for this research component is reported in Chapter 4, Section 4.3.

5. **Palaeo-hydrology component objectives, methodology, data acquisition and development – Chapter 5**

   A full methodology for this research component is reported in Chapter 5, Section 5.3.

6. **Flood-frequency analysis – Chapter 6**

   A full methodology for this research component is reported in Chapter 6, Section 6.2.

7. **Flood mitigation and river management – Chapter 7**

   Outputs from the three service components reported in chapters 3, 4, 5 and 6 to be used in conjunction with data acquired and developed specifically for the purpose of determining what, if any, river management techniques were used by the Romans to mitigate the detrimental impacts of flooding.

8. **Roman Walbrook – Beneficial Use – Chapter 8**

   Data acquired whilst studying the archaeological records of investigations accessed in the course of the research have been used to identify examples of the beneficial use of the waters of the Roman Walbrook. Based upon data developed by the current research, the conjectured use of the Walbrook to power one or more mills has been examined.

9. **Principal research conclusions and future research recommendations – Chapter 9**

   The content and conclusions drawn from the research are summarised and recommendations made for future work, particularly where conclusions might be further refined given the availability of more data. The relevance of the research to London archaeology has been described as its broader application to archaeological science.

2.3 Geographical Information Systems (GIS)

Spatial data acquired in the course of the research has been entered onto a GIS platform, to aid reporting, and a GIS-based model has been developed to analyse stratigraphic data.

The most commonly-used GIS software in the UK and in the archaeology sector is ArcGIS. This software, for which a 40% global market share is claimed, has been developed, marketed and supported by the Environmental Systems Research Institute (ESRI), originally a land-use consultancy, based in Redlands, California (Zeiler and Murphy, 2010). The version of the ESRI software licensed for use by the University of Reading is ArcGIS 10.1 and, together with its extensions, ArcCatalog 10.1 and ArcScene10.1, is the version used in this research.

2.4 Data Sources

The purpose of this section is to provide background to each of the major sources of data used in the research – the Museum of London (MoL), the London Archaeological Archive and Research Centre (LAARC), the Greater London Historic Environment Record (GLHER), the British Geological Survey

(BGS), Ordnance Survey (Perring et al., 1991) and published literature, including MoL publications and the LAMAS Transactions. The data acquired from each of these sources is either detailed in Chapters, 3, 4, 5, 7 and 8, as applicable to the component of the research dealt with in each of those chapters, or in Appendices associated with those chapters, where data have been used by several research components. In the case of the latter, the Appendices are as follows:

- **Appendix 2A Prioritization of Walbrook-Related Archaeological Sites Within the City of London & Site Data Research Undertaken**

  A list of all the archaeological sites, the records of which are stored at the MoL archives, LAARC, and that are within the area of urban Roman London associated with the Walbrook. The method of compilation of the list, and the three levels of priority attached to these sites, is explained in Section 2.4.2. The table clarifies which sites have been included in the research. In addition to their prioritisation, the table provides the site reference, address and location details as well as brief comments.
- **Appendix 2B Site Records Accessed at LAARC - Notes on Archaeological Investigation Reports, Plans and Sections**

  Notes made on 38 archaeological sites, the records of which are stored at LAARC. More than 60 full-day visits were made to the archives to abstract data from archaeological investigation reports, plans and sections. In addition, this Appendix contains a record of a visit made to the Bank of England archives and to those of the John Soane Museum with respect to the course of the Walbrook beneath the northwest corner of the building and the Roman finds made during its 19th C reconstruction.
- **Appendix 2C Archaeological site record accessed at GLHER**

  A list of the 21 “short-listed” archaeological site records accessed at GLHER, providing their respective GLHER file references, LAARC site codes and address details.
- **Appendix 2D Notes on Site Records Accessed at GLHER**

  Notes made on the sites listed in Appendix 2C, the records of which are stored at GLHER. The status of the records stored at GLHER is described in Section 2.4.3 but are restricted to digitised reports; no plans or sections are held in the GLHER records.

- **Appendix 2E URWV - Archaeological Site Investigations - Listing of Significant Finds**

  This Appendix is a single table that summarises significant data drawn from the LAARC and GLHER site records listed in Appendices 2A and 2C as well as publications concerning other sites, including monographs. The table is extensive and can only be accessed on the attached DVD.

- **Appendix 2F Notes on Publications and Journal Papers Consulted Early in the Research**

  Notes on publications and journals that assisted in focussing the early research work.

- **Appendix 2G Notes on Papers Included in the LAMAS Transactions, 1968 to 2014, Relevant to the Current Research Topic – from 1968 to 2014**

  LAMAS Transactions, an annual record of papers delivered through LAMAS, have been produced since 1856 and are available on line to and including 2009, more recent volumes being available only in hard copy. Volumes from 1968 to the present were reviewed for papers reporting Walbrook-related investigations and topics. Notes were made on all articles of interest.

- **Appendix 2H List of All Archaeological Investigation in the Research**
- **Appendix 2I Notes on Data Quality**

2.4.1 Museum of London

The Museum of London published a guide to the work of Professor W F Grimes (Shepherd, 1988, 71-75), Keeper and Secretary of the London Museum, later the Museum of London, whose investigation records are held at LAARC. The most relevant to the current research were those relating to the Bucklersbury House investigation in the early 1950s.

The Museum of London was visited to view particular artefacts found in the course of archaeological investigations within the URWV. Of particular interest were the few finds of large commercial-size milling querns that were exhibited at the Museum and held in the archived collection at Mortimer Wheeler House.

2.4.2 London Archaeological Archive and Research Centre (LAARC)

The London Archaeological Archive and Research Centre (LAARC), recently renamed the Museum of London Archaeological Archive, is part of the museum's Department of Archaeological Collections and Archive. It holds information on nearly 8,500 archaeological sites investigated in the City of London and Greater London over the last 100 years, of which they hold full records for 3,500 sites.

All excavation reports, plans and archive material within Greater London are required to be deposited at LAARC when complete, whether undertaken by public or private sector organisations. However, all but a few of the site investigations used in this research and accessed through LAARC have originated from three organisations. These three organisations were responsible for organising, executing and reporting archaeological investigations in the City of London and Greater London, viz. RMLEC, the Museum of London Archaeology (MOLA), formerly the Museum of London Archaeology Service (MoLAS) and the Department of Greater London Archaeology (DGLA).

The Department of Urban Archaeology (Esper et al., 2012, 862-866), formed in the early 1970s, and the DGLA, formed in the 1980s, were respectively responsible for organising, executing and reporting archaeological investigations in the City of London and Greater London. They were merged in 1991 to form MoLAS which now competes with private sector companies for archaeological investigatory work throughout the UK and abroad. This change of status and need to compete has given rise to some difficulty with respect to the accessing of records of recent investigation works.

A publication by the Museum of London lists the archaeological investigations carried out by the Museum of London in the period 1907 to 1991 (Schofield and Maloney, 1998). Using the large-scale maps included in the publication, all the sites located in the URWV were identified and their address and location details tabulated in an initial longlist of sites that could be of interest to the research. Using the summary descriptions of the individual works in the publication and in discussions with one of the authors, Cath Maloney, the archivist at LAARC, this longlist was broken down into first, second and third priority sites. Priority 1 was attributed to all those sites that appeared, from their descriptions, to be either directly related to the Walbrook or its tributaries or that refer to Walbrook-related buildings, industry and crafts, rituals and artefacts. Priority 3 sites were found to have no Walbrook-related evidence and Priority 2 sites were those for which it was difficult to understand from their description whether they were Walbrook-related. The table of this prioritised longlist of site investigations is reported in Appendix 2A.

From summer 2010 to spring of 2014, more than 60 full-day visits were made to LAARC. The records for a total of thirty-eight Priority 1 and 2 sites were accessed at LAARC and, in addition, the summarised records of two sites were accessed online. The locations of these sites are shown on Figure 2-1.

2.4.3 Greater London Historic Environment Record (GLHER)

Greater London Historic Environment Record is a department within the Greater London Archaeology Advisory Service (GLAAS).

A map of the Greater Walbrook Valley catchment was provided to GLHER with an instruction to limit their search for appropriate sites in their archive to a 150-metre wide band either side of the watercourse from Upper Thames Street to about 150 metres north of Finsbury Circus.

Five visits were made to GLHER in order to access their digital archive. In all, 25 reports relating to 19 archaeological sites were studied. 13 of the GLHER site records were the primary source of data for the sites to which they referred and 6 provided supplementary data for sites archived at LAARC. The GLHER site references and address details, for those sites for which they were the primary data source are listed at the beginning of the thesis, “Archaeological Investigations Included in this Research”. A complete list of the sites researched at GLHER are reported in Appendix 2B, together with short notes on each. The locations of the GLHER sites are shown on Figure 2-2.

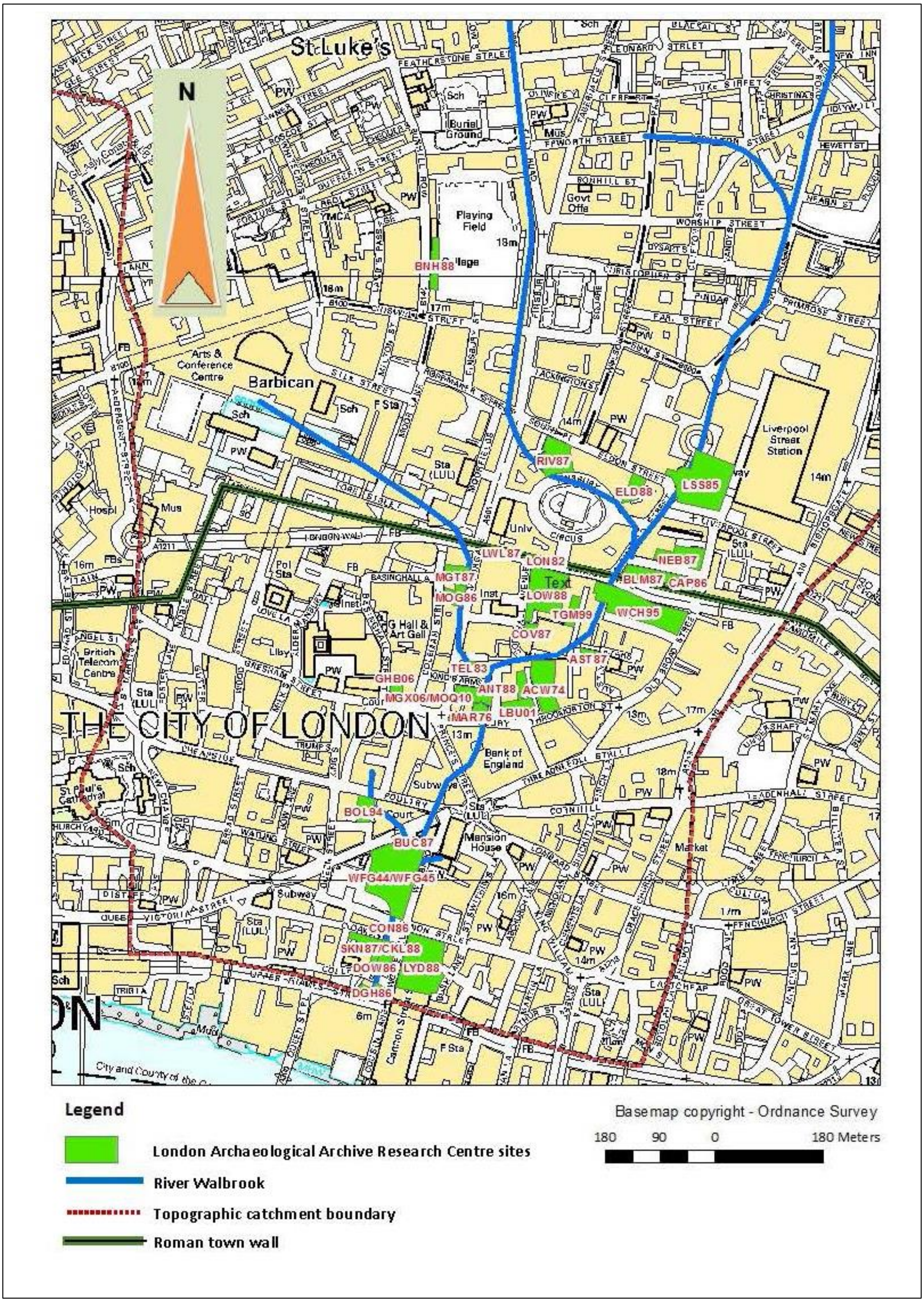


Figure 2-1 Location of archaeological sites for which LAARC is the primary data source

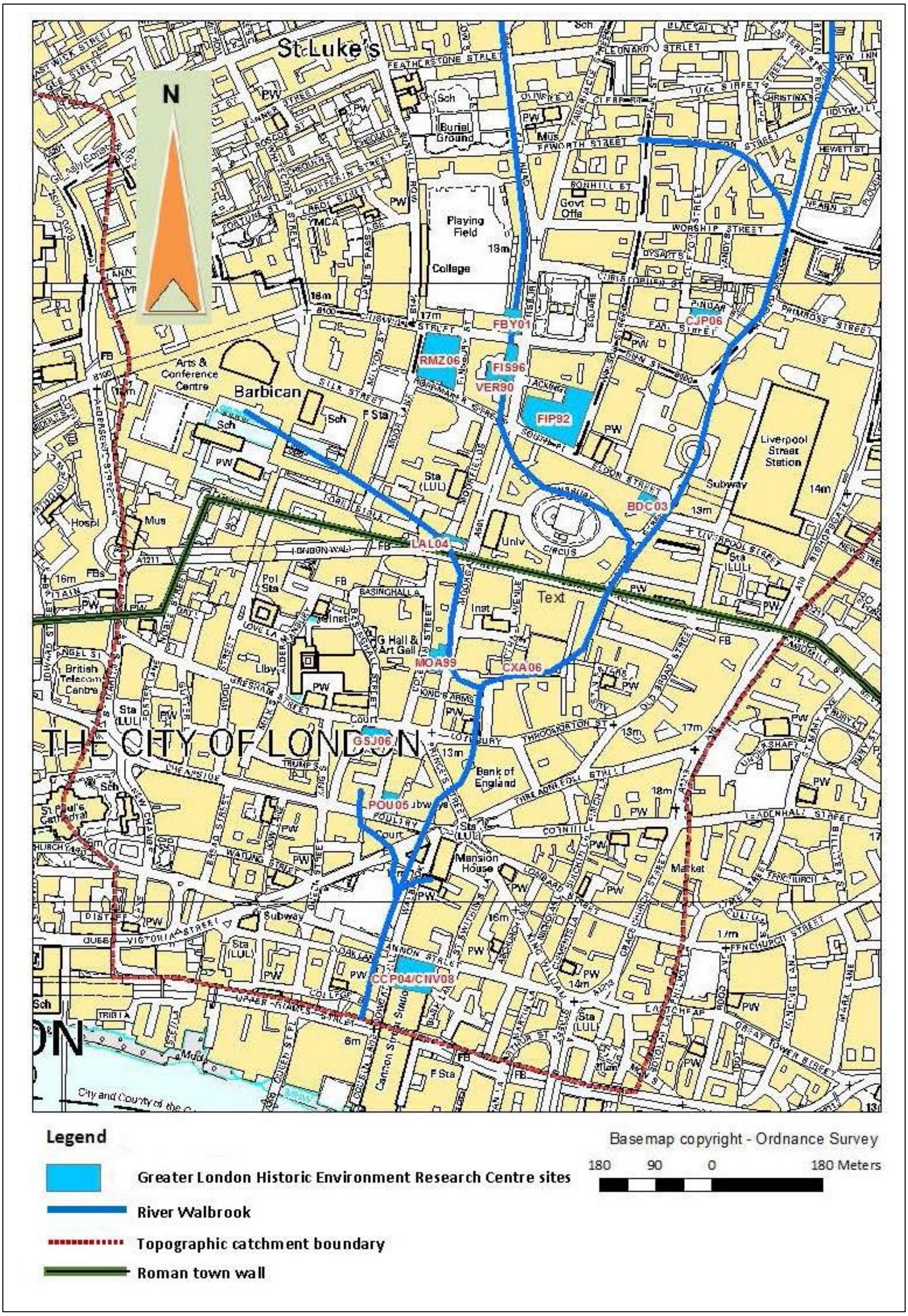


Figure 2-2 **Location of archaeological sites from which GLHER is the primary source of data**

2.4.4 British Geological Survey

Geological maps and publications of the British Geological Survey (BGS) have been cited and used in the research.

As part of its remit, the BGS maintains a register of the records of all boreholes carried out onshore in the UK. This is carried out by its subsidiary, the National Geoscience Data Centre that has a collection of the records of onshore boreholes, shafts and wells that have been scanned into their database. To support the palaeo-stratigraphy component of the research, BGS data was obtained online from their borehole scan service, Onshore GeoIndex Web Map Services within the Single Onshore Boreholes Index.

Forty-three borehole records were accessed from twenty-three sites within the Greater Walbrook Valley between the Thames and the city Road/Old Street intersection.

2.4.5 Ordnance Survey

The Ordnance Survey, the national mapping agency for Great Britain has operated as a government-owned company since April 2015. The base map used in the research, as detailed in Section 4.4.1, was downloaded in a form suitable for use in the ArcGIS software.

2.4.6 Literature Sources

A literature search for publications and journal papers the subjects of which were connected with the River Walbrook was carried out early in the research. Notes made on these publications are reported in Appendix 2F. In addition, LAMAS Transactions from 1968 to 2014 were searched for references to the River Walbrook in the Roman period and notes on these are reported in Appendix 2G.

A considerable amount of data has been drawn from published sources. Where this is the case, the source has been referenced in the text and is listed in the detailed bibliography located at the end of the thesis.

Data from recent archaeological site investigations that could not be obtained through LAARC or GLHER has been obtained from published monographs, research reports and similar publications. The locations of sites for which publications have been the principal source of data are shown on Figure 2.3.

2.5 Data Application in the Research

A table of the archaeological investigations, listed with their LAARC references in alphabetical order, from which data has been drawn for the purposes of this current research is included as Appendix 2H. For each of the investigation listed in the table, information is provided on the source of the data, the address of the site and its hydrological zone within the URWV, the latter being as defined in Section 3.4.8, Sub-divisions of the urban Roman Walbrook, and on Figure 3-10.

Table 2-1 lists the archaeological sites used in the research and the source of the data. They are grouped according to their hydrological zone and the principal components of the research to which they have respectively contributed data are also indicated under the following categories:

- Palaeo-hydrology
- Palaeo-stratigraphy
- Palaeo-environment
- Flood mitigation and river management
- Land raising
- Beneficial use of Walbrook water

The hydrological zone groupings are colour-coded as follows:

- Lower urban Roman Walbrook Valley (estuarine) 7 sites
- Lower urban Roman Walbrook Valley (non-estuarine) 8 sites
- Middle urban Roman Walbrook Valley – south 10 sites
- Middle urban Roman Walbrook Valley – north 29 sites
- Upper urban Roman Walbrook Valley 15 sites

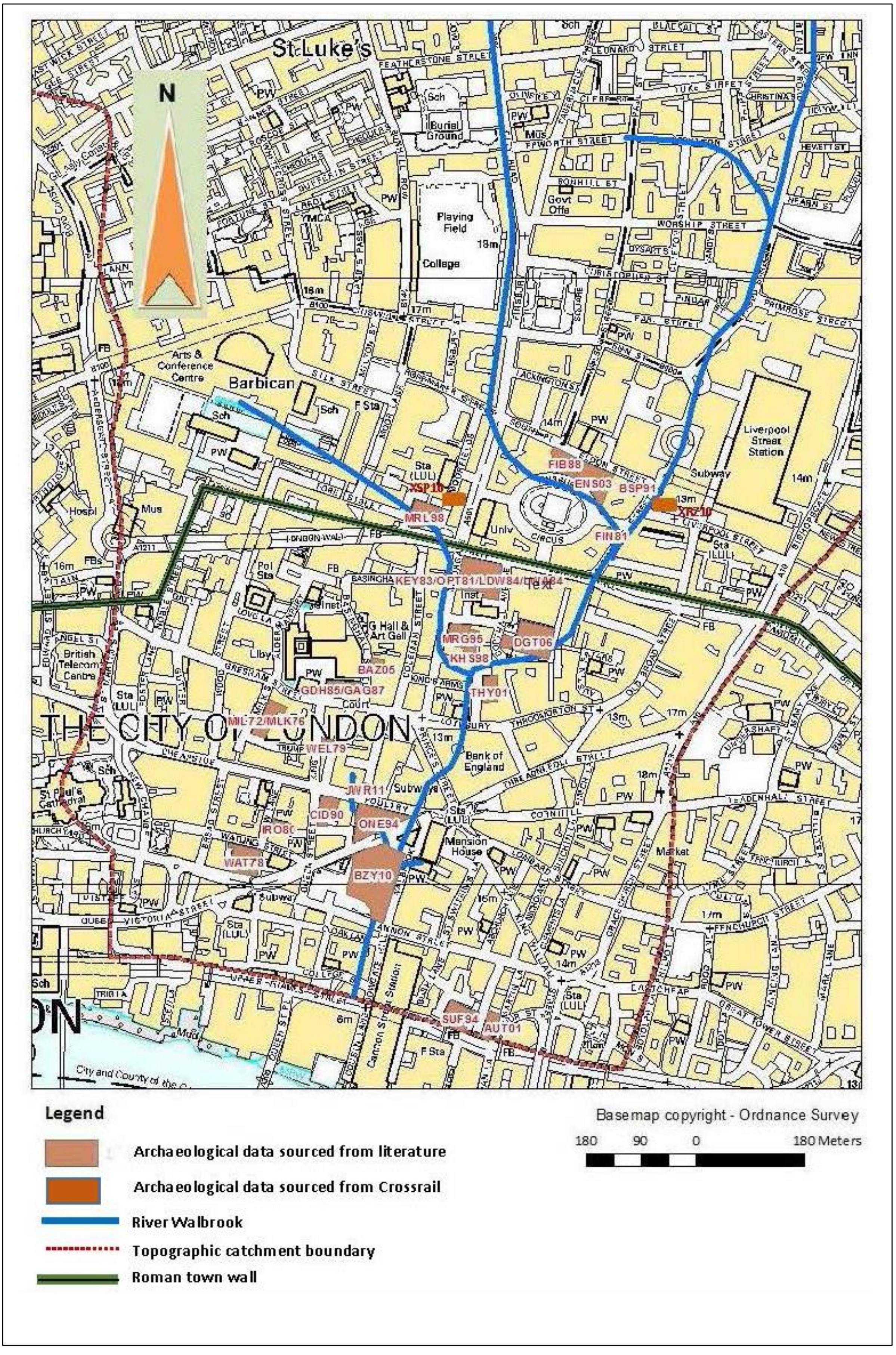


Figure 2-3 Location of archaeological sites for which literature is the main data source

Table 2-1 Use of archaeological site investigation data in the research (page 1 of 4)

LAARC Reference	Source of data	Urban Walbrook Valley Hydrological Zone *(Figure 5-11)*	Site Address in London	Use of archaeological site investigation data in the research					
				Palaeo-archaeology	Palaeo-hydrology	Flood mitigation & river management	Land raising	Beneficial use of Walbrook water	Palaeo-environment
DGH86	LAARC	A	Dowgate Hill House, Dowgate Hill, EC4	Yes	Yes	Yes	Yes	Yes	
DOW86	LAARC	A	3, 5-7 Dowgate Hill, EC4			Yes		Yes	
SUF94	Literature	A	Suffolk House, 5 Laurence Pountney Hill & 154-156 Upper Thames St, EC4			Yes		Yes	
SKN87/CKL88	LAARC	A	Skinner's Hall Kitchen, 8-9 Cloak Lane, EC4	Yes	Yes	Yes	Yes	Yes	
LYD88	LAARC	A	Cannon Street Station N, Upper Thames Street (Dowgate Hill), EC4	Yes	Yes	Yes	Yes	Yes	
CCP04/CNV08	GLHER	A	Cannon Place, EC4	Yes	Yes	Yes	Yes	Yes	
CON86	LAARC	A	76 Cannon Street, EC4	Yes		Yes	Yes	Yes	
BZY10	Literature	B	Blomberg Place, EC4	Yes	Yes	Yes	Yes	Yes	Yes
WFG44 & 45	LAARC/Literature	B	Bucklersbury House (Temple of Mithras), EC4	Yes	Yes	Yes	Yes	Yes	
WAT78	Literarture	B	Watling Court, 39-53 Cannon St & 11-14 Bow Lane, EC2			Yes		Yes	
BUC87	LAARC	B	DLR Shaft, Bucklersbury, (near Queen Victoria St), EC4	Yes		Yes	Yes	Yes	
CID90	Literature	B	72-75 Cheapside & 83-93 Queen Street EC2						
IRO80	Literature	B	24-25 Ironmonger Lane, EC2			Yes		Yes	
BOL94	LAARC	B	Bolsa House, 76-80 Cheapside, EC2	Yes		Yes	Yes	Yes	
ONE94	Literature	B	1 Poultry, EC2		Yes	Yes		Yes	Yes
POU05	GLHER	C	36 Poultry, EC2	Yes	Yes	Yes	Yes	Yes	
WEL79	Literature	C	Well Court, 44-48 Bow Lane, EC2			Yes		Yes	
GSJ06	GLHER	C	54-56 Gresham Street, EC2			Yes		Yes	
MIL72/MLK76	Literature	C	7-1- Milk Street, EC2/1-6 Milk Street, EC2			Yes		Yes	
MAR76	LAARC	C	St Margaret Lothbury Church, Lothbury, EC2	Yes		Yes	Yes	Yes	

Table 2-1 (continued) **Use of archaeological site investigation data in the research (page 2 of 4)**

LAARC Reference	Source of data	Urban Walbrook Valley Hydrological Zone *(Figure 5-11)*	Site Address in London	Use of archaeological site investigation data in the research: Palaeo-archaeology	Palaeo-hydrology	Flood mitigation & river management	Land raising	Beneficial use of Walbrook water	Palaeo-environment
LBU01	LAARC	C	41 Lothbury, EC2	Yes		Yes	Yes	Yes	
MGX06/MOQ10	LAARC online	C	8-10 Moorgate; 3-4 King's Arms Yard; 8-10 Telegraph St & 16-17 Tokenhouse Yard, EC2		Yes	Yes		Yes	
LHY88	LAARC	C	Docklands Light Railway Ventilation Shaft, opp 5 Lothbury, EC2						
GHT00	Literature	C	20-30 Gresham Street, EC2					Yes	
GHB06	LAARC online	C	6-12 Basinghall St & 93-95 Gresham St, EC2			Yes		Yes	
THY01	LAARC/GLHER/ Literature	D	6-8 Tokenhouse Yard, EC2	Yes	Yes	Yes	Yes	Yes	Yes
ACW74	LAARC	D	1-8 Angel Court, 30-35 Throgmorton Avenue, EC2	Yes		Yes	Yes	Yes	
ANT88	LAARC	D	9-10 Angel Court, EC2	Yes		Yes	Yes	Yes	
TEL83	LAARC	D	8 Telegraph St, EC2			Yes		Yes	
GDH85/GAG87	LAARC online	D	Guildhall Art Gallery, Guildhall Yard, EC2 & 81-87 Gresham St, EC2						
BAZ05	Literature	D	35 Basinghall St, EC2			Yes			
KHS98	GLHER/Literature	D	Kent House, 11-16 Telegraph Street, EC2			Yes			
MOA99	GLHER	D	19-31 Moorgate, EC2			Yes		Yes	
MRG95	GLHER/Literature	D	Northgate House, 20-28 Moorgate, EC2			Yes		Yes	
AST87	LAARC/Literature	D	22-25 Austin Friars, EC2	Yes		Yes	Yes	Yes	
CXA06	GLHER	D	2 Copthall Avenue, EC2	Yes		Yes	Yes	Yes	
CHL84	LAARC/Literature	D	4-6 Copthall Avenue, EC2						
COV87	LAARC	D	10-12 Copthall Avenue, EC2	Yes		Yes	Yes	Yes	
DGT06	Literature	D	Drapers' Gardens, EC2			Yes		Yes	

Table 2-1 (continued) Use of archaeological site investigation data in the research (page 3 of 4)

LAARC Reference	Source of data	Urban Walbrook Valley Hydrological Zone *(Figure 5-11)*	Site Address in London	Use of archaeological site investigation data in the research					
				Palaeo-archaeology	Palaeo-hydrology	Flood mitigation & river management	Land raising	Beneficial use of Walbrook water	Palaeo-environment
TGM99	LAARC	D	8-10 Throgmorton Avenue, EC2	Yes		Yes	Yes	Yes	
TRM86	LAARC	D	9-19 Throgmorton Avenue; 21 Austin Friars, EC2						
MOG86	LAARC	D	49-53 Moorgate, 72-74 Coleman Street, EC2	Yes		Yes	Yes	Yes	
MGT87	LAARC	D	55-61 Moorgate, EC2	Yes		Yes	Yes	Yes	
KEY83 (inc OPT81, LWA84 & LDW84)	LAARC/Literature	D	15-35 Copthall Ave, 45-49 London Wall & Cross Keys House (inc. 2-3 Cross Keys Court (OPT81); 43 London Wall (LWA84); 44 London Wall, EC2 (LDW84)	Yes		Yes	Yes	Yes	
WCH95	LAARC/GLHER	D	72 & 74-78 London Wall, EC2	Yes		Yes	Yes	Yes	
LOW88	LAARC/Literature	D	52-63 London Wall, 20-56 Copthall Avenue, EC2 (inc. 60 London Wall)	Yes		Yes	Yes	Yes	
LWL87	LAARC	D	BT Shaft, opp 45-50 London Wall, EC2		Yes	Yes			
LAL04	GLHER	D	London Wall/Moorgate, EC2	Yes			Yes		
MRL98	GLHER/Literature	D	Moor House, London Wall, EC2			Yes		Yes	
MTX11	Literature	D	Moorgate Telephone Exchange, Fore Street, EC2		Yes				Yes
LON82	LAARC	D	London Wall, Junction with Blomfield Street, EC2	Yes			Yes		
BLM87	LAARC	D	Blomfield House, 85-86 London Wall, EC2	Yes		Yes	Yes	Yes	
NEB87	LAARC	D	35-45 New Broad Street, EC2	Yes		Yes	Yes	Yes	
CAP86	LAARC	D	Capel House, 54-62 New Broad Street, EC2	Yes		Yes	Yes	Yes	
BDC03	GLHER	E	6 Broad Street Place, EC2	Yes	Yes	Yes	Yes	Yes	
BSP91	Literature	E	14 Eldon Street & 6 Broad Street Place, EC2			Yes			
FIN81	LAARC/Literature	E	Finsbury House, 23 Blomfield St, EC2	Yes					
ELD88	LAARC/Literature	E	Liverpool House, 15-17 Eldon Street, London, EC2	Yes	Yes	Yes	Yes	Yes	

Table 2-1 (continued) **Use of archaeological site investigation data in the research (page 4 of 4)**

LAARC Reference	Source of data	Urban Walbrook Valley Hydrological Zone *(Figure 5-11)*	Site Address in London	Use of archaeological site investigation data in the research					
				Palaeo-archaeology	Palaeo-hydrology	Flood mitigation & river management	Land raising	Beneficial use of Walbrook water	Palaeo-environment
XSP10	Literature	E	17-31 Moorfields, Moorgate Station, EC2						Yes
ENS03	Literature	E	16-18 Finsbury Circus & 18-31 Eldon Street, EC2			Yes			
XRZ10	Literature	E	Finsbury Circus (Crossrail), EC2						Yes
RIV87	LAARC	E	River Plate House, 7-11 Finsbury Sqare, EC2	Yes		Yes	Yes	Yes	
FIB88	Literature	E	12-15 Finsbury Circus, EC2			Yes			
RMZ06	GLHER	E	Ropemaker St; Finsbury St; Chiswell St; Moore Lane, EC2	Yes			Yes		
LSS85	LAARC	E	Liverpool St Station, Broad St Station, EC2	Yes	Yes	Yes	Yes	Yes	
VER90	GLHER	E	Veritas House, 119-125 Finsbury Pavement, EC2	Yes	Yes	Yes	Yes	Yes	
FIS96	GLHER	E	127-139 Finsbury Pavement, EC1	Yes	Yes	Yes	Yes	Yes	
FIP92	GLHER	E	Dominion Buildings, Island Site, Finsbury Pavement, EC2	Yes			Yes		
FBY01	GLHER	E	1-2 Finsbury Square, EC2	Yes	Yes	Yes	Yes		
BNH88	LAARC	E	Gavrelle House, 2-14 Bunhill Row, EC1	Yes		Yes	Yes		
CJP06	GLHER	E	30 Crown Place, Hackney, EC2	Yes			Yes		

2.6 Data Quality

All of the data used in the research has been drawn from sources with impeccable professional qualifications. The Museum of London, LAARC, GLHER, BGS and the OS are internationally recognised as working at the forefront of their various disciplines. However, the quality of data arising out of archaeological investigations undertaken at any particular point in time varies according to:

- the standards of investigation current at that time;
- the length of time for which a site was made available for archaeological investigation, more often than not far shorter a period than would have been wanted;
- permitted areas for investigation, frequently only a small proportion of any construction site being made available: and
- the physical conditions experienced in the investigations, often cramped, water-logged and dangerous.

Additionally, regarding borehole records, BGS has no control over the quality of the work and reporting of the individual contractors who carried out the work. Therefore the data from both archaeological and borehole investigations warrant comments upon their quality.

2.6.1 Data drawn from archaeological investigations – LAARC and GLHER

Early archaeological investigations, prior to WW1, were frequently carried out in an unplanned manner and there was a wide variation in the quality of reporting. Some of the older references, e.g. articles in Archaeologia and the LAMAS Transactions, that refer to culverts carrying the Walbrook and its tributaries through the Roman town wall are from 19th century investigations. The data obtained from these are basic but trustworthy in both excavation and reporting (Royal Commission on Historical Monuments, 1928) and adequate for the needs of the research. Most notably through the efforts of Sir Mortimer Wheeler and then Professor W F Grimes amongst others, from WW1 through to WW2, attempts were made to bring some discipline into archaeological investigative work carried out in London. Grimes' work at the Bucklersbury House site in 1954 (WFG44 and WFG45), also known as the Temple of Mithras site, which uncovered the Walbrook, has been referred to in this research. The plans of this investigation archived at LAARC are very detailed with respect to stratigraphy but, as no reports of the work are available, interpretation of other aspects have been sourced from his book (Grimes, 1968, 92-98) that describes this and other of his investigations (Shepherd, 1988, 71-75).

However, most of the archaeological data used in the research has been sourced from investigations that took place post-1970. Although it has been assumed that investigative work carried out between WW2 and the end of the 1970s was carried out competently, no standards had yet been set for the investigative work or the reporting of results. Reports produced in this period were in some cases in the form of handwritten notes and where typed were produced by stencil duplication (Gestetner) or carbon copied. The difficulty of revision of a document was frequently evident in that the meaning of some of the wording proved difficult to determine, a difficulty compounded in a few instances by English not being the first language of authors. Fortunately, only four of the archaeological investigations used in the research were undertaken and reported in this manner, viz. 1-8 Angel Court, 30-35 Throgmorton Avenue (ACW74), St Margaret Lothbury (MAR76), 2-3 Cross Keys Court (OPT81) and London Wall, Junction with Blomfield Street (BLM87).

The mechanics of producing a report improved with the advent of electronic typewriters followed by word-processing and eventually computers. More importantly, the organisations responsible for specifying and undertaking the investigative work and its reporting produced a series of manuals. The Museum of London produced an archaeological site manual, the first edition of which was published in 1980, a second edition in 1990 and a third edition in 1994 (Museum of London Archaeological Service, 1994) which is in current use. This manual was supplemented by another on archive report writing (Museum of London and Williams, 1986). Consequent upon the introduction of these two manuals, the undertaking of excavations and their reporting was standardised and the quality of the reporting rapidly improved to a very high standard. The majority of the archived investigations in LAARC and GLHER included in this research have been produced to the standards set in these manuals. In addition, English Heritage produced a guide to the theory, methods and practice of environmental archaeology (English Heritage, 2001) and Greater London Archaeological Advisory Service produced an external consultation document on standards for archaeological work (Greater London Archaeological Advisory Service, 2009). The Chartered Institute for Archaeologists also publishes a set of standards and guidance for its members but these would only be used by archaeologists in London for topics or aspects of topics not covered by the manual issued by the Museum of London and English Heritage.

2.6.2 British Geological Survey

The BGS has no control over the standard of work or reporting of the borehole investigations that it has compiled into its online collection. Some of the borehole records used in the research, the majority, are extremely detailed and depictions of the stratigraphy have been produced to high professional standards. However, other records provide a minimum of technical data, e.g. hand-drawn sketches produced on site during drilling as evidenced by soil residue on the paper used.

As reported in Section 4.3, the methodology for the palaeo-stratigraphy component of the research, three stratigraphic horizons have been identified as of greatest interest to the research, viz. Top Natural, Top Pre-Roman Waterlain and Top Roman Archaeology.

Boreholes are primarily produced to assist in the structural design of foundations to buildings, not for providing archaeological data. Of the three key stratigraphic horizons, only two are readily observable from borehole records – Top Natural and Top Pre-Roman Waterlain, the first as it is often directly referred to as such or as London Clay and the second from a relatively straightforward interpretation of the recorded strata descriptions. Only in a very few cases was it possible to determine an elevation for the third key horizon, Top Roman Archaeology, from the borehole record, generally where the Roman deposits were overlain by marsh deposits in the upper URWV and the immediate environs north of the Roman town wall, at Moorfields. To provide the complete set of data required by the GIS software, the elevation of Top Roman Archaeology was estimated from positive data from nearby archaeological investigations.

2.6.3 Literature sources - archaeological investigations, journals and conferences

Many publications by professional bodies and societies active in the field of archaeology, all produced to the highest standards have been consulted in the course of the research, examples of which are as follows:

- Monographs and investigation reports, e.g. (Perring et al., 1991) (Watson and Heard, 2006) (Hill and Rowsome, 2011) (Leary and Butler, 2012)

- Gazeteers of archaeological investigations in London, e.g. (Schofield and Maloney, 1998) (Shepherd, 1988, 71-75)
- Topic-based reports which include the Walbrook Valley, e.g. (Sidell et al., 2000) (Harward et al., 2015)
- Topic-based publications by professional bodies and societies such as the Council for British Archaeology, e.g. (Maloney and De Moulins, 1990), the Society of Antiquaries of London (Fulford, 1988, 26; 37-38)
- Journals such as Archaeologia (Society of Antiquaries of London), Journal of Roman Studies The Roman Society), LAMAS Transactions and the London Archaeologist (LAMAS)
- Collections of papers, e.g. (Bird, 1996) (Clark et al., 2008)
- Conference proceedings, e.g. (Needham and Macklin, 1991)

2.6.4 Key stratigraphic horizon elevations – a quality warning

Horizon elevations derived from archaeological site investigations and from borehole records should not be taken as indicating absolute Roman period values for the horizon to which they refer. All three key stratigraphic horizons have been subject to considerable pressure by the weight of overburden that has accumulated since the Roman period. In the lower URWV, the depth of overburden today can be as much as 9 metres. In the upper urban valley, depth of overburden is generally less but will be a minimum of 2 metres to a maximum of about 5 metres deep. This weight of overburden has accumulated and exerted its gradually increasing pressure over a period of 1,600 years. Almost certainly every surface elevation quoted in this research – and every other elevation quoted in London archaeological reports – is therefore under-estimating the true surface level in the Roman period. This under-estimation is probably least for Top Natural, as London Clay is not highly compressible, and at its greatest under-estimation for Top Pre-Roman Waterlain as silty, sandy, gravelly mixes are compressible and have been subject to greater compression for longer periods than for the Top Roman Archaeology horizon.

It is virtually impossible to gauge with any accuracy the degree of compression that will have taken place for any layer in a particular location.

However, this phenomenon does not invalidate the use of the data for determining the general topography of any of the three key land surface horizons. The degree of compression in a general location will not vary considerably over that area and so the elevation data derived in the research provides a good representation of the topography of the land surface but not necessarily its absolute elevation value. Similarly, riverbed slopes can be derived from the data, although the actual value of the elevation of the riverbed at any specific location will have been higher than the values shown in the research.

Chapter 3

The Roman Walbrook – Catchments and Streams

3.1 Introduction

The reporting of the palaeo-hydrology service component of the research has been split between this chapter and Chapter 5. The former deals with the definition of the ancient Walbrook's catchments and streams, a basic requirement for all aspects of the research. The latter deals with the objectives, methodology and data acquisition and development related to hydrological analysis of the Walbrook and its catchment. This chapter is developed in three sections:

- Topographic catchment (Section 3.2)
- Superficial geology and the groundwater catchment (Section 3.3)
- The ancient Walbrook – its streams and principal tributaries (Section 3.4)

3.2 Topographic Catchment

When applied to a river system, "catchment" refers to the physical boundary of a land area that contributes water to the principal river of that area. To arrive at the river, all sources of water, whether surface runoff or groundwater depend upon gravity to transport them to the river (Davie, 2008; 5). The topographic boundary of a catchment is therefore the line linking the highest points surrounding an area. The line of the topographic catchment boundary is termed the "watershed" as it marks the boundary between river catchments. Rain falling to one side of that line is shed to one river system whilst rain falling to the other side of the boundary drains to another (Oxford University Press, 1982; 1215).

Depending upon the nature and configuration of the geology underlying the general area of a river system, the boundary of the groundwater catchment may well differ from that of the topographic catchment. With respect to the Walbrook, research work on the groundwater catchment is reported in Section 3.3.3.

Definition of the Walbrook catchment is a primary data requirement for the research. Once defined, the principal watercourses that constitute the Walbrook's river system within that catchment can be identified.

The physical topography of the modern City of London is quite different from that of Roman London, there having been a considerable amount of land raising activity within the eventual line of the town wall and areas close to it. However, the boundary of the Walbrook's topographic catchment lies well outside that of the City of London and areas to the north of Old Street have been relatively unaffected by land raising activity (see Section 5.7.1) and it has been possible to determine the line of the watershed using a modern contoured map. This boundary has then been walked many times to refine its line accurately.

The principal map consulted was a "bespoke" plan of the Walbrook catchment ordered from Stanfords, Long Acre, London and plotted on 18 November 2010 to a scale of 1:10,000. It was sourced from digitally derived data made available by the Ordnance Survey which provides contours at 5-metre intervals (Ordnance Survey, 2010). Due to the broad interval between contours, the map provided only an initial rough indication of the catchment boundary, hence the need to refine the data by walking the catchment boundary. The boundary of the catchment of the whole length of the River Walbrook thus determined was then plotted onto GIS software, ArcGIS 10, Figure 3-1.

The western catchment boundary of the Walbrook is a reasonably well defined one as the ridge that divides the Walbrook and Fleet catchments is a pronounced feature for much of its length from Barnsbury through to the Thames south of St Paul's Cathedral. An accurate definition of its northern and north-eastern boundaries is equally pronounced and discernible on the ground from Barnsbury eastwards to just north of the Regent's Canal at the New North Road. However, the catchment boundary dividing the Walbrook and Hackney Brook catchments is more difficult to identify from the Regent's Canal through Hoxton and Shoreditch to Bishopsgate as the land is flatter. This portion of the catchment boundary has been walked many times and the catchment boundary over this stretch is a best estimate of the probable line.

As shown on Figure 3-1, the River Walbrook catchment is bounded by the catchment of the River Fleet on its western side and from Barnsbury above the Angel, Islington eastwards by the catchment of the

Hackney Brook. The Walbrook catchment within this boundary will be referred to throughout this research project as the “Greater Walbrook Valley” for the reasons described in Chapter 5, Section 5.7.1. As determined by the GIS software, the Greater Walbrook topographic catchment covers an area of 470 ha (4.70 km^2).

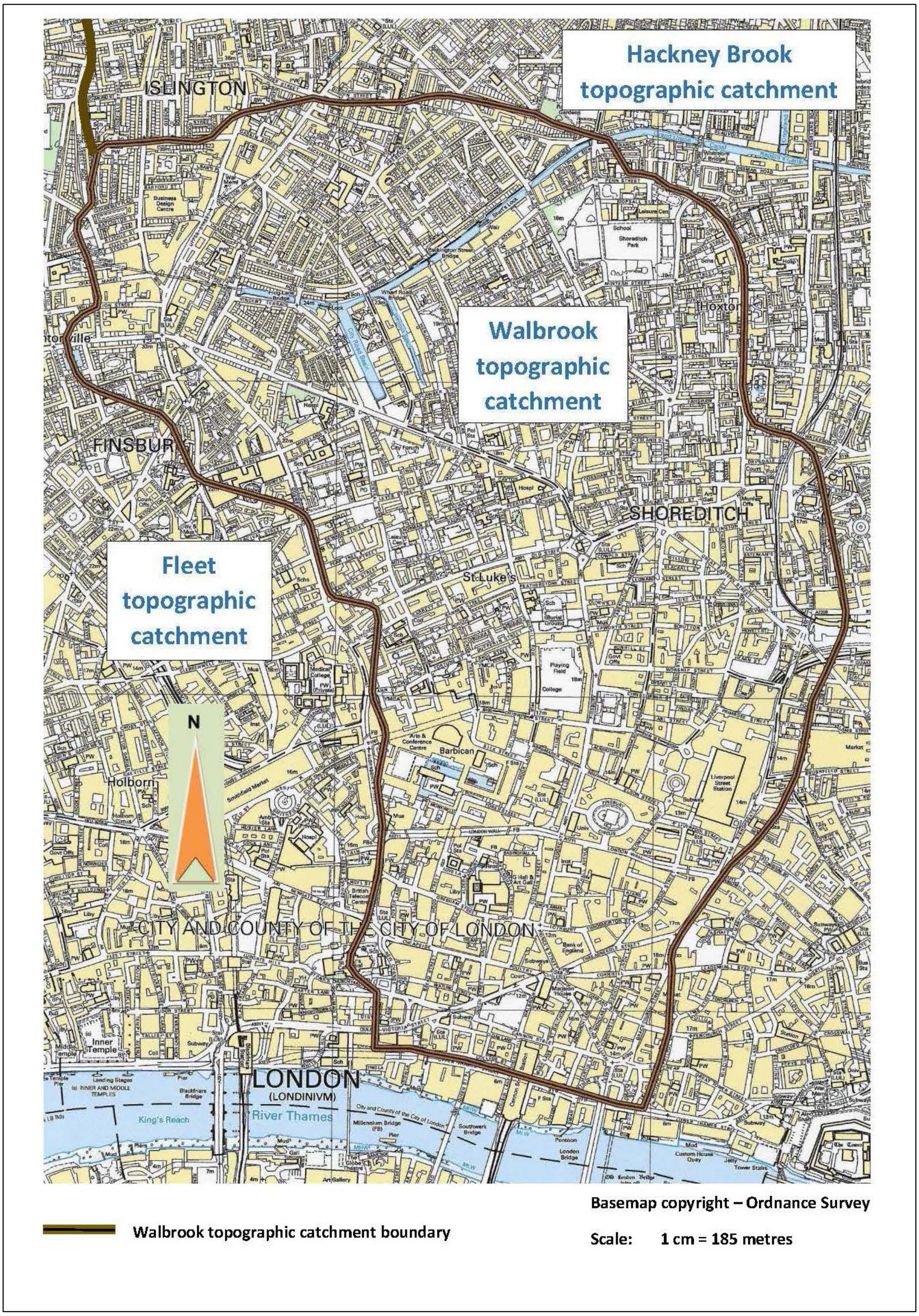


Figure 3-1 The Walbrook catchment showing neighbouring river systems

3.3 Superficial Geology and the Groundwater Catchment

Two aspects of the geology of the Greater Walbrook catchment are of particular interest with respect to the hydrology of the area, viz.

- the nature of the superficial deposits and underlying strata, as this affects the permeability of the ground and the movement of groundwater, and
- the inclination, the slope and direction, of the superficial deposits, particularly that of the interface between a permeable superficial deposit and an underlying impermeable strata as this could mean that the groundwater catchment is either smaller or larger than the topographic catchment.

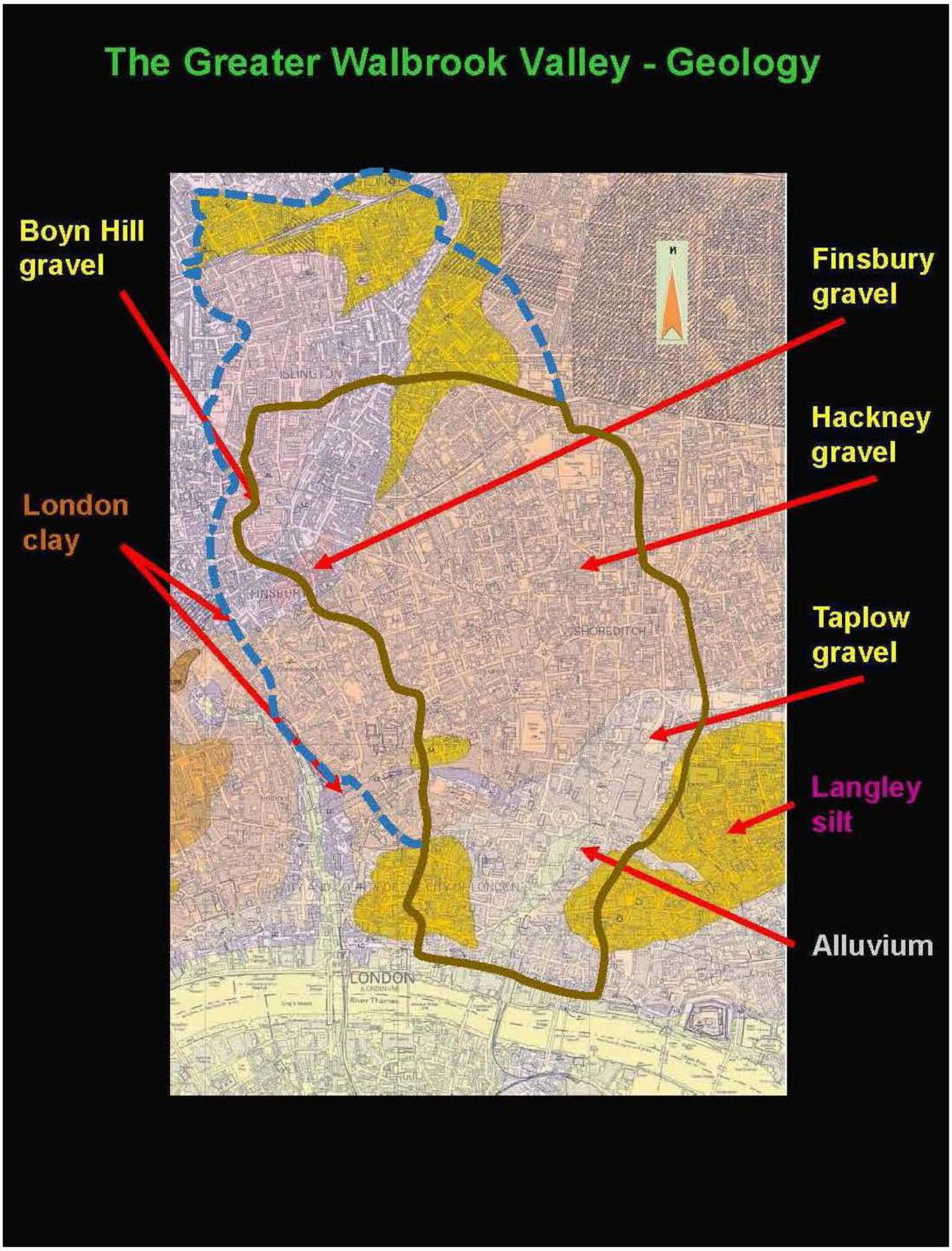
A map, which includes the geology of the Greater Walbrook catchment, was obtained (British Geological Survey, 2002a). An extract from this map covering the Greater Walbrook catchment is shown as Figure 3-2. The standard texts that provide detailed background to, and descriptions of, the geology relating to the map are both published by the HMSO for the British Geological Survey (Ellison et al., 2004, 25-29) (Sumbler, 1996, 103). The geological data for the Greater Walbrook Valley and its influence on the Walbrook's groundwater catchment is drawn from the aforementioned texts and map.

3.3.1 Bedrock

Two types of clay constitute the bedrock underlying all of the superficial deposits of the Greater Walbrook Valley – London Clay and the Lambeth Group laid down in the Eocene Period of the Tertiary between 55 and 35 ma, both conformably and unconformably (Ellison et al., 2004, 25-29). However, it is London Clay which predominates over the whole area (Sumbler, 1996, 103), with the exception of a narrow band of alluvium running south southwest to north northeast centred on the River Walbrook itself, from the Thames at Cannon Street to the east side of Finsbury Circus.

3.3.2 Superficial deposits

The land surface of the Greater Walbrook Valley rises from the south towards the north in a series of terraces. During one of the last significant advances of the glaciers, about 470 ka, the Thames was forced to take a more southerly route in its west to east flow, displacing it to the south,



Basemap copyright – British Geological Survey

Walbrook topographic catchment boundary

Scale: 1 cm = 320 metres

Walbrook groundwater catchment boundary

Figure 3-2 Geology of the Greater Walbrook valley

from the Vale of St Albans to the general area of its present valley (Sumbler, 1996, 103). The terraces mark a progressive down-cutting by the Thames through Quaternary sedimentary deposits, mainly sand and gravel, during its period of migration southwards. The various geological elements that constitute the underlying strata of the London Basin are described in Appendix 3A.

The gravel terraces consist of superficial deposits that rest on the bedrock, principally the London Clay. North from the Thames, these gravel layers are progressively from older to younger and those of the Greater Walbrook Valley have been named Kempton Gravel, Taplow Gravel, Hackney Gravel, Finsbury Gravel and Boyn Hill Gravel (Ellison et al., 2004, 25-29). Only the lowest, oldest gravel deposits, the Kempton Park and Taplow Gravels, interface with the Lambeth Group of clays, the rest overly London Clay. Under the British Geological Service (BGS) classification system, all the gravel deposits are described as “sand and gravel, locally with lenses of silt, clay or peat”.

Urban Roman London within the town wall was founded either on Kempton Park and Taplow terrace gravels or on the Langley Silt that capped Ludgate Hill and Cornhill, itself overlying the Taplow gravel (British Geological Survey. 2002). The Kempton Park Gravel occupies a narrow, discontinuous strip of land closest to the Thames. The Taplow gravel extends only a short distance north of Finsbury Circus, except for the eastern stream of the Walbrook that is founded on Taplow gravel as far as Great Eastern Street. North of the Taplow gravel, the superficial deposits of the Walbrook valley are classified as the Hackney terrace gravels. These cover an extensive area until the ground rises more steeply. The Hackney gravels then give way to a small area of Finsbury gravel and then the Boyn Hill gravels that form the Islington ridge. The gravels are not thick and there are numerous points where the interface between gravel and the underlying clay intersect the surface and a spring point is formed.

Figure 3-3 is a schematic representation of the superficial deposits of the Greater Walbrook Valley.

Gravel with sand, of one nomenclature or another, together with silty clay, therefore constitute the predominating superficial deposits over the whole of the Greater Walbrook Valley with only three exceptions:

a. Two small slivers of land, with their long-axes approximately east-west centred over the Barbican where the gravel deposits have been eroded down to the London Clay bedrock.

b. Two areas of Langley Silt which straddle the western catchment boundary and which cap the gravel deposits beneath them – one a small area immediately to the north of the Barbican which overlies the Hackney Gravel and the other, a larger area forming the top of Ludgate Hill capped by St Paul's Cathedral, its basement founded on the Taplow Gravel below. Cornhill is also capped by Langley Silt.

c. A small, rectangular-shaped area near the northern extremity of the Greater Walbrook catchment, bounded by Sadler's Wells on the southwest side, the Angel, Islington and Upper Street to the northwest, St Peter's Street on the northeast and Danbury Street to the southeast. Here the Boyn Hill Gravel and the Hackney Gravel interface has been eroded to reveal the London Clay beneath. The area where the clay has been exposed has been significantly reduced by a deposit of Finsbury Gravel. This straddles the boundary between the catchments of the Walbrook and Fleet Rivers, its axis running northeast/southwest.

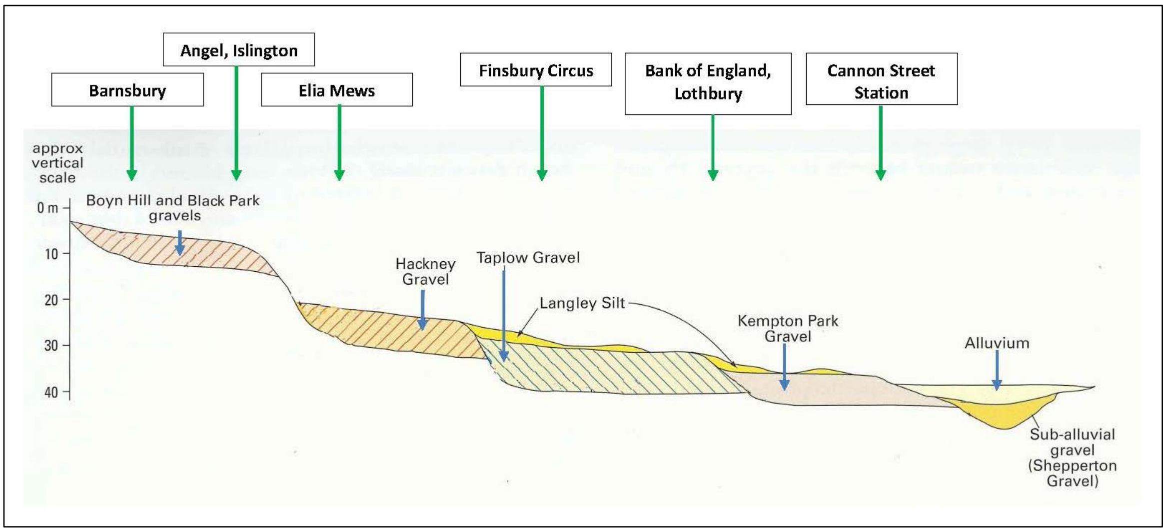


Figure 3-3 Schematic representation of the geology of the Greater Walbrook Valley

3.3.3 Groundwater catchment

There are gravel and other alluvial superficial deposits to the north of the Walbrook's topographic boundary, from the Angel, Islington as far as Highbury Corner. The interface between these gravels and the underlying London Clay has a very shallow inclination, not much more than 0.5°, in a northwest to southeast direction, i.e. in the direction of the Walbrook's topographic catchment (British Geological Survey, 2002b). When this area was undeveloped, as was the situation prior to and during the Roman period, rainfall would have permeated the superficial deposits and flowed along the gravel/clay interface towards and into the Walbrook topographic catchment. The groundwater catchment of the Walbrook therefore covers a significantly larger area than the topographic catchment. The base flow in the Walbrook is composed principally of groundwater fed to it from numerous springs within its catchment and therefore the base rate of flow is greater than would be the case were the groundwater catchment to have been coincident with the topographic catchment. The topographic and groundwater catchment boundaries and the course of the Walbrook are shown superimposed upon the geological map, together with the direction of movement of groundwater, in Figure 3-4.

As determined by the GIS analysis, the Greater Walbrook groundwater catchment covers an area of 240 ha (2.40 km^2) over and above that of the groundwater catchment.

3.3.4 Geology and the groundwater catchment - summary

The dominant geological characteristics and formation of the Greater Walbrook catchment as they affect its hydrology can therefore be summarised as follows:

i. The surface geology of the catchment is composed almost entirely of alluvial deposits dating from the time that the valley of the Thames covered a greater area and flowed on a north-easterly course, through St Albans to the north, rather than its present-day course further south and in a generally easterly direction.

ii. Superficial deposits covering the area are comprised of:
   - Gravel and sand bound by interstitial clay – 353 ha (approximately 84% of the area)
   - Langley Silt, which covers nearly 25 ha (6% approx.)
   - London Clay which outcrops over a further 22 ha (5% approx.)
   - Alluvium (5% approx.)

iii. The Thames cut its way down through the sand and gravel because of a series of exogenic morphological conditions. The gravel terraces were created in stages by different combinations of climate and vertical movement and positioning of the land surface relative to sea levels (Ellison et al., 2004, 25-29). One dominant factor was the raising of the land surface as the burden of glacial ice, which had been up to 200 metres thick, was removed through

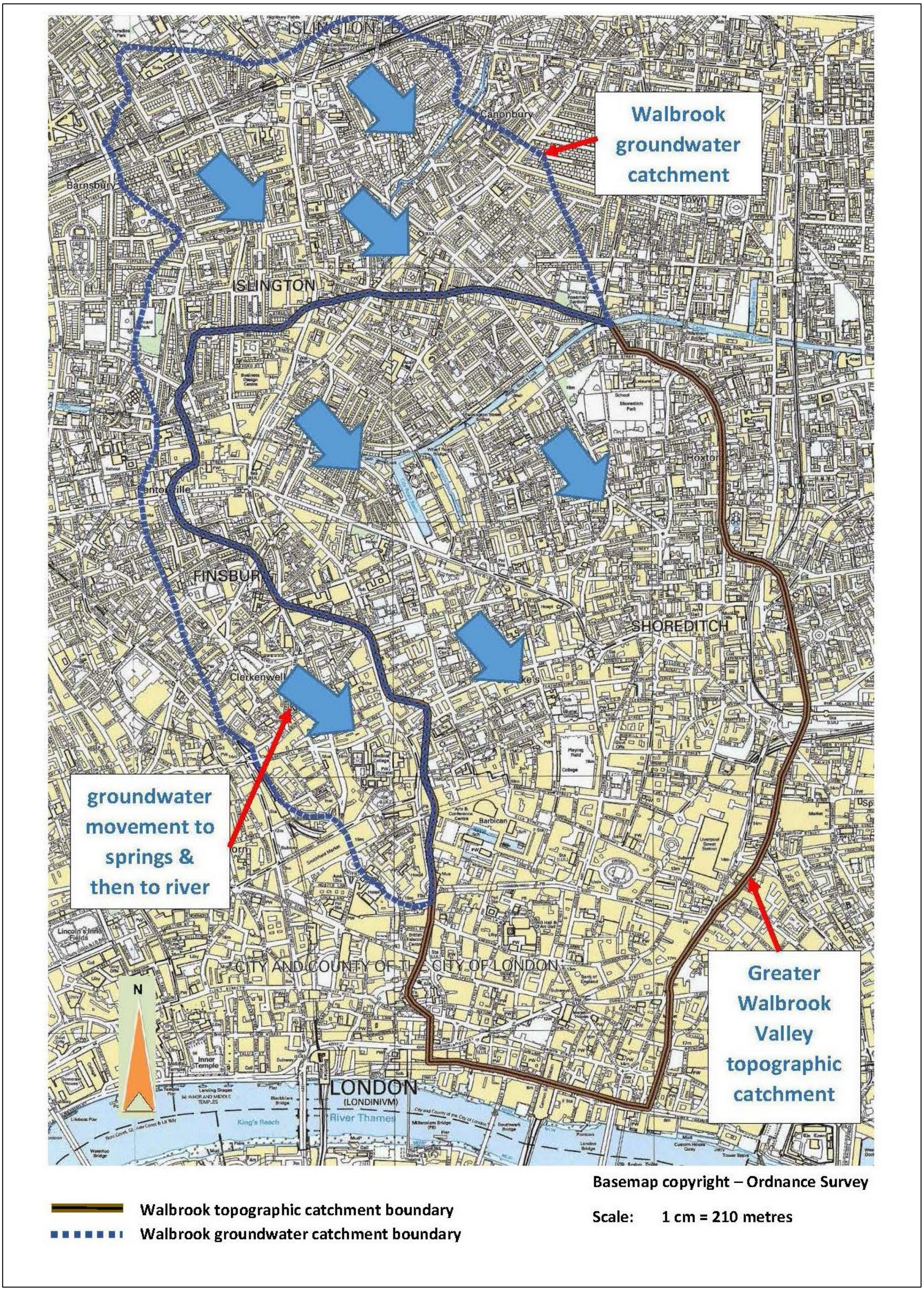


Figure 3-4 Topographic and groundwater catchments

melting. This led to the gravel and sand forming a distinct series of terraces as the Thames eroded to reveal their respective interfaces with the underlying London Clay at their "toes".

iv. From research of the physical topography that has defined the Greater Walbrook topographic catchment, it occupied a total land area of 470 ha (4.7 km²).

v. The groundwater catchment area for the Walbrook extended beyond that of the topographic catchment towards the north and northwest of the Angel, Islington, and has been measured at an additional area of 240 ha (2.4 km²).

vi. The total extent of the groundwater catchment with respect to its contributing base flow to the River Walbrook was therefore 711 ha (7.11 km²).

vii. Apart from a narrow littoral band of alluvium along the north bank of the Thames and the bed of the Walbrook watercourse for a distance of about 1 km from the Thames, the Walbrook catchment is underlain by a bedrock of London Clay. The narrow band of alluvium occupies an area of 21 ha (approximately 5% of the catchment area).

viii. Virtually all of the base flow in the Walbrook, that is flow outside of periods of rainfall, would have been generated from the issue of many springs or seepages from the ground where the permeable gravel and sand terraces interfaced with impermeable underlying clay. These springs and seepages would, over time, have created a multiplicity of natural runnels, small ditches and brooks feeding the main river channel along its whole length. Surface water runoff feeding the river flows as a result of rainfall would have arrived at the Walbrook through this same fine network of small channels.

The geological situation of the Greater Walbrook valley is depicted and summarised in Figure 3-5.

3.4 The Roman Walbrook – Streams and Principal Tributaries

3.4.1 The Walbrook stream prior to this research

The Stukeley map, Section 1.1.3, Figure 1-2, has been the basis of all later maps through to the 20th century when a map – again limited to the same stretches of the river - was produced based upon the results of archaeological investigations (Ordnance Survey, 1981). The latest version of this map is currently used as the basis for most reports and publications (Museum of London Archaeology, 2011).

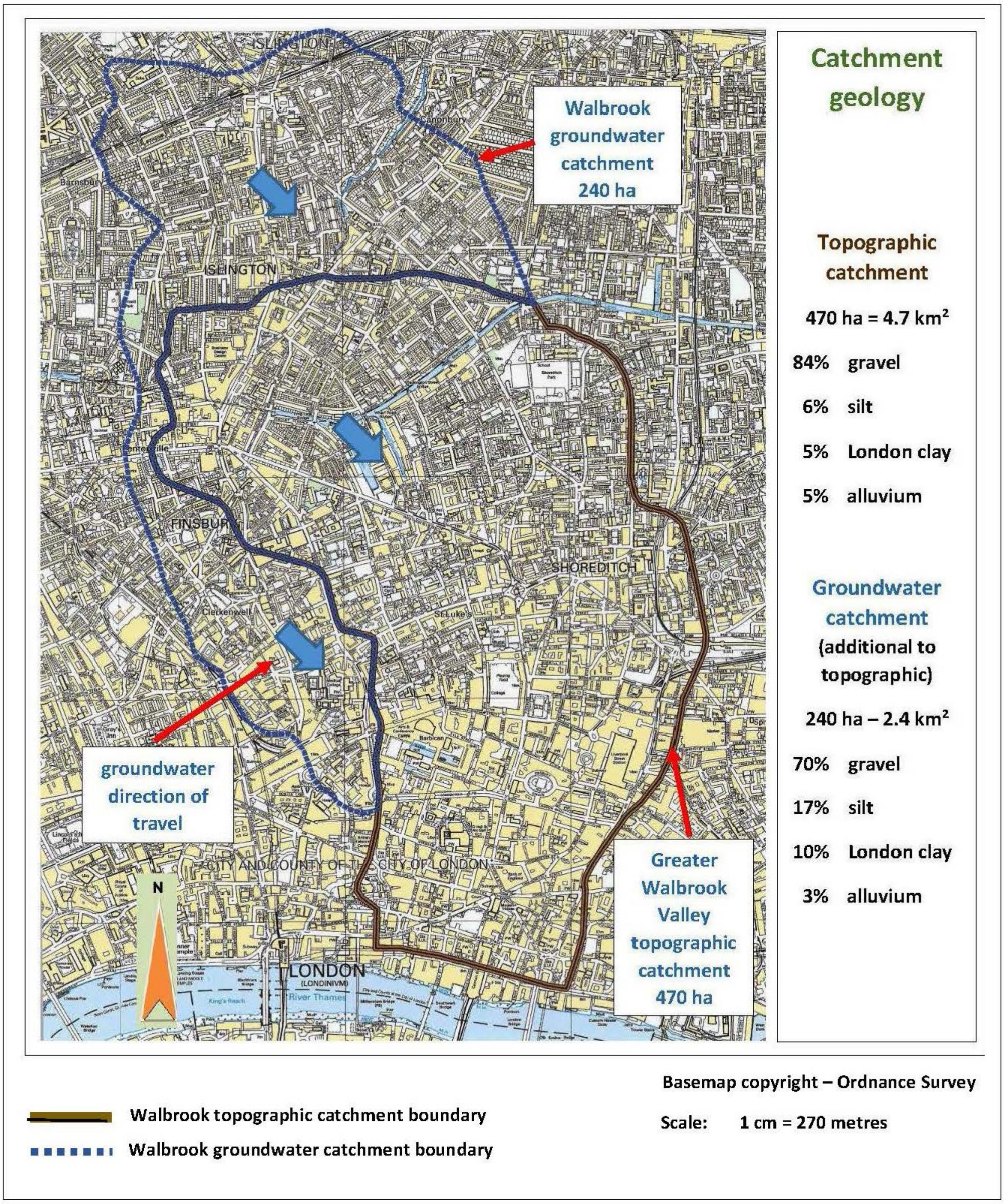


Figure 3-5 Greater Walbrook Valley – a summary of its geological situation

A modern map of the Walbrook, as known prior to this research, together with its related notional catchment, is shown in Figure 3-5. In Sections 3.2 and 3.3.3, it has been demonstrated how the topographic and groundwater catchments are considerably larger than the notional catchment shown in Figure 3-5. However, a hydrological analysis of the Walbrook must be based upon the full extent of its main streams and tributaries. It has been proposed that the Walbrook had a previously unknown, and so unmapped, western stream (Myers, 2011). The content of this section describes how this research project has mapped the full extent of the ancient Walbrook river system, more than doubling the length of known streams, based upon maps, literature, topographic and archaeological evidence, literature sources and the professional water engineering experience of the researcher.

The following sections respond to three research questions:

1. *In addition to the known eastern stream, did the River Walbrook have a second source stream, hitherto unknown, which drained the western areas of its catchment?*
2. *If a western stream existed, were there sources of water that would have created a perennial flow within a recognisable watercourse and why was this stream never shown on maps?*
3. *If a western stream existed, where was the point of confluence of the eastern and western streams?*

Details of the evidence responding to these three questions have been presented in Annex 3B. The following sections summarise that evidence:

- Topographic evidence for a western stream as far as Old Street (Section 3.4.2)
- Archaeological evidence for the western stream downstream of Old Street (Section 3.4.3)
- Evidence drawn from map and literature sources (Section 3.4.4)

Having presented the evidence for a western stream of the Walbrook, alternative scenarios for the point of confluence of the western and eastern streams are presented and discussed (Section 3.4.5), as is archaeological evidence for the route of the urban Walbrook (Section 3.4.6). The full extent of the ancient Walbrook river system is shown on a map (Section 3.4.7).

Figure 3-6 River Walbrook main stream and tributaries as known prior to this research and its notional catchment

3.4.2 Topographic evidence for a western stream as far as Old Street

Much of the City of London has undergone re-sculpting of its physical topography and the original contours of the land have long ago disappeared beneath centuries of fill. This is not the case for the Greater Walbrook catchment outside the Roman wall, areas that were rapidly developed from the late 17th century through the 19th century. With respect to the Walbrook catchment, the contours of the land north of Old Street are similar to their natural state and it is possible to discern natural drainage patterns.

Above Old Street, a course carved out by a western Walbrook stream is clearly visible today. There is an almost continuous depression in the ground surface from the area of the former White Conduit House, at Barnsbury above the Angel, Islington, through to the junction of the City Road with Old Street. The only break in the depression is where the route taken by the river crosses the City Road Basin of the Regent's Canal, completed in 1820, between Garden Row and the Eagle public house on the corner of Shepherdess Walk and the City Road.

The thalweg followed by the western stream can be traced from Cloudeseley Square along Cloudesley Street, across Tolpuddle Street after which it followed the curve of Liverpool Road and across Upper Street at the Angel, Islington. From here, it continued south-eastwards crossing beneath the channel of the New River, the latter being sandwiched between Duncan Terrace and Colebrooke Row, and down Elia Mews. Downstream, it meandered across the flatter land later occupied by the City Road Basin of the Regent's Canal passing the Eagle pub on Shepherdess Walk bending gently around the curve of City Road to Old Street.

The route taken by the river is most clearly demonstrated through Elia Mews, immediately south of Colebrooke Row. Here the land falls with a relatively steep gradient, paralleling the line and fall of City Road to its west. However, its most striking characteristic is its pronounced V-shaped cross-section, evidence that it was carved out by a fast-flowing stream.

At the lower end of the City Road incline immediately before it crosses Old Street and continues in to the City, the western and eastern streams are not far from each other. Originally, it was thought that the two streams joined at Old Street and continued south along the known course of the eastern stream. However, a ridge of high ground, 1.5m to 1.8m high, runs north to south between Vestry

Street East and East Street immediately north of the City Road/Old Street intersection. If this ridge is natural, it would have acted as a barrier to the passage of the western stream, directing it southwards and would have kept the western and eastern streams separate.

City Road is a relatively modern construction and is not shown on John Rocque's 1746 map (Rocque, 1746 & 1769). Streets and roads frequently have their origins as paths that follow along the banks of ditches and streams. The long curve taken by City Road immediately before it crosses Old Street at St Agnes le Clere Circle ("Silicon Roundabout") could indicate the route taken by the former western stream as it continued to follow the later City Road in the direction of Moorfields and Moorgate. An ancient description hints at two main drainage ditches forming the eastern and western limits of the Moorfields area (Ellis, 1798, 83; 156-183; 219; 225). It is therefore proposed that the westerly branch of the Walbrook, arriving from the Angel, Islington cut a separate course to the City, turning south at Old Street and through the marsh at Moorfields.

The land from Old Street southwards into the City has undergone considerable alteration through dumping to raise it and any natural thalweg has been subsumed under a depth of overburden. To determine whether a western channel existed through the marsh, it was considered prudent to investigate whether there was any archaeological evidence of a western channel south of Old Street.

3.4.3 Archaeological evidence for the western stream downstream of Old Street

Archaeological evidence of a 7 metre-wide channel, pre-dating the early medieval period, passing from north to south down the west side of Finsbury Square and Finsbury Pavement has been found in the course of the research (Figure 3-8, Section 3.4.6). Evidence of this wide, ancient and natural channel has been uncovered in three archaeological investigations to the west side of Finsbury Square and Finsbury Pavement along the southern extension of City Road, viz. VER90 – Veritas House, 119-125 Finsbury Pavement, EC2; FIS96 – 127-139 Finsbury Pavement, EC2; FBY01 – 1-2 Finsbury Square, EC2.

London's gravel and chalk streams only achieve a width of 7 metres several kilometres from their main source (Myers and Barton, 2016). Although there were some springs at Old Street, it is most unlikely that, on their own account, they would have cut a wide channel. A wide channel is indicative of the need to carry a significant quantity of storm runoff, produced by a larger catchment than that of the immediate locality. It is concluded that the channels found are almost certainly those of a substantial, western Walbrook stream.

Other archaeological evidence is presented in Appendix 3B, relating to the discovery of a channel crossing between Moorgate and Finsbury Circus, found in the early 20th century (Lambert, 1921, 55-112), and a channel across Finsbury Circus (ELD88 and BDC03). A recent report on the upper (urban) RWV cemetery (Harward et al., 2015) and the implications of a catastrophic breach in the eastern embankment of the Walbrook stream in Blomfield Street opposite the eastern end of Finsbury Circus, further discussed in Section 3.4.5, have also added to evidence to support the former existence of a western stream.

3.4.4 Evidence drawn from map and literature sources

According to a historian of late Elizabethan London (Stow, 1603 (reprinted 1908), 13-14), the Walbrook was completely covered over well before the meticulous recording of his perambulations around the city

> *"This water course hauing diuerse Bridges, was afterwards vaulted ouer with bricke, and passed leuell with the Streetes and Lanes where through it passed, and since that also houses haue beene builded thereon, so that the course of the Walbroke is now hidden vnder grovnd, and thereby hardly knowne."* (Stow, 1603 (reprinted 1908), 13-14): 14).

Stow details the responsibilities of the various wards through which the river passed for maintaining the watercourse clean and clear of obstructions. However, although these were set down in the 14th century, the wards did not carry out their duties. The river had become a means of carrying away the sewage produced by the hundreds of privies that discharged directly to it as it passed through the city. As is common in most developing cities, this abuse of the river became its accepted purpose and it was covered over as a public foul sewer.

The historical evidence for a hitherto unknown western stream with its origins being the springs and ponds above the Angel, Islington is detailed in Appendix 3B which draws upon historical and modern publications (Stow, 1603 (reprinted 1908), 13-14) (Ellis, 1798, 83; 156-183; 219; 225) (Tomlins, 1858)

(Thornbury, 1878) (Ward, 2003, 14-15) (Faulkner, 2005, 32) (Porter, 2012) and maps (Charterhouse Priory, 1430) (Strype, 1720) (Rocque, 1746 & 1769) (Clerkenwell Parish, 1788) (Islington Parish, 1806). The evidence for this western stream is substantial and is only summarised here. For details and sources of the supporting evidence refer to Appendix 3B.

At the beginning of the 15th century, the base flow in the Walbrook was substantially reduced by a series of events. In 1410, the monks at St Bartholomews in Smithfields required a supply of fresh water to replace their on-site wells which drew from a plague burial site (Tomlins, 1858) (St John Hope, 1902). They constructed a gravity pipeline from their priory at Canonbury to Smithfields and diverted the copious springs of that area for use at their inner city premises. These springs were the headwaters that fed the Walbrook's eastern stream that passed through Shoreditch and Hoxton into the city. By cutting off the source of base flow to the eastern stream, flow in the river along the lower eastern boundary of the Moorfields marsh and into the City would have been reduced. However, this was only the first of the events to reduce the Walbrook's base flow.

In 1370, St Bartholomew's had sold part of their land at Smithfields to the Carthusians upon which the latter established their Charterhouse (Porter, 2012: private communication). The land being a former Black Death plague burial ground, the monks decided that they would also seek a fresh source of water to replace that abstracted from wells on their property. Emulating their neighbours, and with Royal Assent (Tomlins, 1858), in 1430 they constructed a gravity pipeline from Barnsbury above the Angel, Islington to their premises at Smithfields and diverted many of the springs, wells and ponds of the area into it (extracts from the original 15th C construction plan are provided in Annex 3B). In 1456, requiring further water, the remaining Walbrook headwater sources were diverted into the pipeline (St John Hope, 1902). Whether knowingly or unwittingly, Charterhouse had diverted the headwaters of a western tributary of the Walbrook into the Fleet catchment. In the middle of the 17th century, a conduit house was constructed at the gathering point for those headwaters, called the White Conduit, which became the site of a famous spa. The original drawings relating to the construction of the 15th century pipeline are kept archived today at Charterhouse and clearly show the many points of collection and diversion of the Walbrook's source waters.

The diversion of the two sets of headwaters, one set of which had fed the eastern stream and the other the western stream, significantly reduced flow in the Walbrook as far as Old Street/Great

Eastern Street. As a result of the reduction in its base flow, Moorfields began to dry out from the first decades of the 15th century, and the Mayor was able for the first time to construct a new gate in the wall, Moorgate, and construct paths to Islington. Indeed by the middle of the 16th century, the unknown artist of the Copperplate Map of c 1559 (Copperplate Map (Unattributed), c1559) showed washerwomen drying clothes laid out on the grounds of Moorfields. This land, formerly a perennial marsh, dried out due to substantially reduced flow in the Walbrook and the assistance of three mills that pumped water arriving at the moor from springs at Old Street/City Road, Figure 3-7.

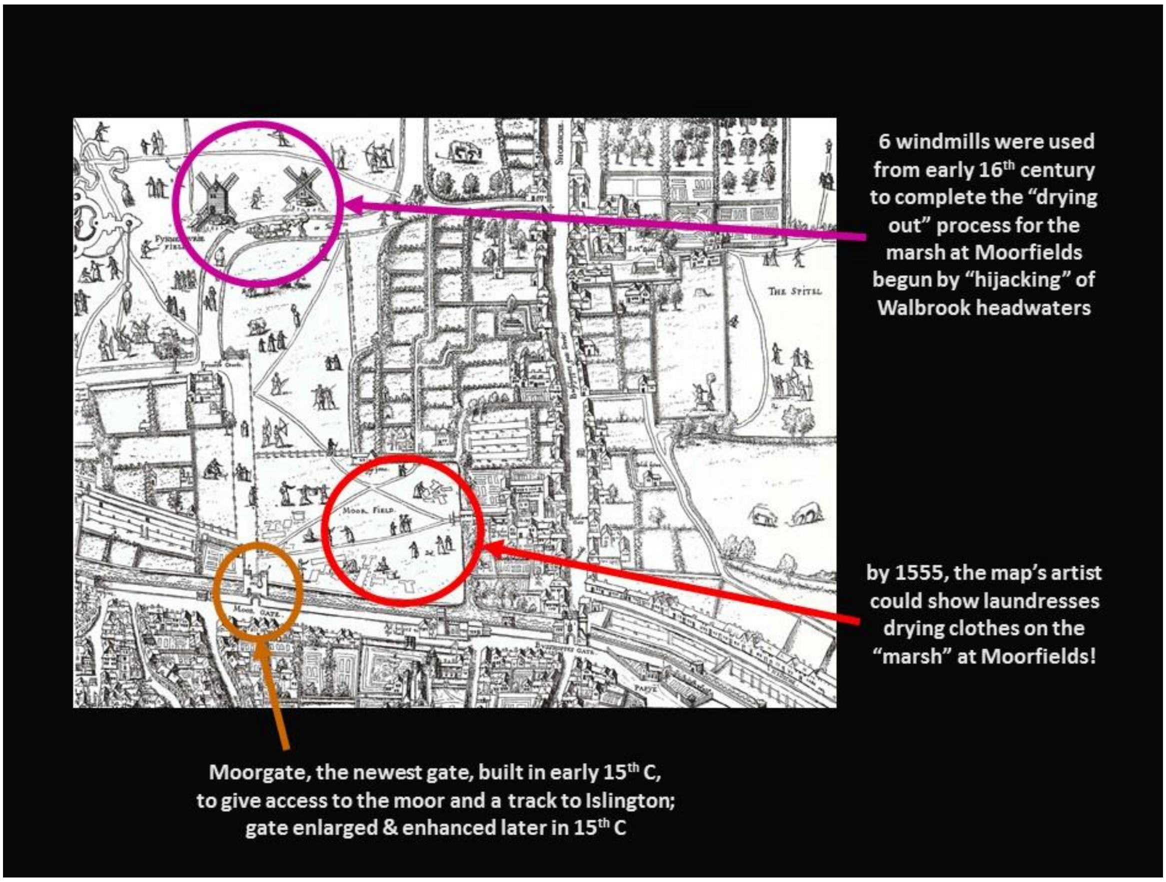


Figure 3-7 Extract from the "Copperplate Map" c. 1555-8 (City of London, London Metropolitan Archives)

As it had dried up, the western stream of the Walbrook was gradually erased from public memory from the middle of the 15th century. Accurate mapping of London only began in the 17th century, and the erstwhile western stream, from above the Angel, Islington to downstream of Old Street, was never shown on maps. Its possible existence was first proposed in 2009 and a possible course for the western

Walbrook stream was mapped (Myers, 2011) (Myers and Barton, 2016: 36-37). This publication showed the western stream joining the eastern stream, coming from Shoreditch and Hoxton, just east of the City Road/Old Street roundabout. However, the current research, whilst providing evidence showing the existence of the western stream, has demonstrated how the two streams remained separate as far south as Moorgate. The point of confluence of western and eastern streams is discussed in Section 3.4.5.

It is proposed that the foregoing map and literature sources provide evidence that demonstrates that:

- there were copious springs and ponds at Barnsbury, above the Angel, Islington, sufficient to provide water for a perennial stream, designated in this research as the western Walbrook stream; and
- the probable reason this stream was never shown on maps was that, in 1431, Charterhouse diverted source springs and ponds out of the Walbrook catchment to their monastery in the Fleet catchment; as a consequence, the western stream no longer flowed and had disappeared by the time that accurate maps were first made of the area in the mid-18th century.

3.4.5 Point of confluence of the western and eastern channels

Archaeological evidence supports a course taken by the western Walbrook stream downstream of Old Street continuing to follow the line of City Road extension south towards Moorgate. However, the point of confluence of the western and eastern streams is less clear. On an east-west line immediately north of Finsbury Circus, the western stream is oriented southwards along Finsbury Pavement and the eastern stream is also oriented southwards across the Broadgate Development towards Blomfield Street. The two streams were approximately 250 metres apart at this point. A short tributary drained the Barbican area from the western catchment boundary towards the east-southeast in the direction of Moorgate. There are three candidate options for the point of confluence of the eastern and western streams, as illustrated on Figure 3-8, viz.

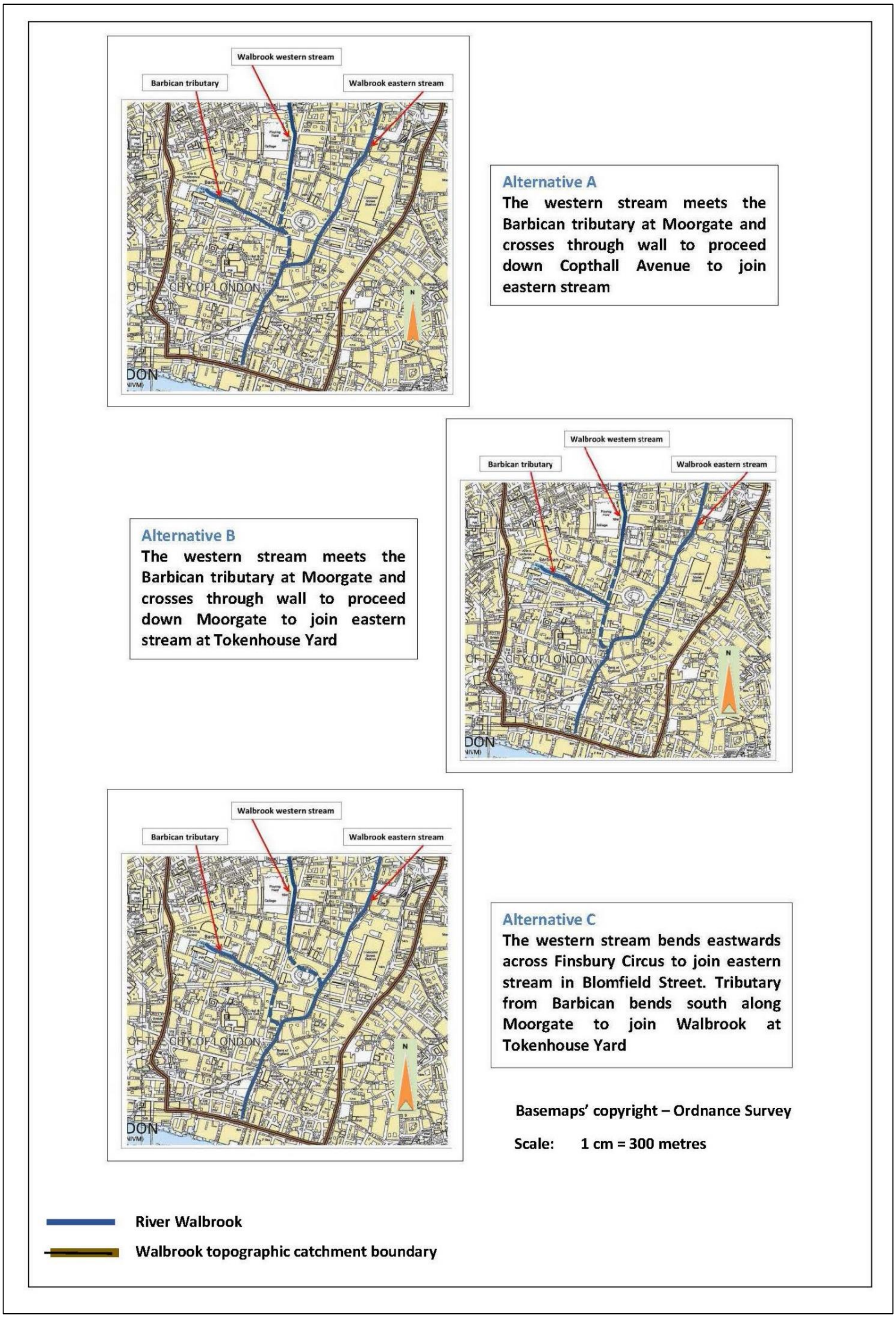


Figure 3-8 Alternative scenarios for the point of confluence of the western and eastern streams of the Walbrook

- **Alternative A – The Copthall Avenue Option**

  The western stream would have met the Barbican tributary at Moorgate and crossed the line of the Roman wall after which it would have proceeded along the line of Copthall Avenue to join the eastern stream arriving from the east along the southern boundary of Draper's Gardens. Two culverts have been found through the foundations of the wall that could have conveyed the western stream, one just west of Copthall Avenue (RHCM. 1928:87) and the other a short distance west opposite 48 London Wall (LWL87).

- **Alternative B – The Tokenhouse Yard Option**

  The western stream would have met the Barbican tributary at Moorgate and crossed through wall using one or other of the culverts described for Alternative A. The western stream would then have proceeded southwards down Moorgate, turning eastwards to join eastern stream at Tokenhouse Yard. The MGX06/MOQ10 investigation uncovered a tributary to the Walbrook arriving from the west.

- **Alternative C – The Blomfield Street Option**

  The western stream would have turned eastwards across Finsbury Circus to join the eastern stream in Blomfield Street about 50 metres from the eventual Roman wall. The combined eastern and western streams would then have proceeded southwards traversing the foundations of the wall in a culvert discovered by C Roach Smith in 1841 (RHCM. 1928: 87). The tributary from the Barbican would have remained separate from the western stream, turned south to pass through the wall as in the other two options and proceeded along Moorgate to join the combined Walbrook stream at Tokenhouse Yard.

Alternative A is shown on a current map of Roman London (Museum of London Archaeology, 2011) and represents a view commonly held, prior to the current research and the proposed existence of a western stream, for the route taken by the Barbican tributary through to its confluence with the eastern stream. However, palaeo-stratigraphic work, reported in Chapter 6 of the main text, has shown there to be a depression in the general ground surface in the area that included Copthall Avenue and it is unlikely that the western stream, which would have carried very substantial storm flows, would have passed through this area without it becoming a major, perennial lake.

The revetted west bank of a stream has been found along Moorgate (MGT87), of an unknown width, with Roman industrial premises close to the stream. On the 8 – 10 Moorgate site (MGX06/MOQ10), the channel of a fast-flowing stream was found entering the site from the Copthall Avenue area and flowing south- southwest, almost parallel with Tokenhouse Yard. A tributary was also discovered entering the northwest corner of the excavation from the direction of Moorgate. This tributary was almost certainly an extension of the stream passing the MGT87 site, a short distance to the north along Moorgate.

However, large amounts of glass waste had been dumped over the revetment at the MGT87 site and remained on the bank and in its southeast corner, the revetted channel executed a very tight 90° turn in an easterly direction. If the stream had carried the considerable storm flows as frequently as estimated in Chapter 5 of the main text, it is probable that these large amounts of dumped material would have been swept away downstream. That they remained are an indication that flows along the channel were modest – and more likely to have been related to the short Barbican tributary. It is also unlikely that a stream with a significant flow could have been safely made to execute the tight bend that was found.

In Alternative C, the southbound western stream would have executed a bend towards the east and crossed Finsbury Circus along its northern side. This is supported by Lambert's finding of a stream at the point of the initial bend, cited in Section 3.4.3, which was found with a northwest to southeast alignment. Also in that section, the finding of a channel carrying flows sufficient to wash out graves from the Walbrook cemetery and convey skulls downstream is further evidence that this could be the western stream. However, the most substantial evidence, in support of Alternative C, relates to the findings of the BLM87 investigation. It is difficult to envisage another cause of the breach in the east embankment of the Walbrook's eastern stream other than the force of a catastrophic flood issuing from the stream passing across the north side of Finsbury Circus and impacting the bank opposite.

A fourth alternative is also possible which would combine Alternative A and Alternative C. In this option, the western and eastern streams would have remained separate through to the construction of the wall. To maximise the throttling effect of culverting the river through the wall and thereby reduce the threat of flooding through the urban area to a minimum, the western stream may have been diverted across Finsbury Circus, upstream of the wall, to join with the flow of the eastern stream.

Although further evidence may be found in the future to support a different view, it would appear that the most plausible point of confluence of the western and eastern streams with the current state of knowledge was therefore Blomfield Street and Alternative C has therefore been adopted for the purposes of this current research.

3.4.6 Archaeological evidence for the urban Roman Walbrook

The route taken by the Walbrook downstream of the confluence of the western and eastern streams in Blomfield Street and the passage of the combined stream through the wall through to the Thames at Cannon Street is well documented in numerous publications, supported by the findings of archaeological investigations. Figure 3-9 shows the location of the archaeological investigations, the reports of which have been consulted in the course of this research and which have noted finding the channel of the Walbrook or one of its major tributaries. These are further detailed in Appendix 3B. In addition to these sources, an early publication, summarising findings of archaeological observations from 1906 to 1912 (Norman and Reader, 1912, 311-317), a tributary has been shown to rise north of the Guildhall. It was oriented towards the southeast and, having been viewed again passing through a building site at the most southerly end of Moorgate, appearing to cross Lothbury and join with the Walbrook in Princes Street. Given that the town was founded on gravel with clay not far beneath the surface, there would have been numerous springs and small streams within the urban valley feeding the Walbrook.

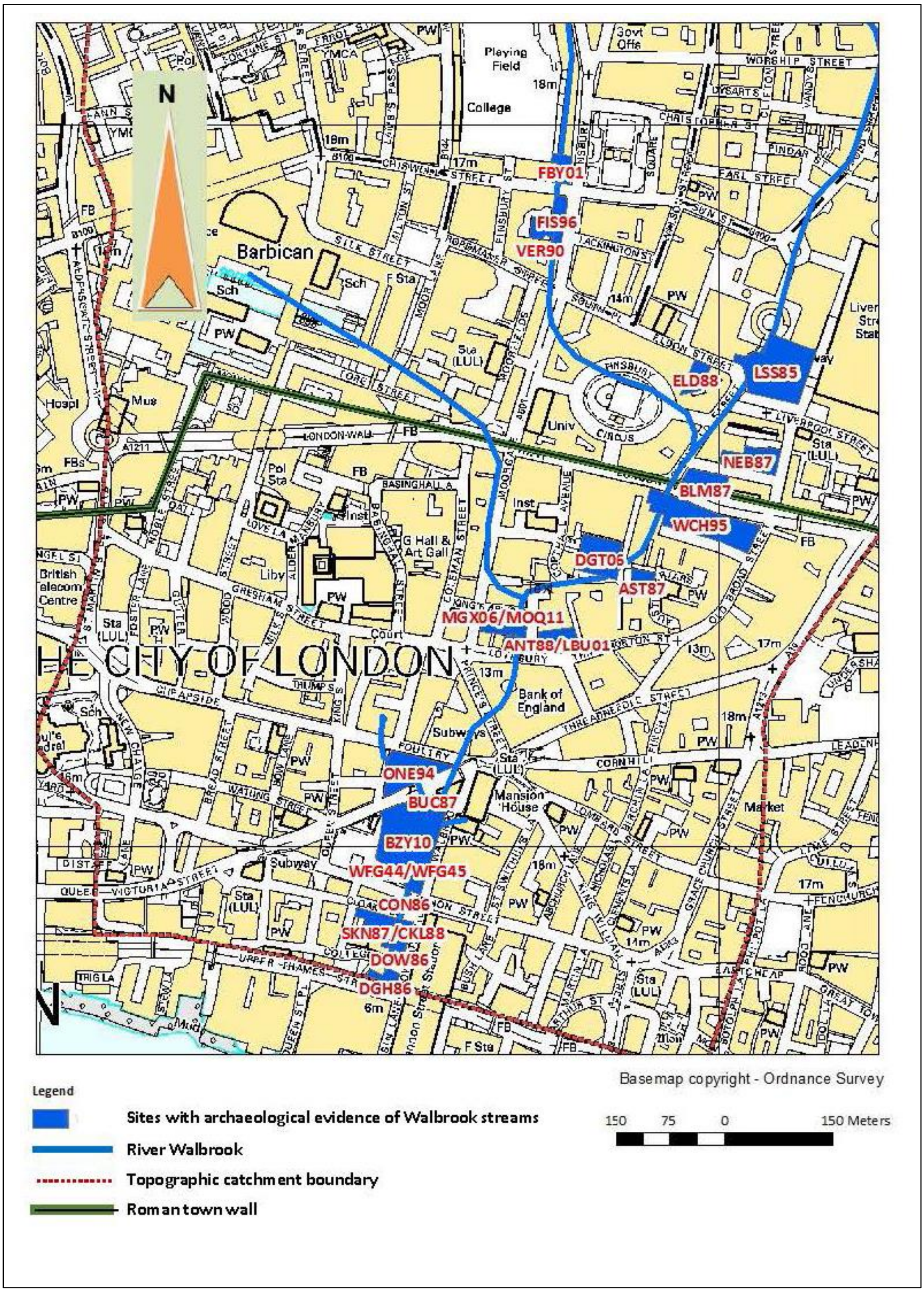


Figure 3-9 Archaeological sites with evidence of Walbrook streams or principal tributaries consulted in the course of the research

3.4.7 The Roman Walbrook streams mapped

Arising out of the foregoing, the Walbrook river system is shown on Figure 3-10. The routes of the Walbrook streams have been plotted onto a digital map using the spatial analysis software ArcGIS 10, together with their physical and groundwater catchments and sub-catchments. The lengths of the constituent principal streams are shown in Table 3-1. The areas of their sub-catchments as well as the overall catchment have been computed by the ArcGIS software and have been reported in Section 3.3.

Table 3-1 Lengths of the three constituent main stream watercourses

Main stream watercourses	Length (m)
Western stream - Barnsbury to Blomfield Street	3,260
Eastern stream – Hoxton to Blomfield Street	2,040
Combined stream Blomfield Street – Upper Thames Street	890

3.4.8 Sub-divisions of the urban Roman Walbrook

In the 1980s, DUA personnel were referring to urban Roman London as being divided between three areas in their reports and publications. The boundaries of these areas, running west-northwest to east-southeast across the city were never formally defined but were in common use and appear to have referred to the following geographic limits:

- Lower Walbrook - from the Thames at Upper Thames Street to Cannon Street
- Middle Walbrook - Cannon Street to about 20 metres north of Telegraph Street
- Upper Walbrook - about 20 metres north of Telegraph Street to Finsbury Circus

These three divisions give the impression that the Walbrook catchment was confined to an area not far from the limits of urban Roman London. This nomenclature has been perpetuated in various publications and in the reports of many archaeological investigations and are in current use today. They remain a useful classification of the Walbrook Valley, insofar as it is understood to refer only to urban Roman London. They have become deeply ingrained into general usage by authoritative publications (Maloney and De Moulins, 1990) (Wilmott, 1991) (Hill and Rowsome, 2011).

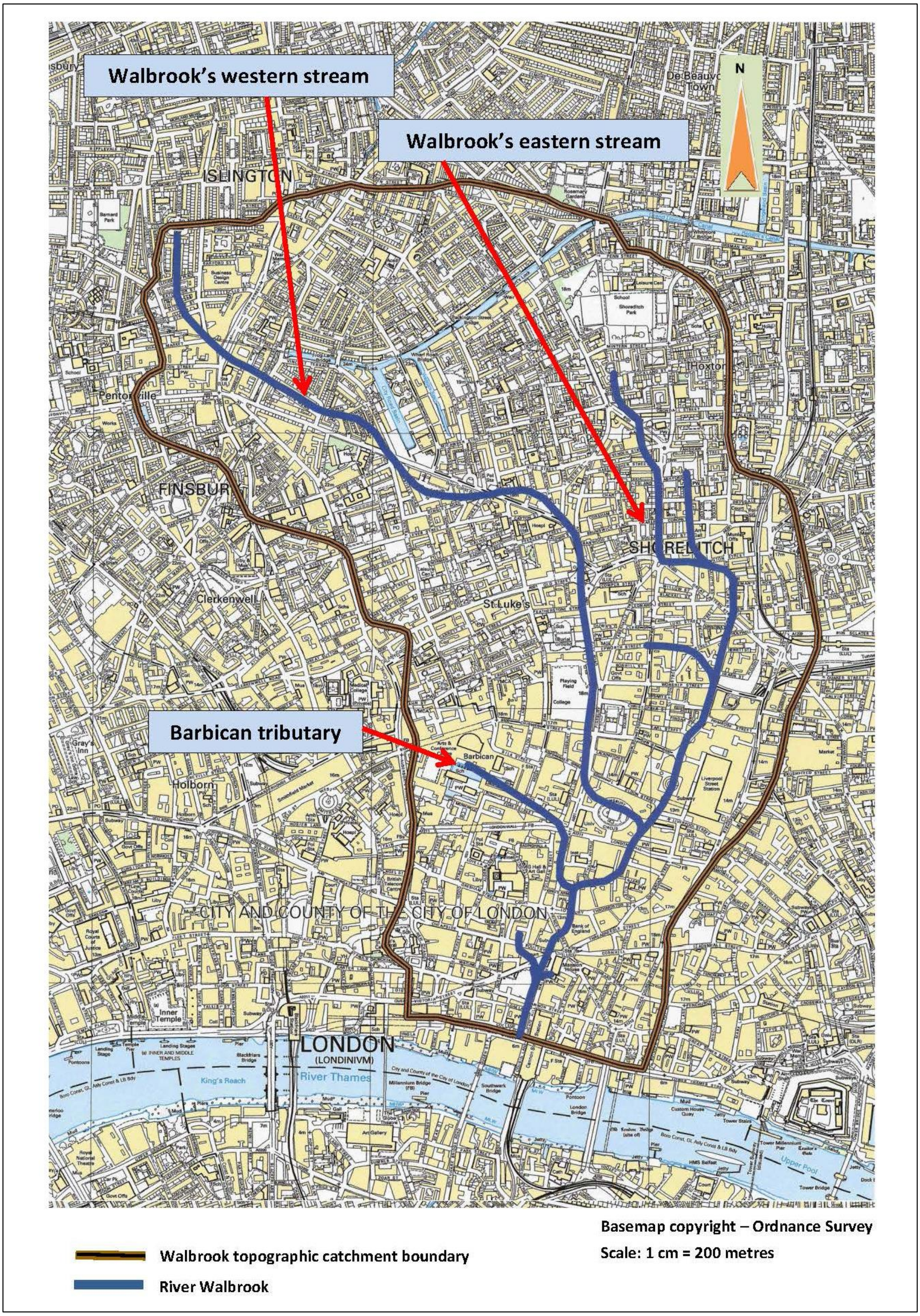


Figure 3-10 The Roman Walbrook river system

However, whilst accepting the same basic nomenclature for urban Roman London, this research has defined five zones, A to E, based upon the different bed slopes for the Walbrook as determined by the palaeo-archaeological element of the research and reported in Chapter 4, Section 4.5.2 and Figure 4-19. These are shown on Figure 3-11, URWV being an acronym for “Urban Roman Walbrook Valley”:

- Zone A - Lower URWV – estuarine Upper Thames St to Cannon Street
- Zone B – Lower URWV – non-estuarine Cannon Street to Cheapside/Lombard Street
- Zone C – Middle URWV – south Cheapside/Lombard Street to Lothbury
- Zone D – Middle URWV – north Lothbury to north side of Finsbury Circus
- Zone E – Upper URWV north side of Finsbury Circus to Old Street

3.4.9 Conclusions – Roman Walbrook – its streams and principal tributaries

The current research has established that:

1. the catchment of the Walbrook extended north to the Islington ridge between Barnsbury, above the Angel, Islington, northeast to Canonbury, a topographic catchment more than double the area than previously thought to be the case;
2. the area of the White Conduit House and its immediate surrounds to its north and east were the site of numerous springs, ponds and wells, as evidenced in map and literature references and supported by 15th C construction plans; these springs and ponds would have constituted the headwaters of a hitherto unknown western source stream of the River Walbrook to supplement that of the known eastern stream;
3. a course carved out by the western stream is clearly visible today by a continuous depression in the surface of the ground, with only a short break at the crossing of the City Road Basin of the Regent’s Canal, from the area of White Conduit House through to the junction of the City Road with Old Street. This depression is particularly marked through Elia Mews, south of Colebrooke Row, below the Angel;
4. as demonstrated by archaeological evidence compiled in the course of the research, a wide, ancient and natural channel existed in the Roman period from Finsbury Square, along City Road at Moorgate, which crosses the north side of Finsbury Circus to Blomfield Street. This channel is almost certainly the continuation of the western stream of the Walbrook;

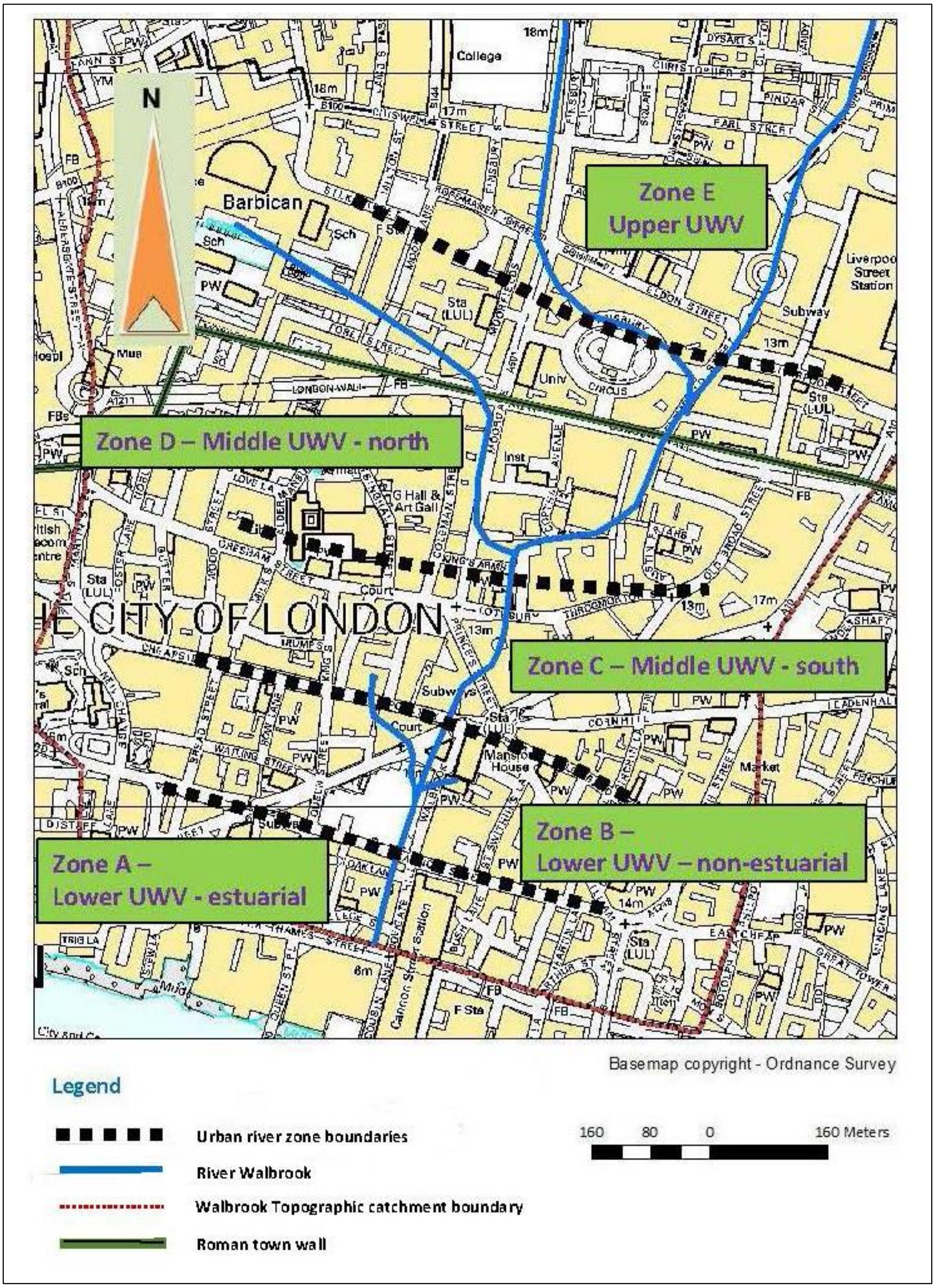


Figure 3-11 Geographic zoning of the URWV

5. the reason that the western stream has never been previously mapped and remained unrecognised is primarily due to the progressive diversion of its headwaters into the Fleet catchment by Charterhouse in 1431 and 1456 in order to provide a source of clean water for their use. From this time, there would have been no base flow in the Walbrook from White Conduit House through to the City Road/Old Street intersection – leaving that section of the Walbrook as a dry ditch except for times of rainfall sufficient to cause significant runoff. Reduced to a ditch, the former course of the Walbrook would no longer have been recognisable as a river channel and, over time, the stream passed from public memory;
6. this topographic, map, literature and archaeological evidence combines to confirm the existence of the western stream of the Walbrook. The principal points of this evidence are summarised on Figure 3-12;
7. three candidate options have been identified as being the potential point of confluence of the western and eastern streams but the most probable is in Blomfield Street directly opposite the eastern extremity of Finsbury Circus;
8. archaeological evidence has been presented for the route taken by the combined Walbrook stream through urban Roman London. The Walbrook river system as identified by the current research has been shown on Figure 3-10;
9. the marsh at Moorfields began to dry out through the 15th century, a process completed by the building of windmills on Moorfields to drain the land completely in the first half of the 16th century; and
10. the Walbrook, in its natural state and through the period of settlement and occupation by the Romans, therefore had two principal perennial sources:
    - the springs and ponds at the White Conduit House area, on high ground above the Angel, Islington, at an elevation of about 40 metres AOD; and
    - springs and wells in Canonbury, Shoreditch, the principal of these being Holywell in Hoxton on the eastern side of Curtain Road, at an elevation of 24 to 25 metres AOD

Along its full length, there would have been other secondary sources, some seasonal and some dependent upon heavy and persistent rainfall, e.g.

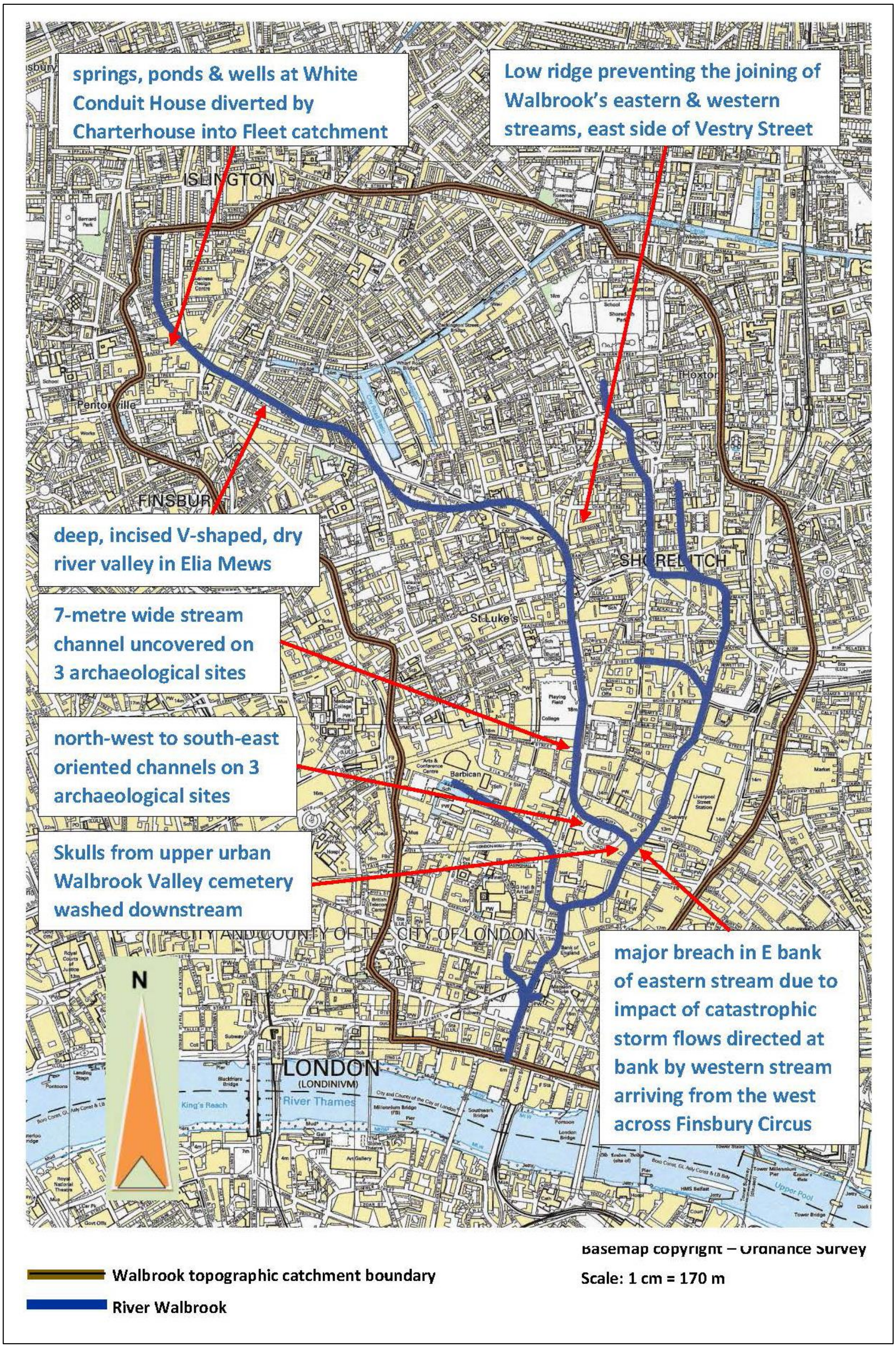


Figure 3-12 **Summary of principal evidence supporting the existence and course of a western Walbrook stream**

- the springs around the St Agnes le Clere well t the City Road/Old Street intersection;
- other point sources, springs and wells (probably systemised springs) – giving rise to many short tributaries, some recorded as a result of excavations in the City and probably a greater number as yet undiscovered, and
- diffuse sources, less-defined spring lines, “leaking groundwater into ditches which, sooner or later, reached the course of the Walbrook or its tributaries.

Chapter 4

Palaeo-stratigraphy of the URWV

4.1 Objectives

The whole of the Walbrook valley south of the Roman town wall has undergone a significant process of urban land management as successive developments added ever-increasing cover to the Roman ground surfaces. So much material has accumulated that, in the lower reaches of the river, present land surfaces can be as much as 9 metres above the bed of the Walbrook of the Roman period. The physical topography of urban Roman London was therefore quite different to that of the same area of the City of London today, as is illustrated on a map of Roman London (Museum of London Archaeology, 2011).

Archaeological investigations and borehole investigations within the catchment of the urban Roman London Walbrook provide data on the stratigraphy relating to the Roman occupation and earlier, referred to in this research as palaeo-stratigraphy. This evidence feeds into two categories of stratigraphic research:

- ***Geomorphology*** (Section 4.6) - more specifically, key features and surfaces which determined the hydrology of the urban stretches of the Roman Walbrook and its potential for beneficial use; and
- ***Sedimentology*** (Section 4.7) – indicating the depth and nature of the material constituting the deposits between key land surfaces and their origin, natural or anthropological, and with respect to the latter, the extent of land raising activity by the Romans.

4.1.1 Geomorphology objectives

The hydrology of a river catchment is significantly affected by its physical topography. Whether or not the Walbrook posed a flood risk to urban Roman London will depend upon the physical topography of its land surfaces. Therefore, in order to carry out an analysis of the potential of the Walbrook to flood urban Roman London, the contemporaneous physical topography of the URWV needs to be determined. The physical topography will assist in identifying the flatter areas and depressions in the land surface most likely to be at risk of flooding. It will also provide the basis for determining the slope of the riverbed, a key parameter in calculating a flow rate in the Walbrook in excess of which its banks would have been over-topped and flooding would have occurred. Combining this with the results of a storm runoff analysis, it can be determined if the Walbrook would have flooded urban Roman London and, if so, where and with what frequency.

The potential of a river as a source of power is a combination of the rate at which water arrives at the point of abstraction or storage and the difference in water level between abstraction and the point of use. The physical topography of the land surface of the urban Roman Walbrook catchment dictates the slope of the riverbed along the thalweg and hence determines the potential of the river to act as a power source. Morphological data can therefore indicate whether the Walbrook had the potential to drive water mills, as well as indicating where such a mill or mills might have been located.

4.1.2 Sedimentology objectives

A study of the palaeo-stratigraphy underlying the URWV, in particular based on the results of archaeological investigations, can provide a picture of the physical topography of the land surface immediately prior to the arrival of the Romans in 43 CE as well as the land surface at the beginning of the 5th century. The difference in level between the two surfaces is an indication of the amount of topographic re-shaping and land reclamation work undertaken by the Romans. Such land raising activity may have been undertaken to even out undulations in land surfaces to be built upon, to assist in drainage or to raise areas above flood level.

The nature of the soil within a catchment, i.e. the upper layer beneath the ground surface at any point in time supporting and influencing vegetation, plays a significant role in determining the amount and rate of rainfall run-off. A study of the natural portion of the deposits forming the stratigraphy of the Walbrook catchment, particularly those laid down prior to the arrival of the Romans, provides an indication of the nature of the soil of the general catchment in that period. Although these deposits are progressively covered by later land raising activity, whether due to natural forces or construction, they did constitute the upper layer, the soil, of the area at the time.

As reported in Section 3.3.2, the natural geological strata underlying London, including the Walbrook valley, is London Clay, which when found with a silt and sand content is known as brickclay or brick-earth (Ellison et al., 2004, 25-29). It is of archaeological interest to understand whether, and under what conditions, flows in the Walbrook had the potential to transport clay, silt, sand and larger granular material from its upper reaches to cover the natural geology of the lower valley. Analysis of this aspect requires both an understanding of the deposits constituting the catchment stratigraphy as well as the velocities of flow in the Walbrook in dry weather and at times of storm run-off. The sediment transport potential of the Roman Walbrook is reported in Chapter 6, Section 6.6, following an analysis of velocities of flow in the Walbrook that forms part of the flood frequency assessment.

4.1.3 Palaeo-stratigraphy research objectives

The objectives of the palaeo-stratigraphic research are therefore to:

1. derive and pictorially depict key stratigraphic land surfaces, as defined in Section 4.2, underlying the Walbrook valley catchment within the confines of urbanised Roman London in order to define the sedimentology and geomorphology, including notable points of topographic interest for each of those surfaces;
2. determine the slope of the bed of the urban Roman Walbrook from Moorfields through to the Thames, in order to assess the potential of the Roman Walbrook to flood all or part of the urban area, as reported in Chapter 6 – Flood-risk Analysis - Urban Roman Walbrook;
3. determine which, if any, of the areas of urban Roman London were at risk of flooding by the Walbrook;
4. determine whether there is any stratigraphic evidence of catastrophic flooding by the Walbrook of the Roman urban area;
5. determine whether the physical topography of the urban Walbrook catchment affected the potential for beneficial use of the river, in particular as a source of power;
6. determine the nature of the deposits in the URWV, both natural and of anthropogenic origin, which constituted the material which resulted in land raising during the Roman period;
7. assist in determining the nature of the soil of the Walbrook Valley prevalent immediately prior to and during the Roman period;
8. assist in an assessment, reported in Chapter 6, Section 6.6, of the potential of the Walbrook to transport superficial deposit material, e.g. gravel, sand and alluvium, along and down the valley; and

9. contribute to an assessment, reported in Chapter 7, of the efforts of Roman society to control the flood-risk and to manage the Walbrook, in particular by providing data on the amount of ground-raising and terrain re-shaping carried out during the period of occupation.

4.2 Data Requirements

The palaeo-stratigraphy component of the research is restricted to the area urbanised by the Romans and its "suburbs" outside of the wall, extending northwards along the Greater Walbrook Valley as far as Old Street/Great Eastern Street. The limits of the area of this data "envelope" are further defined in Section 4.4.2 and its related Figure 4.1.

Sources of palaeo-stratigraphy data are described in Section 4.3, Methodology.

In order to achieve the objectives of the palaeo-stratigraphy component of the research, three stratigraphic surfaces within the URWV were chosen as most appropriate to the research, viz.

a. ***"Top natural"*** - the surface of the natural geology underlying the URWV; the significance of this layer is that the nature and depth of superficial deposits between it and the "Top pre-Roman" layer might provide an indication of the solids transportation and deposition properties of the ancient Walbrook.

b. ***"Top pre-Roman waterlain" (shortened version, "Top pre-Roman")*** - the surface of the ground immediately prior to the arrival of the Romans, before any re-shaping of the urban area took place. This is the waterlain land surface overlying natural on which the Romans developed a town. As very few archaeological investigations have located the bed of the ancient Walbrook, the lowest point of the slope of this surface along the route taken by the river, the thalweg, has been used in this research as a surrogate for the slope of the bed of the Walbrook through urban Roman London.

c. ***"Top Roman archaeology"*** - the surface of the ground at the end of the Roman period. In general, this was determined by lack of any further Roman artefacts. The strata between this layer and "Top pre-Roman" is the material within which archaeological investigations have found evidence of Roman occupation. Close to the Walbrook, this depth is indicative of the magnitude of the works carried out by the Romans to re-shape the land, possibly to avoid the area being flooded but also to dispose of urban solid waste.

The stratigraphic data abstracted for each of the archaeological sites and boreholes were as follows:

- site reference (as reported by the source organisation)
- site address and location (easting and northing)
- note as to whether the source was a borehole or form of archaeological excavation, trench, test-pit or open
- specific trench or pit reference and location on the above site (where more than one)

With respect to the geomorphology sub-component, the following additional data were abstracted:

- elevation of each of the three stratigraphic horizons, as defined above, in "m OD"

With respect to the sedimentology sub-component, for those sites where detailed stratigraphic data were available, generally those archived at LAARC, the following additional data were abstracted:

- elevation of changes in stratigraphic material
- constituent materials of each context
- anthropogenic material embedded in the various strata (data used to indicate start and end of Roman occupation)

In addition, the reports of archaeological investigations were consulted for evidence of river management and flood protection:

- land raising activity
- flood protection infrastructure, e.g. revetments and drainage
- overbank flooding
- catastrophic flooding
- dumping of domestic occupation waste
- dumping of industrial occupation waste

The above are reported upon and discussed in Chapter 7.

4.3 Methodology

The following methodology has been employed for the palaeo-stratigraphy component of the research:

1. Data on the stratigraphy underlying the URWV were acquired from four sources – LAARC, including MoLAS and DGLA data, GLHER, BGS and various publications detailing archaeological site investigations. More than 60 visits were made to LAARC (Section 2.4.2) and 5 visits to GLHER (Section 2.4.3) to abstract information from their archived records. BGS borehole data were obtained from their online website (Section 2.4.4). The locations from which palaeo-stratigraphic datasets were acquired were mapped onto a GIS base (Section 4.4.7, Figure 4-3).
2. Site reference and location details for the data abstracted from LAARC, GLHER and BGS were tabulated (Section 4.4.7, respectively Tables 4-1, 4-2 and 4-3).
3. Detailed abstracted stratigraphy data, together with its source details, were recorded graphically, where sufficient data rendered this worthwhile (Section 4.7.1, Figures 4-28 and 4-29 and 4-31 to 4-36), or in tabulated form where of a basic nature.
4. Stratigraphic data for the three key horizons, Top Natural, Top pre-Roman and Top Roman Archaeology, from all sources were entered onto an Excel spreadsheet (Section 4.5.1, Table 4-5 and Appendix 4A); a version of this Excel data spreadsheet, with data entered in a format compatible for uploading into GIS software was produced.
5. A GIS-based model was developed for recording and interpreting the stratigraphic data. A step-by-step description of the development of the model used in the research is set out in Appendix 4B.
6. Based upon the stratigraphic data collected, tabulated and entered, the GIS model was used to generate the following outputs:
    a. the separate, contoured depiction in 2D (Section 4.5.1, Figures 4-7 to 4-9) and 3D, the latter from 5 directions (Section 4.5.1, Figures 4-10 to 4-14) of each of the three key palaeo-stratigraphy surfaces, i.e.
        i. Top Natural
        ii. Top pre-Roman waterlain
        iii. Top Roman Archaeology

b. conversion to raster form of that stretch of the Walbrook which extends from the point of confluence of the westerly and easterly streams at Blomfield Street to the Thames at Upper Thames Street to enable bed level data to be abstracted and for its course to be depicted in 3D layer form (Section 4.5.2, Figures 4-15 and 4-16) and in 2D (Section 4.5.2, Figure 4-17);
c. generation of riverbed level data for the urban Roman London stretch of the river rasterised in Step 4b, at 20-metre intervals along the stream; data, in turn, were used in spreadsheet form to calculate the bed slopes of the Walbrook over any chosen length of the river (Step 8).

7. In addition, the model was used to automatically display, together with their metadata, locations of the LAARC and GLHER archaeological site investigations from which data has been abstracted for the research. Locations of the British Geological Survey boreholes from which data has been drawn for the research Walbrook and Walbrook-related stream courses found in the course of archaeological investigations have also been recorded on the GIS base.
8. Using the Greater Walbrook Valley thalweg as a surrogate for the riverbed (Section 4.5.2, Figure 4-17), elevation data along the rasterised stretch of the urban Roman Walbrook, at 20-metre intervals, were extracted to an Excel 2013 spreadsheet. In addition to its point reference data, each point was further identified by its easting and northing coordinates as well as its level above or below Ordnance Datum in metres. Bed slopes were then calculated along this stretch of the Walbrook at 20 metre, 60 metre and 100 metre intervals (Section 4.5.2, Table 4-6).
9. A longitudinal profile for the Walbrook through urban London was generated based on the data developed in Step 8 (Section 4.5.2, Figure 4-17) and average bed slopes were also derived (Table 4-7 and Section 4.5.2, Figure 4-20).
10. Soil data determined in this palaeo-stratigraphy research component (Section 4.7.2) were used to assist in the choice of catchment descriptor values relating to soil permeability (Section 5.7.3) and natural vegetation land cover in the palaeo-hydrology component of the research (Section 5.7.5).
11. The bed slopes generated in the GIS-generated Excel spreadsheet were used in the flood-risk analysis component of the research as were the GIS outputs relating to the topography of the Top Pre-Roman and Top Roman Archaeology stratigraphic horizons, (Chapter 6). Bed slope

being a significant factor in determining river flow velocities, this palaeo-stratigraphy output also contributed to the assessment of the river's capability to convey superficial deposits.

12. Site-specific stratigraphic data from the palaeo-stratigraphy component were also used as an input to the assessment of societal interventions, in particular those relating to flood mitigation and river management (Chapter 7).

The methodology for the palaeo-stratigraphy service component is shown on Figure 4-1.

4.4 Data Acquisition

4.4.1 Maps

As originally intended, two maps were to have been used in the palaeo-stratigraphy component, viz. a base map showing modern London and a contoured map of Roman London, both in a format appropriate for entry into the ArcGIS software.

Base Map – Modern Street Map The principal map base upon which the spatial and statistical data were entered into the ArcGIS software was obtained through the Edina online mapping service, Digimap, which offers Ordnance Survey (Perring et al., 1991) and British Geological Survey (BGS) maps to educational institutions for research and education. The OS map in raster format (compressed TIFF) downloaded to form the base map was:

tq38sw (raster-10k_508852)

By using this map as the underlying layer for the data layers, the modern context of any parameter depicted would be more readily apparent.

Base Map – Roman London The Museum of London, in partnership with the OS, produces a contoured map of Roman London which has been recently updated (Museum of London Archaeology, 2011). It had been hoped that this map could have been made available to the researcher in a raster format compatible with ArcGIS. This would have enable the data layers to have been depicted on a plan of Roman London in addition to a modern street map. Unfortunately, the digitised map could not be made available. However, the published hard-copy map was a useful reference and was used to enter the line of the Roman town wall onto the ArcGIS model.

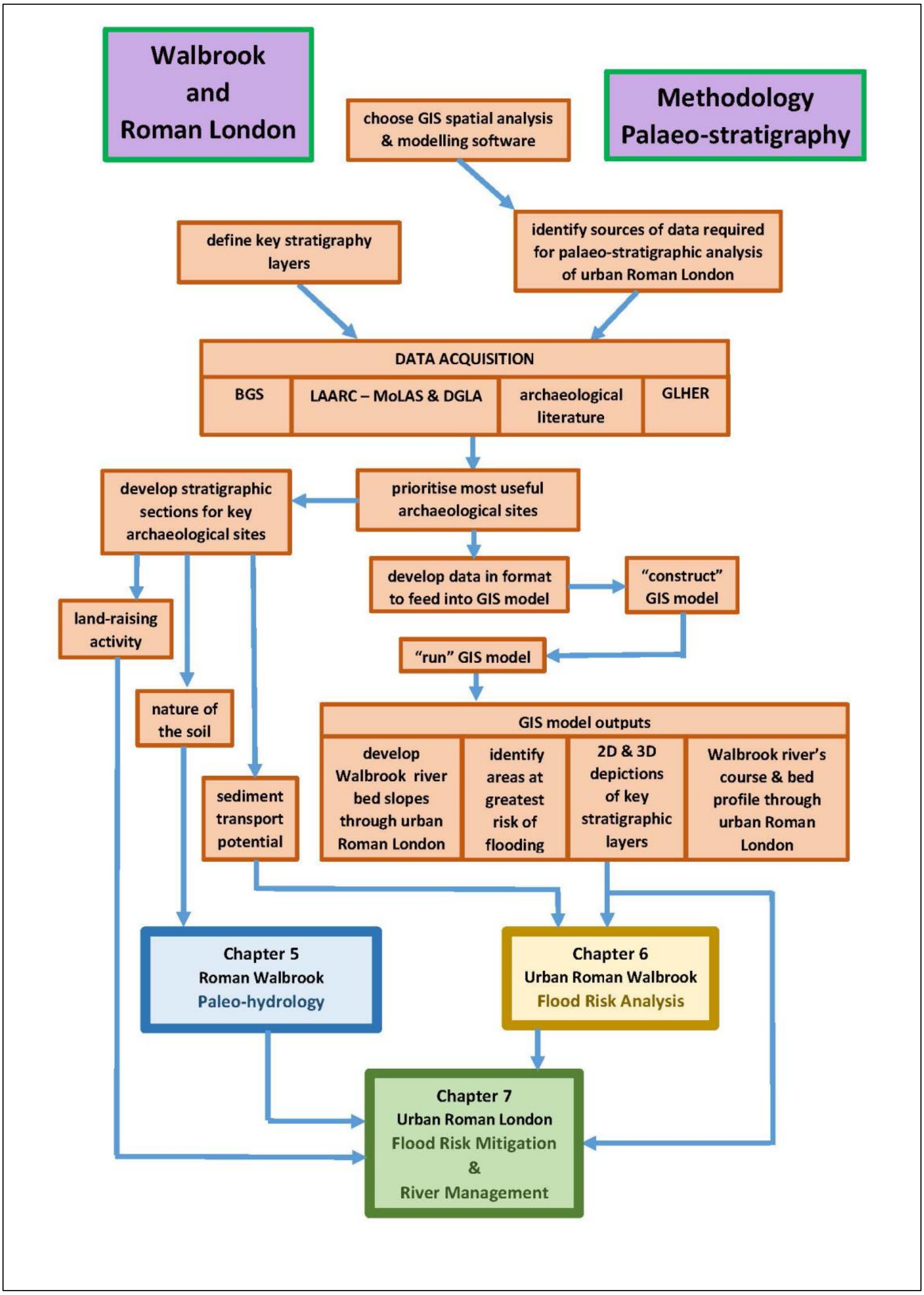


Figure 4-1 Methodology of the palaeo-stratigraphy service component

4.4.2 Areal limits of the palaeo-stratigraphy component

The areal limits of the palaeo-stratigraphy component were defined as having a north-south axis, including the urban area of Roman London within the Walbrook Valley and its immediate northern suburbs, i.e. from the Thames northwards as far as Old Street/Great Eastern Street. The east-west limit does not generally exceed a distance of 150m from both banks of the Walbrook's principal streams. This area is shown on Figure 4-2.

4.4.3 Topographic catchment boundary

Topographic catchment boundaries were identified by consulting contoured OS maps, delineating the boundaries on a hard copy OS map and walking the boundaries thus obtained in order to precisely define their line. A fuller explanation of how the topographic catchment was defined, including a plan of the topographic catchment boundary, has been provided in Section 3.2. The boundary thus obtained was entered into the GIS model as vector data polygon shapefiles.

4.4.4 Groundwater catchment boundary

The slope of the gravel/London Clay and alluvium/London Clay interfaces are from northwest down towards the southeast (section 3.3.3). The Walbrook thus receives groundwater from beyond its topographic catchment boundary from the west around to the northeast. The outer limit of that groundwater catchment has been taken to be where the gravel or alluvium encounters the London Clay at the ground surface. This boundary has therefore been defined using the BGS geological maps of the area concerned. A fuller explanation of how the groundwater catchment was defined, including a plan of the topographic catchment boundary, is provided in Section 3.3.3. The boundary thus obtained was then entered into the GIS model as vector data polygon shapefiles.

4.4.5 Walbrook watercourses

The routes taken by the western, eastern and combined streams of the Walbrook have been researched using ancient maps, literary sources and visual inspection of the topography of the Walbrook. The routes have been developed and marked onto a hard copy OS map. A fuller explanation of how the watercourses were discovered and defined is provided in Section 3.4 and Appendix 3B, that also includes a plan showing the Walbrook stream system. The routes thus obtained were then entered into the GIS model as vector data polyline shapefiles.

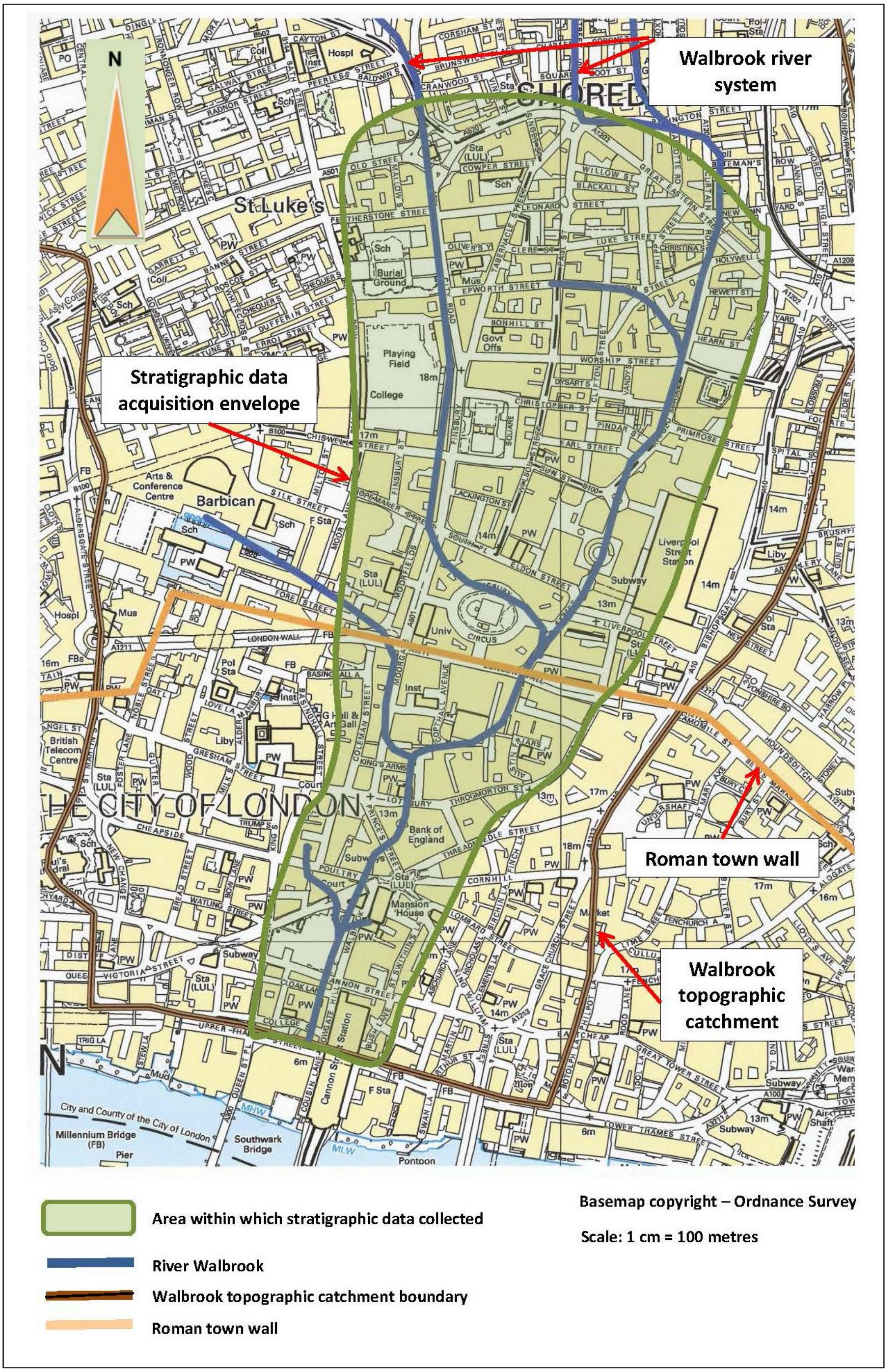


Figure 4-2 Area within which stratigraphic data were obtained, including urban Roman London Walbrook Valley and its "suburbs" as far north as Old Street/Great Eastern Street

4.4.6 Roman town wall

The Roman town wall, circa 200 CE, was transposed into the GIS model through creation of a polyline shapefile layer based upon a map of Roman London (Museum of London Archaeology, 2011). It is shown for its relevant length on Figure 4-2.

4.4.7 Palaeo-stratigraphy data

Elevation data for each of the three research horizons – Top Natural, Top Waterlain and Top Roman Archaeology – were abstracted from the records of the following sources:

a. London Archaeological Archive and Research Centre (LAARC)
b. Greater London Historic Environment Record (GLHER)
c. Department of Greater London Archaeology
d. British Geological Survey
e. Archaeological publications

Descriptions of these sources and the methodology employed for each in obtaining data applied to the research is the subject of Chapter 2, Outline Methodology, Data Sources and Quality. Figure 4-3 shows the 71 locations from which the 139 datasets were abstracted for the palaeo-stratigraphy research.

The palaeo-stratigraphy data acquired through the reports, plans and trench and test-pit sections were the most detailed of all of the sources. From the mid-1980s, DUA and MoLAS site investigation staff worked to a standard set of guidelines for the recording of the data. A complete set of reports, plans and sections was available for a majority of the sites. However, archived records were not always complete and in some cases, site reports were available but unsupported by plans and sections and in a very few cases, plans and sections were available but supported by incomplete reports.

a. London Archaeological Archive and Research Centre (LAARC)

Figure 4-4 shows the location of the 34 LAARC site investigations supplemented by a single DGLA investigation, BNH88, (see following section) from which palaeo-stratigraphy data were acquired and

Table 4-1 provides the location details. Stratigraphic data related to these sites is tabulated in Section 4.5.1, Table 4-5.

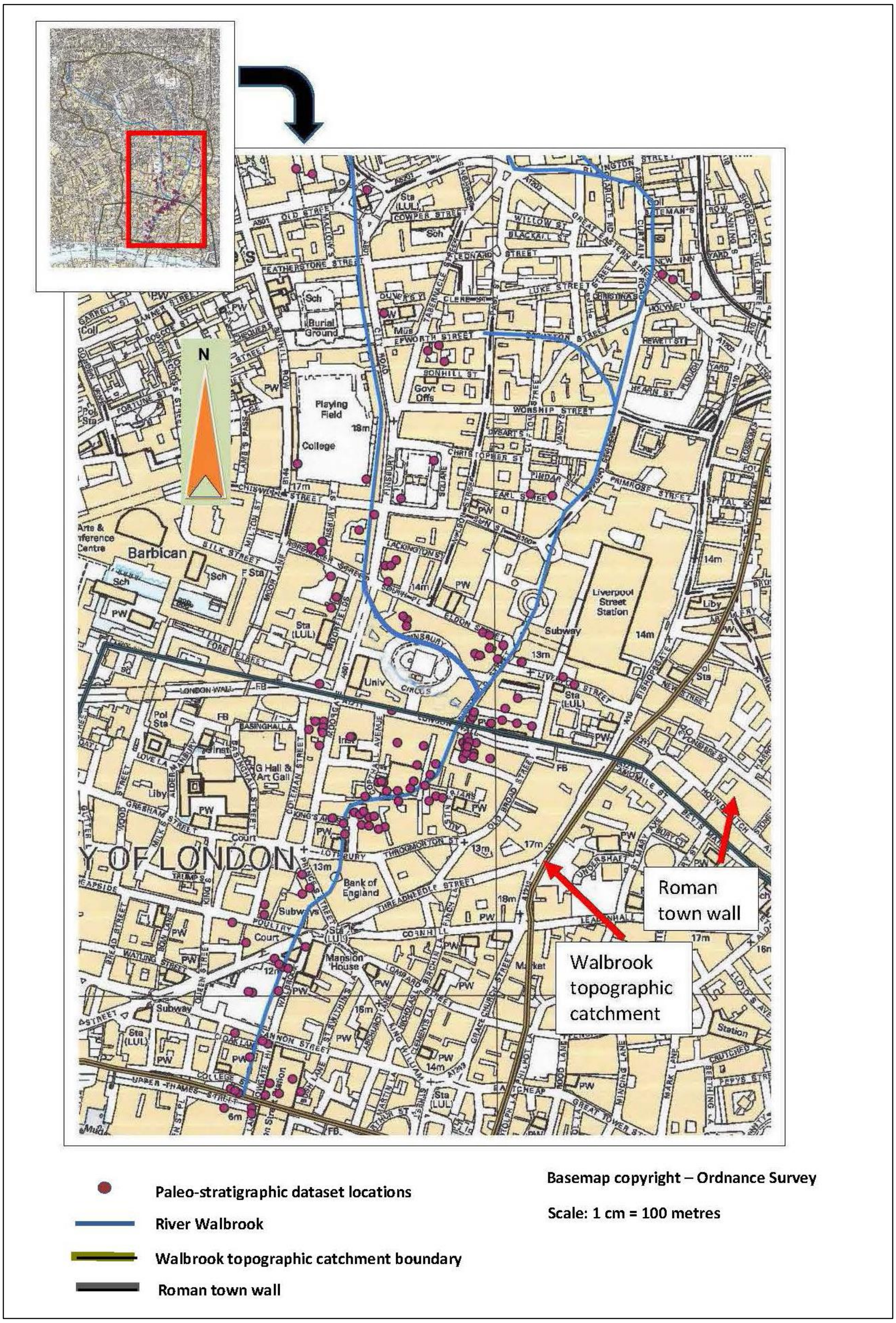


Figure 4-3 Locations from which the palaeo-stratigraphic datasets were acquired

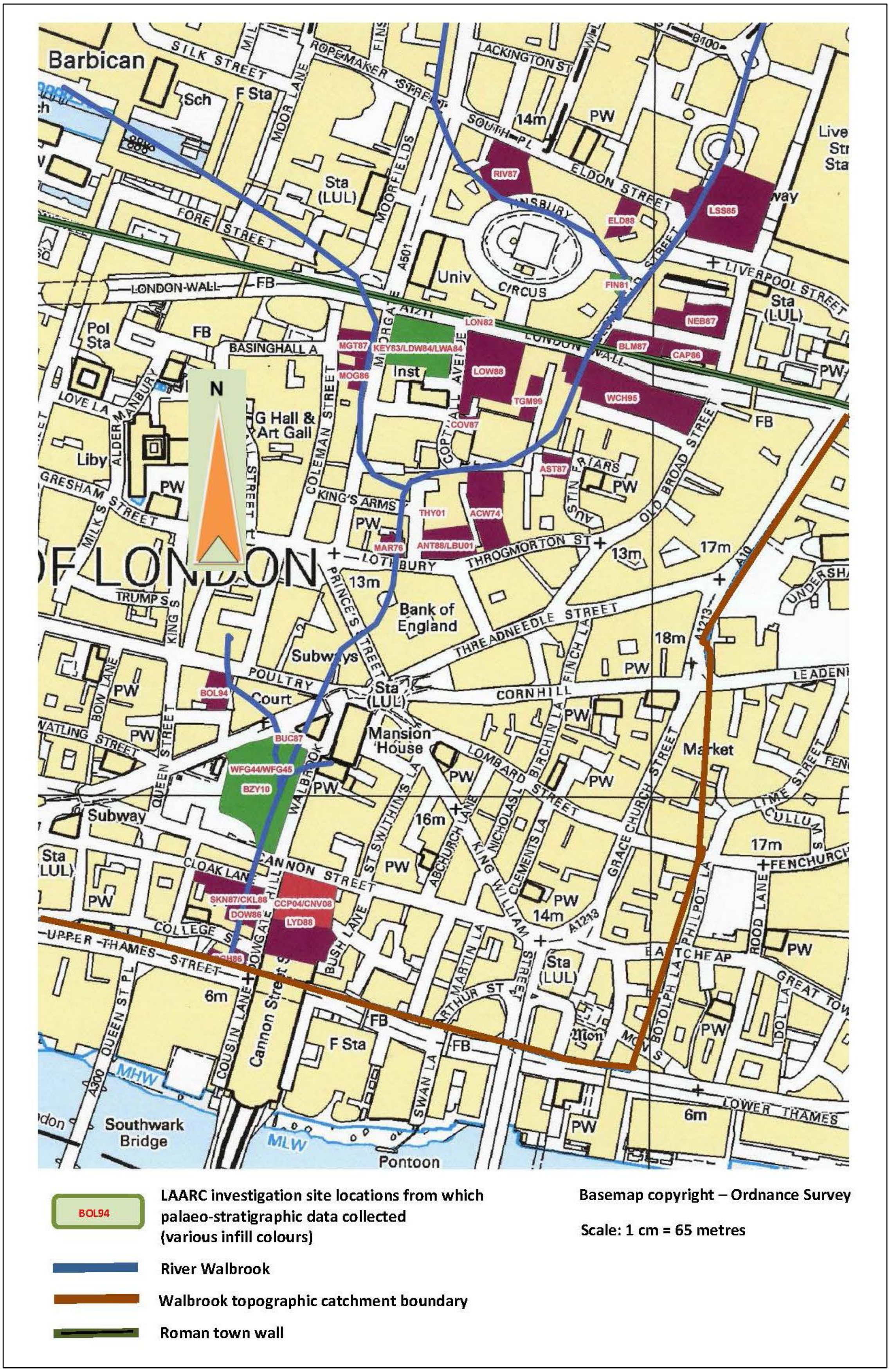


Figure 4-4 Locations from which LAARC palaeo-stratigraphic datasets were acquired

Table 4-1 Reference and location details of LAARC archaeological site records from which palaeo-stratigraphic data has been acquired

LAARC site reference	Archaeological Site Address	Type of Investigation	Borehole, trench or pit site reference	Easting	Northing
ACW74	1-8 Angel Court, 30-35 Throgmorton Avenue, London, EC2	excavation	Trench A - NE end of site	532821	181361
ANT88	9-10 Angel Court, London, EC2	excavation	Section 1	532750	181336
ANT88	9-10 Angel Court, London, EC2	excavation	Section 2	532757	181342
AST87	22-25 Austin Friars, London, EC2	excavation	Section 3	532877	181361
AST87	22-25 Austin Friars, London, EC2	excavation	Section 8	532902	181367
AST87	22-25 Austin Friars, London, EC2	excavation	Section 11	532800	181380
BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench A	532992	181505
BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench B	532954	181512
BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench C	532958	181517
BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench E	532961	181526
BNH88	Gavrelle House, 2-14 Bunhill Row, London, EC1	excavation	Section 2 watching brief	532640	181990
BOL94	Bolsa House, 76-80 Cheapside, London, EC2	borehole	Borehole 1 - NW crnr site	532516	181136
BOL94	Bolsa House, 76-80 Cheapside, London, EC2	borehole	Borehole 2 - SE crnr site	532541	181098
BUC87	Dockland Light Rail Shaft, Bucklersbury, EC4	excavation	Typical section through shaft	532593	181068
BZY10	Bloomberg Place, London, EC4	geotechnical	W-E transect - mid Walbrook	532609	181052
BZY10	Bloomberg Place, London, EC4	geotechnical	W-E transect - western end	532601	181058
BZY10	Bloomberg Place, London, EC4	geotechnical	N-S transect - northern end	532618	181050
BZY10	Bloomberg Place, London, EC4	geotechnical	N-S transect - southern end	532600	181008
CAP86	Capel House, 54-62 New Broad Street, London, EC2	excavation	Trench B	533012	181511
CAP86	Capel House, 54-62 New Broad Street, London, EC2	excavation	Trench F	533067	181500
CON86	76 Cannon Street, London, EC4	excavation		532570	180915
COV87	10-12 Copthall Avenue, London, EC2	borehole	Borehole No 1	532843	181385
COV87	10-12 Copthall Avenue, London, EC2	borehole	Borehole No 2	532849	181398
DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	excavation	E-W section S25	532526	180818
DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	pile hole	PH2	532512	180826
DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	test pit	TP - W	532520	180822
DOW86	3-7 Dowgate hill, London, EC 4	excavation		532560	180885
ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	test pit	TP 1	532978	181673
ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	test pit	TP2	532990	181668
ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	excvation	Area A	532963	181635
ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	excvation	Area B	532972	181632
KEY83 *OPT81: LWA84; LDW84*	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court, EC2	excavation	trench - stream channel	532737	181481
KEY83	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court, EC2	excavation	trench - W bank stream channel	532734	181481
LBU01	41 Lothbury, London, EC2	borehole	Borehole 2 (Angel Court)	532796	181313
LON82	London Wall, Junction with Blomfield Street, London, EC2	excavation	telephone MH watching brief	532810	181530
LOW88	52-63 London Wall, 20-56 Copthall Avenue, London, EC2	excavation	Section through Road 2	532820	181470
LSS85	Liverpool St Station, Broad St Station, London, EC2	excavation	Section 7	533048	181619
LSS85	Liverpool St Station, Broad St Station, London, EC2	excavation	Section 7	533049	181619
LYD88	Cannon Street Station north, Upper Thames Street (Dowgate Hill), EC4	excavation	centre-south site ref 35(r)	532600	180817
LYD88	Cannon Street Station north, Upper Thames Street (Dowgate Hill), EC4	excavation	western-south site ref 42®	532575	180814
MAR76	St Margaret Lothbury Church, Lothbury, London, EC2	excavation	section through Walbrook channel	532723	181300
MGT87	55-61 Moorgate, London, EC2	excavation	Trench G	532685	181510
MGT87	55-61 Moorgate, London, EC2	excavation	Trench H	532670	181510
MGT87	55-61 Moorgate, London, EC2	excavation	Trench F-F	532682	181494
MGT87	55-61 Moorgate, London, EC2	excavation	Trench F-F	532684	181499
MGT87	55-61 Moorgate, London, EC2	excavation	Trench F-F	532683	181489
MGT87	55-61 Moorgate, London, EC2	excavation	Trench B	532658	181495
MOG86	49-53 Moorgate, 72-74 Coleman Street, London, EC2	excavation	Area M	532677	181465
NEB87	35-45 New Broad Street, London, EC2	test pit	TP13	533041	181552
NEB87	35-45 New Broad Street, London, EC2	test pit	TP16	533039	181505
NEB87	35-45 New Broad Street, London, EC2	test pit	TP18	533018	181533
RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2	excavation	Room/Area D	532839	181698
RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2	excavation	Room/Area A	532832	181704
RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2	excavation	Room/Area F	532838	181686
SKN87 & CKL88	Skinner's Hall Kitchen, 8-9 Cloak Lane, London, EC4	excavation	composite of trench W & trench B	532547	180885
TGM99	8-10 Throgmorton Avenue, London, EC2	test pit & borehol	TP1 & BH 2	532856	181428
TGM99	8-10 Throgmorton Avenue, London, EC2	test pit & borehol	TP8 & BH1	532868	181464
THY01	6-8 Tokenhouse Yard, London, EC2	excavation	Trench 2	532784	181309
THY01	6-8 Tokenhouse Yard, London, EC2	excavation	Trench 1	532776	181333
WCH95	72 & 74-78 London Wall, London, EC2	borehole	Borehole A	532949	181480
WCH95	72 & 74-78 London Wall, London, EC2	excavation	Area 1	532951	181471
WCH95	72 & 74-78 London Wall, London, EC2	excavation	Area 2	532948	181462
WCH95	72 & 74-78 London Wall, London, EC2	excavation	Area 3	532959	181444
WFG44 &WFG45	Bucklersbury House (Temple of Mithras), London, EC4	excavation	Walbrook middle - cutting (F)	532552	181005
WFG44 &WFG45	Bucklersbury House (Temple of Mithras), London, EC4	excavation	Walbrook W bank - cutting F	532545	181007

b. Department of Greater London Archaeology (DGLA)

Only one site under the supervision of the DGLA furnished stratigraphy data. The site reference is BNH88, Gavrelle House, 2-14 Bunhill Row, London, EC1. DGLA records are archived at LAARC and consisted of reports, plans and sections and the same high level of confidence applies to the data acquired as for site investigations carried out by or under the supervision of the Museum of London Archaeology Service. The site is important as it is the furthest north of the archaeological sites included in the research and therefore the archaeological data acquired on the BNH88 site provided a check on the credibility of data emanating from boreholes at the northern extremity of the palaeo-stratigraphic research.

c. Greater London Historic Environment Record (GLHER)

The GLHER archive does not include plans and sections from site investigations, only reports. Of the 19 sites included in this research from their archives, 16 contained data on stratigraphy of sufficient detail to be included in this research. However, the degree of stratigraphic detail varied widely between reports, some providing complete sections through trenches and pits whilst others provided only very basic data.

Figure 4-5 shows the location of the 13 GLHER and single DGLA site investigation records from which palaeo-stratigraphy data were acquired and Table 4-2 provides the location details. Stratigraphic data from 27 locations related to these sites is tabulated in Section 4.5.1, Table 4-5.

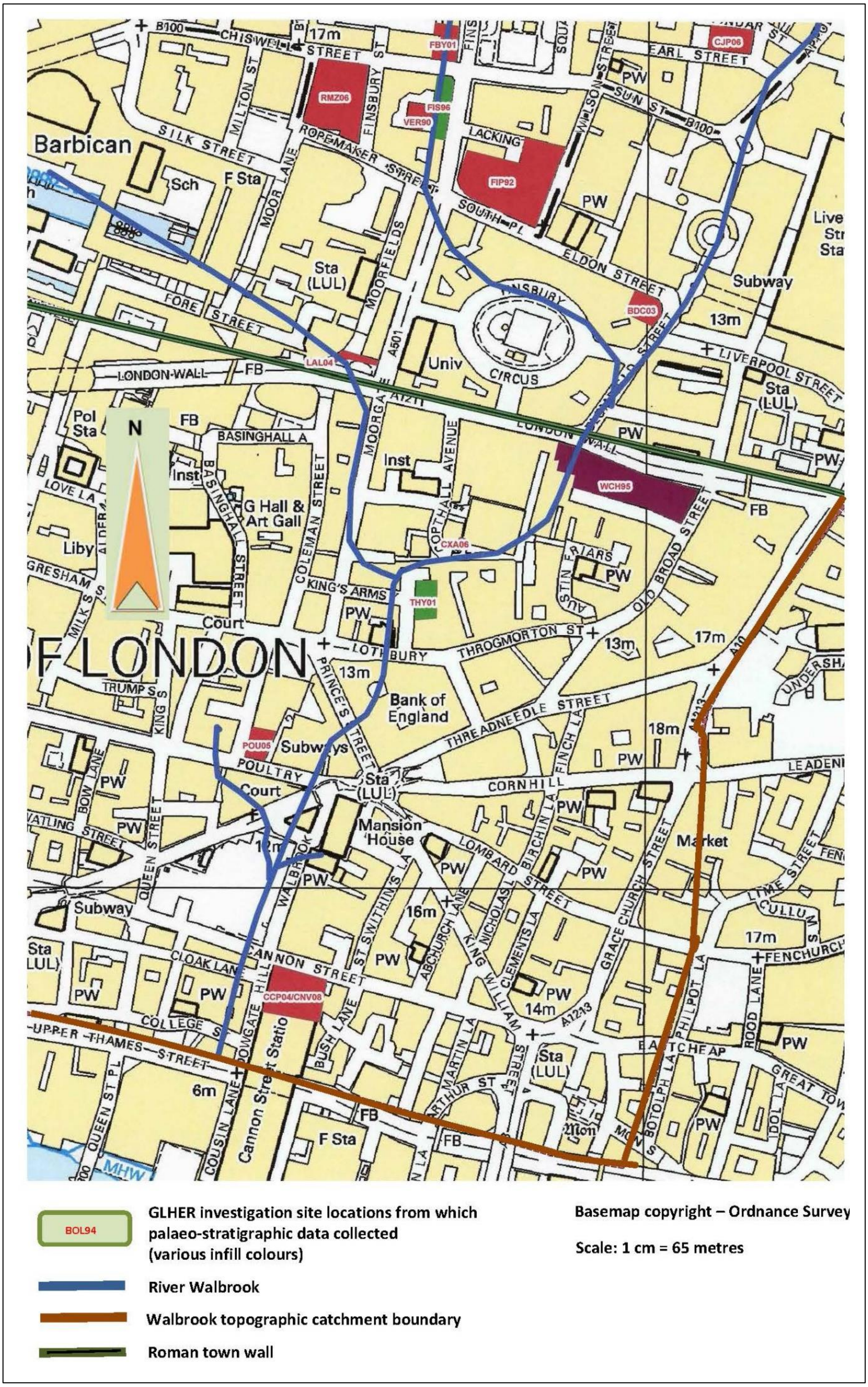


Figure 4-5 GLHER site investigations from which palaeo-stratigraphic datasets were acquired

Table 4-2 Reference and location details of GLHER and DGLA archaeological site records from which palaeo-stratigraphic data has been acquired

LAARC Archive Code	GLHER or DGLA Reference	Address	Nature of investigation	Location or reference	OS Grid Reference Easting	Northing
BDC03	07_368_SLO77259 & 77684	6 Broad Street Place, London, EC2	evaluation & excavation	Test pit 3	532990	181645
BDC03	07_368_SLO77259 & 77684	6 Broad Street Place, London, EC2	evaluation & excavation	Test pit 5	533015	181650
BDC03	07_368_SLO77259 & 77684	6 Broad Street Place, London, EC2	evaluation & excavation	Test pit 6	533005	181625
CJP06	12_307_SLO78278 & 78551	30 Crown Place, Hackney, London, EC2	evaluation & post-excvn	Test pit 6	533067	181932
CJP06	12_307_SLO78278 & 78551	30 Crown Place, Hackney, London, EC2	evaluation & post-excvn	Test pit 8	533107	181929
CNV08	07_404_SLO77747 & 70956	Cannon Place, London, EC4	archaeological evaluatn	Trial Pit 1 & Borehole 1	532583	180836
CNV08	07_404_SLO77747 & 70956	Cannon Place, London, EC4	archaeological evaluatn	Trial Pit 5	532625	180844
CXA06	07_394_CSLO80554	2 Copthall Avenue, London, EC2	excavtn & watching brief	Borehole 2	532794	181396
CXA06	07_394_CSLO80554	2 Copthall Avenue, London, EC2	excavtn & watching brief	Borehole 25	532784	181396
CXA06	07_394_CSLO80554	2 Copthall Avenue, London, EC2	excavtn & watching brief	Borehole 27	532790	181398
FBY01	19_253_SLO75940	1-2 Finsbury Square, London, EC2	archaeological evaluatn	Trench 4	532766	181961
FIP92	19_158_SLO75924	Dominion Buildings, Island Site, Finsbury Pavement, London, EC2	archaeological evaluatn	Test Pit 6	532805	181770
FIS96	19_117_SLO75771	127-139 Finsbury Pavement, London, EC1	post-excavation assessment	Trench1/Section 11	532780	181895
LAL04	07_438_SLO78324	London Wall/Moorgate, London, EC2	watching brief	Trench 1	532678	181580
POU05	07_157_SLO80258 & 77826	36 Poultry, London, EC2	archaeological evaluatn	Test Pit 3	532575	181169
POU05	07_157_SLO80258 & 77826	36 Poultry, London, EC2	archaeological evaluatn	Test Pit 8	532574	181150
RMZ06	19_321_SLO78994	Ropemaker Street/Finsbury Street, Islington, EC2	watching brief	Bay 6	532685	181845
RMZ06	19_321_SLO78994	Ropemaker Street/Finsbury Street, Islington, EC2	watching brief	Bay 20	532683	181827
RMZ06	19_321_SLO78994	Ropemaker Street/Finsbury Street, Islington, EC2	watching brief	Bay 30	532664	181834
THY01	07_353_SLO76858 & 76027	6-8 Tokenhouse Yard, London, EC2	watching brief	Borehole 1	532753	181317
THY01	07_353_SLO76858 & 76027	6-8 Tokenhouse Yard, London, EC2	watching brief	Borehole 2	532767	181315
THY01	07_353_SLO76858 & 76027	6-8 Tokenhouse Yard, London, EC2	watching brief	Borehole 3	532767	181331
VER90	19_168_SLO44434	Veritas House, 119-125 Finsbury Pavement, London, EC2	archaeological excavatn	Trench VII	532752	181866
WCH95	07_036_SLO62603	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 1 Pile No 177	532948	181475
WCH95	07_036_SLO62603	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 1 Piles Nos 184 & 185	532964	181469
WCH95	07_036_SLO62603	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 2 Pile No 169	532944	181462
WCH95	07_036_SLO62603	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 3 TC1 &TC3	532946	181450
BNH88		Gavrelle House, 2-14 Bunhill Row, London, EC1	excavation	Section 2 watching brief	532640	181990

d. British Geological Survey

All of the boreholes included in this research were driven for the purposes of providing the basis for the structural design of construction projects, not for archaeological purposes. The data were therefore subject to a much greater degree of interpretation than was necessary for the data obtained from organisations the main purpose of which is archaeology. All of the boreholes used were those driven up to a depth of 30m – thereby always encountering natural geology. In general, it was possible to interpret the nature of the material overlying natural to identify the limit of the waterlain deposits laid down prior to the arrival of the Romans – although with less confidence than could be attributed to data collected specifically for archaeological purposes.

Figure 4-6 shows the location of all of the 43 BGS boreholes, located on 23 construction sites from which palaeo-stratigraphy data has been acquired. Table 4-3 provides the borehole location details. Stratigraphic data related to these sites is tabulated in Section 4.5.1, Table 4-5.

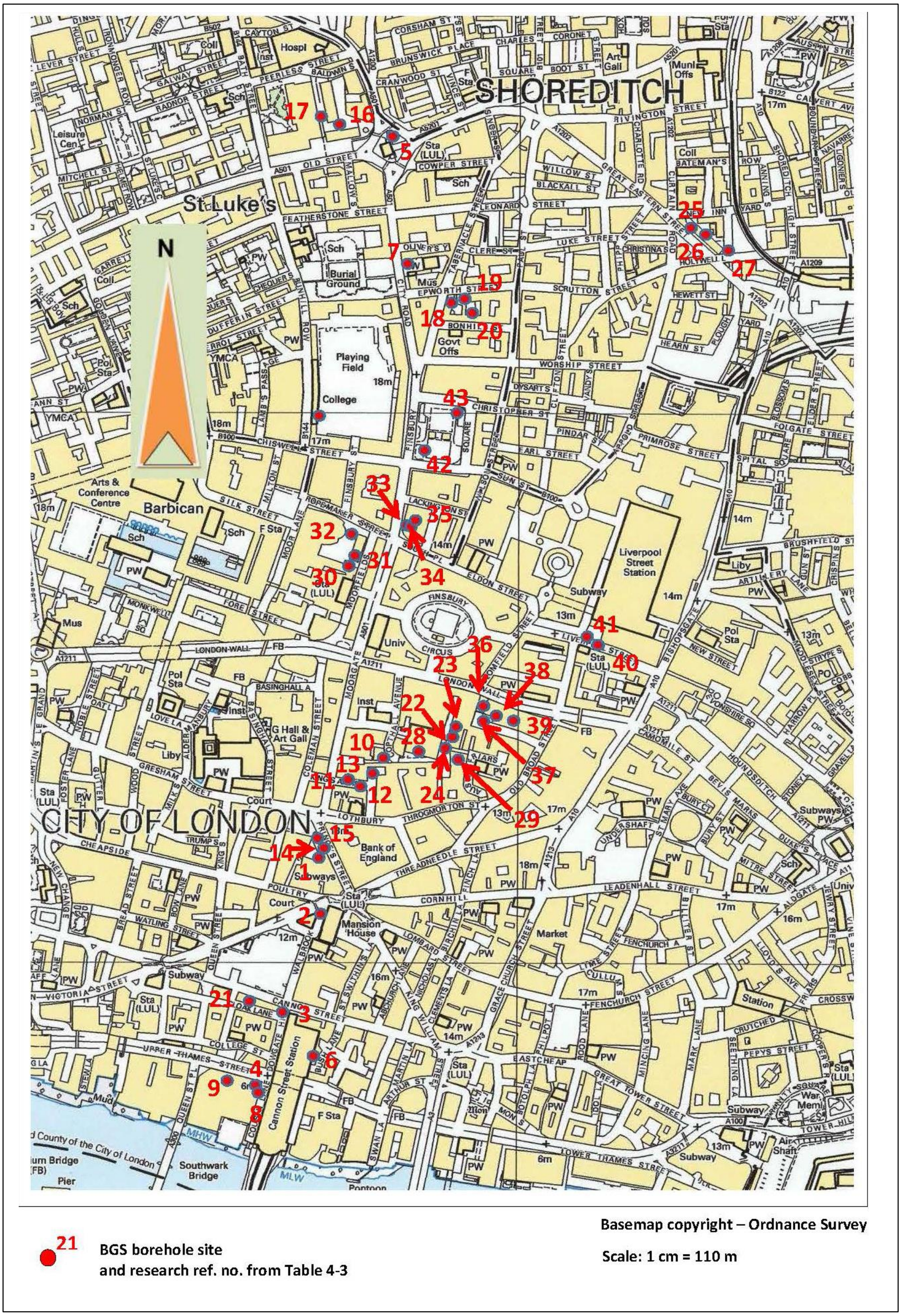


Figure 4-6 BGS borehole sites from which palaeo-stratigraphic data acquired

Table 4-3 Reference and location details of BGS borehole records from which palaeo-stratigraphic data has been acquired

BGS Reference	Research reference	Address	Site borehole reference	OS Grid Reference Easting	Northing
BGS-1055943	1	Princes Street, EC2	Borehole A	532644	181189
BGS-1063309	2	Mansion House, EC4	borehole	532650	181090
BGS-1063322	3	Corner Cannon Street & Dowgate Hill, EC4	borehole	532580	180910
BGS-1063323	4	Corner Dowgate Hill & College Street, EC4	borehole	532550	180790
BGS-1063634	5	Junction Old Street & City Road, EC2	borehole	532770	182500
BGS-1064166	6	Cannon Street Station, EC4	borehole	532640	180820
BGS-1064961	7	Old Street Tunnels, EC2	Borehole 4	532800	182270
BGS-1065533	8	Cousin Lane/Upper Thames St, EC4	borehole	532550	180780
BGS-1065534	9	Bell Wharf/Upper Thames Street, EC4	borehole	532500	180790
BGS-1065848	10	3 Copthall Buildings, Moorgate, EC2	borehole	532760	181370
BGS-1065911	11	17 Tokenhouse Yard, EC2	borehole	532700	181330
BGS-1065912	12	17 Tokenhouse Yard, EC2	borehole	532720	181320
BGS-1065913	13	17 Tokenhouse Yard, EC2	borehole	532740	181340
BGS-1065945	14	Princes Street, EC2	Borehole C	532658	181200
BGS-1065946	15	Princes Street, EC2	Borehole D	532644	181225
BGS-1066133	16	Immediately NW of City Road/Old Street Junction, EC1	Borehole 2	532640	182540
BGS-1066133	17	Immediately NW of City Road/Old Street Junction, EC1	Borehole 4	532670	182530
BGS-1066506	18	Tabernacle Street, EC2	Borehole 1	532880	182200
BGS-1066507	19	Tabernacle Street, EC2	Borehole 2	532900	182210
BGS-1066508	20	Tabernacle Street, EC2	Borehole 3	532910	182180
BGS-1066549	21	62-64 Cannon Street, EC4	borehole	532520	180930
BGS-1066681	22	Throgmorton Avenue, EC2	borehole	532880	181410
BGS-1066683	23	Throgmorton Avenue, EC2	borehole	532890	181430
BGS-1066685	24	Throgmorton Avenue, EC2	borehole	532870	181390
BGS-1066689	25	New Inn Yard, EC2	Borehole A	533310	182340
BGS-1066690	26	New Inn Yard, EC2	Borehole B	533330	182330
BGS-1066691	27	New Inn Yard, EC2	Borehole C	533370	182300
BGS-1067651	28	Drapers' Gardens, Throgmorton Avenue, EC2	borehole	532820	181380
BGS-1067694	29	Austin Friars at Throgmorton Avenue, EC2	borehole	532890	181370
BGS-15397050	30	Moorfields Development, EC2	borehole	532700	181720
BGS-15937054	31	Moorfields Development, EC2	borehole	532710	181740
BGS-15937103	32	Moorfields Development, EC2	borehole	532700	181780
BGS-165992	33	60-72 Finsbury Pavement, EC2	Borehole 1	532800	181800
BGS-165992	34	60-72 Finsbury Pavement, EC2	Borehole 2	532810	181800
BGS-165992	35	60-72 Finsbury Pavement, EC2	Borehole 4	532820	181810
BGS-17098092	36	Great Winchester Street, EC2	Borehole 1	532940	181470
BGS-17098098	37	Great Winchester Street, EC2	Borehole 2	532940	181440
BGS-17098101	38	Great Winchester Street, EC2	Borehole 3	532960	181450
BGS-17098103	39	Great Winchester Street, EC2	Borehole 4	532990	181440
BGS-19343188	40	Liverpool Street Station, EC2	Borehole 1	533145	181577
BGS-19343400	41	Liverpool Street Station, EC2	Borehole 3	533124	181591
BGS-19343402	42	Proposed car park at Finsbury Square, EC2	Borehole 1	532829	181925
BGS-19343403	43	Proposed car park at Finsbury Square, EC2	Borehole 2	532890	181995

The location of each of the 43 boreholes has been shown on large-scale plans in Appendix 4C.

Data values were required for all three research horizons for all data locations included in the GIS model. However, the Top Roman Archaeology horizon could only be identified with confidence in only three of the 43 BGS boreholes from the 23 borehole sites included in this work. For those boreholes for which no horizon elevation value could be confidently abstracted from borehole records, values were estimated based upon horizon elevation data from the nearest archaeological sites.

e. Archaeological Publications

Four archaeological publications were used as an additional source of palaeo-stratigraphic data,

- (Maloney and De Moulins, 1990)

  This publication was used to supplement data drawn from LAARC-archived reports and plans for the following site investigations - KEY83, FIN81, OPT81, CHL84, LWA84, LDW84 – being sites all grouped around the following site addresses 15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court, London, EC2

- (Lees and Woodger, 1990)

  This publication was used to supplement data drawn from LAARC-archived reports and plans for the following site investigation – LOW88, 52-63 London Wall, 20-56 Copthall Avenue, London, EC2.

- (Seeley and Drummond-Murray, 2005)

  This publication was used to supplement data drawn from a GLHER-archived report for the following site investigations – MRG95 and KHS98, Northgate House & Kent House, 20-28 Moorgate & Telegraph Street, London, EC2.

- (Leary and Butler, 2012)

  This publication was used to supplement data drawn from a GLHER-archived report for the following site investigations – THY01, 6-8 Tokenhouse Yard, London, EC2.

4.5 Data Development

The following guidelines were used to abstract palaeo-stratigraphic data from the source material, detailed in Section 4.4, with respect to the three key horizons – Top Natural, Top Pre-Roman Waterlain and Top Roman Archaeology:

- where natural geology was not specifically named as such, it was assumed that the uppermost elevation of the London Clay layer was Top Natural – this was frequently the case with respect to the BGS boreholes;
- where Top Pre-Roman Waterlain was not specifically dated as commencement of Roman occupation, it was taken to be the interface between those layers that showed signs of anthropogenic material, e.g. ubiquitous charcoal flakes and oyster shells and those layers that were not contaminated with such material; and
- where end point of Roman occupation (Top Roman Archaeology) was not specifically dated in site investigation reports or plans, the following were considered as providing a reasonable estimation of its elevation value:
    - for archaeological site investigations outside of the town wall, the base level of any peat strata was adopted, as a considerable thickness of peat was laid down over much of Moorfields over many centuries following construction of the wall and the consequent blockage of Walbrook culverts through the wall:
    - for those few site investigations within the urban area for which there was no date, absence of Roman finds, charcoal or oyster shell remains were taken to indicate end of Roman occupation, particularly where strata higher up contained medieval or post-medieval anthropogenic material; and
    - with respect to borehole records, the elevation of the interface between loamy soil or similar and made ground (MGRD) was adopted).

Wherever an estimate of the horizon elevation was made using one of the foregoing approaches, the level adopted was compared with other more reliable data acquired for nearby sites.

Where one of the foregoing approaches was not considered appropriate, horizon elevation data have been estimated from nearby sources. This was the case for the majority of the BGS boreholes for which the available data was considered less secure for estimating TRA ground level. These estimated values are highlighted in red font in the Excel table, reported in Appendix 4A. The numbers of total data points and those with estimated values are summarised in Table 4-4.

For all but three of the data-points analysed from BGS borehole data, the values for the Top Roman Archaeology layer were estimated, due to the difficulty of identifying this level from their records. This represents 59% of the total number of estimated values for TRAfrom all four sources, equivalent to 17% of the total number of data-points.

Table 4-4 Number of palaeo-stratigraphy data-points for which horizon elevation values are as measured on-site or have had to be estimated

Source of Data	Number of Data-points								
	Total (all 3 layers)			Top Natural		Top pre-Roman waterlain		Top Roman archaeology	
	Total	Measured Values	Estimated Values	Measd. Values	Est. Values	Measd. Values	Est. Values	Measd. Values	Est. Values
MoLAS	189	169	20	60	3	53	10	56	7
GLHER	81	74	7	21	6	26	1	27	0
BGS	129	89	40	43	0	43	0	3	40
DGLA	3	2	1	1	0	0	1	1	0
Total Nos.	***402***	***334***	***68***	***125***	***9***	***122***	***12***	***87***	***47***

Archaeological investigations note the level at which a context has been found. At the time the deposit was laid down, its top surface will almost certainly have been at a higher elevation. In the context of the City of London, this is an unavoidable consequence of two mechanisms:

- the imposition of a progressively accumulated overburden made up of demolition waste and imported fill, from 2 to 9 metres thick, weighing down on the lower stratigraphy for up to 1,600 years compressing it by an unquantifiable amount; and
- the weight of generations of buildings, the more recent many stories high; the compression effect of these will also be unknown and impossible to calculate.

All horizon elevation data abstracted from archaeological records can therefore only be considered an approximate measure of the actual elevations at the time horizon that each of the top surfaces of the layers is intended to represent. It is probable that the Top Natural layer is the most representative of its actual horizon elevations as London Clay will have been the least compressible of the materials. As each layer within a specific section will have undergone a similar amount of compression, this factor may only be of importance in assessing two situations:

- when the height between the Top Roman Archaeology and Top Pre-Roman Waterlain horizons is used to calculate the depth of material laid down by the inhabitants; the resulting thickness of fill would normally be an under-estimate due to compression of the layer by subsequent overburden; although virtually impossible to calculate by how much the fill has been compressed, it is unlikely that it will have been very significant; and
- when assessing whether the heights to which the embankments and wharves along the Thames and the Walbrook, at or near the Walbrook estuary, were adequate to avoid tidal flooding; a view would need to be taken as to by how much the top of the embankment or wharf revetment had been driven downwards by later overburden.

The stratigraphic elevation data of the three key horizons, as defined in Section 4.2 and as acquired from the sources detailed in Section 4.4.7, are reported in Table 4-5.

4.5.1 Depictions of palaeo-stratigraphy – 2D and 3D

Data listed in Table 4-5 were converted to a format compatible with its entry into the GIS model of the Greater Walbrook Valley, for that portion of the catchment shown on Figure 4-2. The "construction" and application of this model are described in Appendix 4B. Based upon the stratigraphic data collected, tabulated and entered, the GIS model generated the following outputs:

1. The separate, contoured depiction in 2D of each of the three key palaeo-stratigraphy horizons which also show the course of the Walbrook through the Roman urban area and town wall:
    a. Top Natural (Figure 4-7)
    b. Top Pre-Roman waterlain (Figure 4-8)
    c. Top Roman Archaeology (Figure 4-9)

2. The separate, contoured depiction in 3D of each of the three key palaeo-stratigraphy horizons as viewed from five directions:
    a. Southeast (Figure 4-10)
    b. East (Figure 4-11)
    c. South (Figure 4-12)
    d. Southwest (Figure 4-13)
    e. Northeast (Figure 4-14)

These depictions are used to describe the surface topography of the URWV in Section 4.6.1. Figures 4-7 to 4-14 have been inserted in the main text at small-scale in order to facilitate a comparison of the alterations to the land surface over time, from natural to the arrival of the Romans and from their arrival in the mid-1st century to their departure in the early 5th century. Each of the Figures is presented to a larger scale in Appendix 4D to facilitate their closer inspection.

Table 4-5 Table of Stratigraphic Data Compiled from MoLAS, GLHER, BGS and DGLA records

Ref	Address	Excavation or borehole	Location or reference	Easting	Northing	Top natural (m OD)	Top pre-Roman waterlain (m OD)	Top Roman Archae (m OD)
BGS-1055943	Princes Street, EC2	borehole record	Borehole A	532644	181189	3.50	7.46	5.00
BGS-1063309	Mansion House, EC4	borehole record	borehole	532650	181090	3.99	7.80	9.00
BGS-1063322	Corner Cannon Street & Dowgate Hill, EC4	borehole record	borehole	532580	180910	4.04	7.14	6.00
BGS-1063323	Corner Dowgate Hill & College Street, EC4	borehole record	borehole	532550	180790	-2.01	0.04	1.60
BGS-1063634	Junction Old Street & City Road, EC2	borehole record	borehole	532770	182500	13.11	13.72	13.80
BGS-1064166	Cannon Street Station, EC4	borehole record	borehole	532640	180820	1.51	2.12	7.00
BGS-1064961	Old Street Tunnels, EC2	borehole record	Borehole 4	532800	182270	8.87	15.03	15.10
BGS-1065533	Cousin Lane/Upper Thames St, EC4	borehole record	borehole	532550	180780	-8.65	-0.42	1.50
BGS-1065534	Bell Wharf/Upper Thames Street, EC4	borehole record	borehole	532500	180790	-8.24	-0.29	1.50
BGS-1065848	3 Copthall Buildings, Moorgate, EC2	borehole record	borehole	532760	181370	4.76	5.90	8.50
BGS-1065911	17 Tokenhouse Yard, EC2	borehole record	borehole	532700	181330	5.85	7.40	8.20
BGS-1065912	17 Tokenhouse Yard, EC2	borehole record	borehole	532720	181320	4.25	6.75	8.20
BGS-1065913	17 Tokenhouse Yard, EC2	borehole record	borehole	532740	181340	4.90	6.25	8.20
BGS-1065945	Princes Street, EC2	borehole record	Borehole C	532658	181200	3.03	7.04	5.00
BGS-1065946	Princes Street, EC2	borehole record	Borehole D	532644	181225	5.07	8.17	5.00
BGS-1066133	Immediately NW of City Road/Old Street Junction, EC1	borehole record	Borehole 2	532640	182540	11.05	14.09	14.10
BGS-1066133	Immediately NW of City Road/Old Street Junction, EC1	borehole record	Borehole 4	532670	182530	10.15	15.34	15.40
BGS-1066506	Tabernacle Street, EC2	borehole record	Borehole 1	532880	182200	9.86	11.86	12.00
BGS-1066507	Tabernacle Street, EC2	borehole record	Borehole 2	532900	182210	9.60	12.00	12.00
BGS-1066508	Tabernacle Street, EC2	borehole record	Borehole 3	532910	182180	10.19	11.89	12.00
BGS-1066549	62-64 Cannon Street, EC4	borehole record	borehole	532520	180930	1.25	3.60	4.00
BGS-1066681	Throgmorton Avenue, EC2	borehole record	borehole	532880	181410	5.11	6.51	8.80
BGS-1066683	Throgmorton Avenue, EC2	borehole record	borehole	532890	181430	5.40	6.70	8.80
BGS-1066685	Throgmorton Avenue, EC2	borehole record	borehole	532870	181390	5.40	6.10	8.80
BGS-1066689	New Inn Yard, EC2	borehole record	Borehole A	533310	182340	7.50	11.92	12.00
BGS-1066690	New Inn Yard, EC2	borehole record	Borehole B	533330	182330	8.29	11.34	12.00
BGS-1066691	New Inn Yard, EC2	borehole record	Borehole C	533370	182300	8.02	10.76	12.00
BGS-1067651	Drapers' Gardens, Throgmorton Avenue, EC2	borehole record	borehole	532820	181380	4.72	6.25	8.80
BGS-1067694	Austin Friars at Throgmorton Avenue, EC2	borehole record	borehole	532890	181370	5.90	6.05	8.80
BGS-15397050	Moorfields Development, EC2	borehole record	borehole	532700	181720	6.59	8.57	9.60
BGS-15937054	Moorfields Development, EC2	borehole record	borehole	532710	181740	6.40	8.99	9.60
BGS-15937103	Moorfields Development, EC2	borehole record	borehole	532700	181780	7.96	9.94	9.60
BGS-165992	60-72 Finsbury Pavement, EC2	borehole record	Borehole 1	532800	181800	6.70	9.76	11.00
BGS-165992	60-72 Finsbury Pavement, EC2	borehole record	Borehole 2	532810	181800	6.71	9.76	11.00
BGS-165992	60-72 Finsbury Pavement, EC2	borehole record	Borehole 4	532820	181810	6.86	9.30	11.00
BGS-17098092	Great Winchester Street, EC2	borehole record	Borehole 1	532940	181470	5.34	6.56	8.69
BGS-17098098	Great Winchester Street, EC2	borehole record	Borehole 2	532940	181440	4.88	6.86	8.69
BGS-17098101	Great Winchester Street, EC2	borehole record	Borehole 3	532960	181450	5.64	8.54	8.70
BGS-17098103	Great Winchester Street, EC2	borehole record	Borehole 4	532990	181440	5.03	8.69	8.70
BGS-19343188	Liverpool Street Station, EC2	borehole record	Borehole 1	533145	181577	6.20	9.25	9.30
BGS-19343400	Liverpool Street Station, EC2	borehole record	Borehole 3	533124	181591	6.15	7.15	9.30
BGS-19343402	Proposed car park at Finsbury Square, EC2	borehole record	Borehole 1	532829	181925	9.57	11.71	12.10
BGS-19343403	Proposed car park at Finsbury Square, EC2	borehole record	Borehole 2	532890	181995	9.36	12.10	12.10

Ref	Address	Excavation or borehole	Location or reference	Easting	Northing	Top natural (m OD)	Top pre-Roman waterlain (m OD)	Top Roman Archae (m OD)
DGLA-BNH88	Gavrelle House, 2-14 Bunhill Row, London, EC1	excavation	Section 2 watching brief	532640	181990	13.65	13.70	13.90
GLHER-BDC03	6 Broad Street Place, London, EC2	evaluation & excavation	Test pit 3	532990	181645	6.50	8.10	8.90
GLHER-BDC03	6 Broad Street Place, London, EC2	evaluation & excavation	Test pit 5	533015	181650	6.46	8.90	8.85
GLHER-BDC03	6 Broad Street Place, London, EC2	evaluation & excavation	Test pit 6	533005	181625	6.45	8.15	8.49
GLHER-CJP06	30 Crown Place, Hackney, London, EC2	evaluation & post-excvn	Test pit 6	533067	181932	11.29	11.29	11.29
GLHER-CJP06	30 Crown Place, Hackney, London, EC2	evaluation & post-excvn	Test pit 8	533107	181929	10.70	10.70	10.70
GLHER-CNV08	Cannon Place, London, EC4	archaeological evaluatn	Trial Pit 1 & Borehole 1	532583	180836	5.15	5.35	6.20
GLHER-CNV08	Cannon Place, London, EC4	archaeological evaluatn	Trial Pit 5	532625	180844	4.15	6.45	6.75
GLHER-CXA06	2 Copthall Avenue, London, EC2	excavtn & watching brief	Borehole 2	532794	181396	5.56	5.94	7.80
GLHER-CXA06	2 Copthall Avenue, London, EC2	excavtn & watching brief	Borehole 25	532784	181396	6.09	6.38	7.80
GLHER-CXA06	2 Copthall Avenue, London, EC2	excavtn & watching brief	Borehole 27	532790	181398	5.53	6.41	7.80
GLHER-FBY01	1-2 Finsbury Square, London, EC2	archaeological evaluatn	Trench 4	532766	181961	11.78	11.78	11.78
GLHER-FIP92	Dominion Buildings, Island Site, Finsbury Pavement, London, EC2	archaeological evaluatn	Test Pit 6	532805	181770	8.74	10.01	10.01
GLHER-FIS96	127-139 Finsbury Pavement, London, EC1	post-excavation	Trench1/Section 11	532780	181895	12.28	11.29	12.28
GLHER-LAL04	London Wall/Moorgate, London, EC2	watching brief	Trench 1	532678	181580	8.20	8.20	9.40
GLHER-POU05	36 Poultry, London, EC2	archaeological evaluatn	Test Pit 3	532575	181169	7.00	9.10	9.80
GLHER-POU05	36 Poultry, London, EC2	archaeological evaluatn	Test Pit 8	532574	181150	7.00	9.10	9.90
GLHER-RMZ06	Ropemaker Street/Finsbury Street, Islington, EC2	watching brief	Bay 6	532685	181845	10.80	10.80	10.80
GLHER-RMZ06	Ropemaker Street/Finsbury Street, Islington, EC2	watching brief	Bay 20	532683	181827	9.15	9.15	9.15
GLHER-RMZ06	Ropemaker Street/Finsbury Street, Islington, EC2	watching brief	Bay 30	532664	181834	10.35	10.35	10.35
GLHER-THY01	6-8 Tokenhouse Yard, London, EC2	watching brief	Borehole 1	532753	181317	4.93	7.82	8.32
GLHER-THY01	6-8 Tokenhouse Yard, London, EC2	watching brief	Borehole 2	532767	181315	5.24	8.74	9.24
GLHER-THY01	6-8 Tokenhouse Yard, London, EC2	watching brief	Borehole 3	532767	181331	5.25	7.15	9.05
GLHER-VER90	Veritas House, 119-125 Finsbury Pavement, London, EC2	archaeological excavatn	Trench VII	532752	181866	12.33	11.33	12.33
GLHER-WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 1 Pile No 177	532948	181475	5.62	6.75	9.02
GLHER-WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 1 Piles Nos 184 & 185	532964	181469	6.92	7.67	8.67
GLHER-WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 2 Pile No 169	532944	181462	5.14	6.64	9.44
GLHER-WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2	excavtn & watching brief	Area 3 TC1 &TC3	532946	181450	7.02	7.47	9.07
MOLAS-ACW74	1-8 Angel Court, 30-35 Throgmorton Avenue, London, EC2	excavation	Trench A - NE end of site	532821	181361	7.08	7.15	8.52
MOLAS-ANT88	9-10 Angel Court, London, EC2	excavation	Section 1	532750	181336	6.10	6.20	9.47
MOLAS-ANT88	9-10 Angel Court, London, EC2	excavation	Section 2	532757	181342	4.50	4.55	9.22
MOLAS-AST87	22-25 Austin Friars, London, EC2	excavation	Section 3	532877	181361	6.80	7.60	8.80
MOLAS-AST87	22-25 Austin Friars, London, EC2	excavation	Section 8	532902	181367	8.33	8.79	9.57
MOLAS-AST87	22-25 Austin Friars, London, EC2	excavation	Section 11	532800	181380	6.04	7.48	9.06
MOLAS-BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench A	532992	181505	7.40	7.60	7.70
MOLAS-BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench B	532954	181512	6.80	7.00	8.25
MOLAS-BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench C	532958	181517	6.89	7.10	7.80
MOLAS-BLM87	Blomfield House, 85-86 London Wall, London, EC2	excavation	Trench E	532961	181526	7.25	7.30	8.35
MOLAS-BOL94	Bolsa House, 76-80 Cheapside, London, EC2	borehole	Borehole 1 - NW crnr site	532516	181136	7.30	8.40	9.75
MOLAS-BOL94	Bolsa House, 76-80 Cheapside, London, EC2	borehole	Borehole 2 - SE crnr site	532541	181098	6.80	8.40	9.00
MOLAS-BUC87	Dockland Light Rail Shaft, Bucklersbury, (near Queen Victoria St),	excavation	Typical section through shaft	532593	181068	3.87	4.13	7.30
MOLAS-BZY10	Bloomberg Place, London, EC4	geotechnical	W-E transect - mid Walbrook	532609	181052	1.00	1.60	2.50
MOLAS-BZY10	Bloomberg Place, London, EC4	geotechnical	W-E transect - western end	532601	181058	2.00	3.80	7.70
MOLAS-BZY10	Bloomberg Place, London, EC4	geotechnical	N-S transect - northern end	532618	181050	1.80	5.20	7.20
MOLAS-BZY10	Bloomberg Place, London, EC4	geotechnical	N-S transect - southern end	532600	181008	2.30	3.60	3.60
MOLAS-CAP86	Capel House, 54-62 New Broad Street, London, EC2	excavation	Trench B	533012	181511	7.60	7.75	8.60
MOLAS-CAP86	Capel House, 54-62 New Broad Street, London, EC2	excavation	Trench F	533067	181500	8.65	8.70	9.05
MOLAS-CON86	76 Cannon Street, London, EC4	excavation	excavation	532570	180915	2.74	3.00	5.74
MOLAS-COV87	10-12 Copthall Avenue, London, EC2	borehole	Borehole No 1	532843	181385	7.02	7.72	8.40
MOLAS-COV87	10-12 Copthall Avenue, London, EC2	borehole	Borehole No 2	532849	181398	6.94	7.62	8.40
MOLAS-DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	excavation	E-W section S25	532526	180818	-2.10	-0.78	1.00
MOLAS-DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	pile hole	PH2	532512	180826	-4.85	-0.80	1.60

Ref	Address	Excavation or borehole	Location or reference	Easting	Northing	Top natural (m OD	Top pre-Roman waterlain (m OD)	Top Roman Archae (m OD)
MOLAS-DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	test pit	TP - W	532520	180822	-4.85	-0.85	1.60
MOLAS-ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	test pit	TP 1	532978	181673	8.07	8.10	8.77
MOLAS-ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	test pit	TP2	532990	181668	8.13	8.23	8.53
MOLAS-ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	excvation	Area A	532963	181635	8.20	8.30	8.44
MOLAS-ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	excvation	Area B	532972	181632	7.87	8.00	8.33
MOLAS-KEY83 FIN81 OPT81 CHL84	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court,	excavation	trench - stream channel	532737	181481	5.28	5.84	8.48
MOLAS-KEY83 FIN81 OPT81 CHL84	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court,	excavation	trench - W bank stream chnnl	532734	181481	5.50	6.54	8.76
MOLAS-LBU01	41 Lothbury, London, EC2	borehole	Borehole 2 (Angel Court)	532796	181313	5.50	8.17	9.97
MOLAS-LON82	London Wall, Junction with Blomfield Street, London, EC2	excavation	telephone MH watching brief	532810	181530	6.80	7.65	7.83
MOLAS-LOW88	52-63 London Wall, 20-56 Copthall Avenue, London, EC2	excavation	Section through Road 2	532820	181470	6.50	7.28	8.50
MOLAS-LSS85	Liverpool St Station, Broad St Station, London, EC2	excavation	Section 7	533048	181619	7.20	7.53	9.35
MOLAS-LSS85	Liverpool St Station, Broad St Station, London, EC2	excavation	Section 7	533049	181619	7.18	7.81	9.30
MOLAS-LYD88	Cannon Street Station north, Upper Thames Street (Dowgate	excavation	centre-south site ref 35(r)	532600	180817	-0.14	1.07	1.50
MOLAS-LYD88	Cannon Street Station north, Upper Thames Street (Dowgate	excavation	western-south site ref 42	532575	180814	-0.02	0.63	1.50
MOLAS-MAR76	St Margaret Lothbury Church, Lothbury, London, EC2	excavation	section thru Walbrook chnnl	532723	181300	5.00	6.00	7.00
MOLAS-MGT87	55-61 Moorgate, London, EC2	excavation	Trench G	532685	181510	7.10	7.30	8.90
MOLAS-MGT87	55-61 Moorgate, London, EC2	excavation	Trench H	532670	181510	7.20	7.30	8.86
MOLAS-MGT87	55-61 Moorgate, London, EC2	excavation	Trench F-F	532682	181494	6.50	7.00	8.48
MOLAS-MGT87	55-61 Moorgate, London, EC2	excavation	Trench F-F	532684	181499	6.50	7.00	8.48
MOLAS-MGT87	55-61 Moorgate, London, EC2	excavation	Trench F-F	532683	181489	6.50	7.00	8.48
MOLAS-MGT87	55-61 Moorgate, London, EC2	excavation	Trench B	532658	181495	7.55	7.90	9.00
MOLAS-MOG86	49-53 Moorgate, 72-74 Coleman Street, London, EC2	excavation	Area M	532677	181465	8.92	9.08	9.20
MOLAS-NEB87	35-45 New Broad Street, London, EC2	test pit	TP13	533041	181552	8.80	8.83	9.18
MOLAS-NEB87	35-45 New Broad Street, London, EC2	test pit	TP16	533039	181505	9.08	9.20	9.54
MOLAS-NEB87	35-45 New Broad Street, London, EC2	test pit	TP18	533018	181533	7.86	8.00	8.78
MOLAS-RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2	excavation	Room/Area D	532839	181698	9.13	9.77	11.04
MOLAS-RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2	excavation	Room/Area A	532832	181704	9.21	9.35	9.47
MOLAS-RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2	excavation	Room/Area F	532838	181686	8.80	9.20	9.45
MOLAS-SKN87 & CKL88	Skinner's Hall Kitchen, 8-9 Cloak Lane, London, EC4	excavation	composite of trenches W & B	532547	180885	0.87	1.15	5.06
MOLAS-TGM99	8-10 Throgmorton Avenue, London, EC2	test pit & borehole	TP1 & BH 2	532856	181428	5.45	7.50	9.10
MOLAS-TGM99	8-10 Throgmorton Avenue, London, EC2	test pit & borehole	TP8 & BH1	532868	181464	5.20	7.50	8.85
MOLAS-THY01	6-8 Tokenhouse Yard, London, EC2	excavation	Trench 2	532784	181309	4.09	4.68	7.81
MOLAS-THY01	6-8 Tokenhouse Yard, London, EC2	excavation	Trench 1	532776	181333	4.09	5.07	8.58
MOLAS-WCH95	72 & 74-78 London Wall, London, EC2	borehole	Borehole A	532949	181480	5.34	7.28	9.18
MOLAS-WCH95	72 & 74-78 London Wall, London, EC2	excavation	Area 1	532951	181471	5.96	7.09	9.00
MOLAS-WCH95	72 & 74-78 London Wall, London, EC2	excavation	Area 2	532948	181462	5.37	7.30	8.92
MOLAS-WCH95	72 & 74-78 London Wall, London, EC2	excavation	Area 3	532959	181444	6.92	7.62	9.10
MOLAS-WFG44&WFG45	Bucklersbury House (Temple of Mithras), London, EC4	excavation	Walbrook middle - cutting (F)	532552	181005	0.29	2.07	3.20
MOLAS-WFG44&WFG45	Bucklersbury House (Temple of Mithras), London, EC4	excavation	Walbrook W bank - cutting F	532545	181007	2.13	3.50	5.55

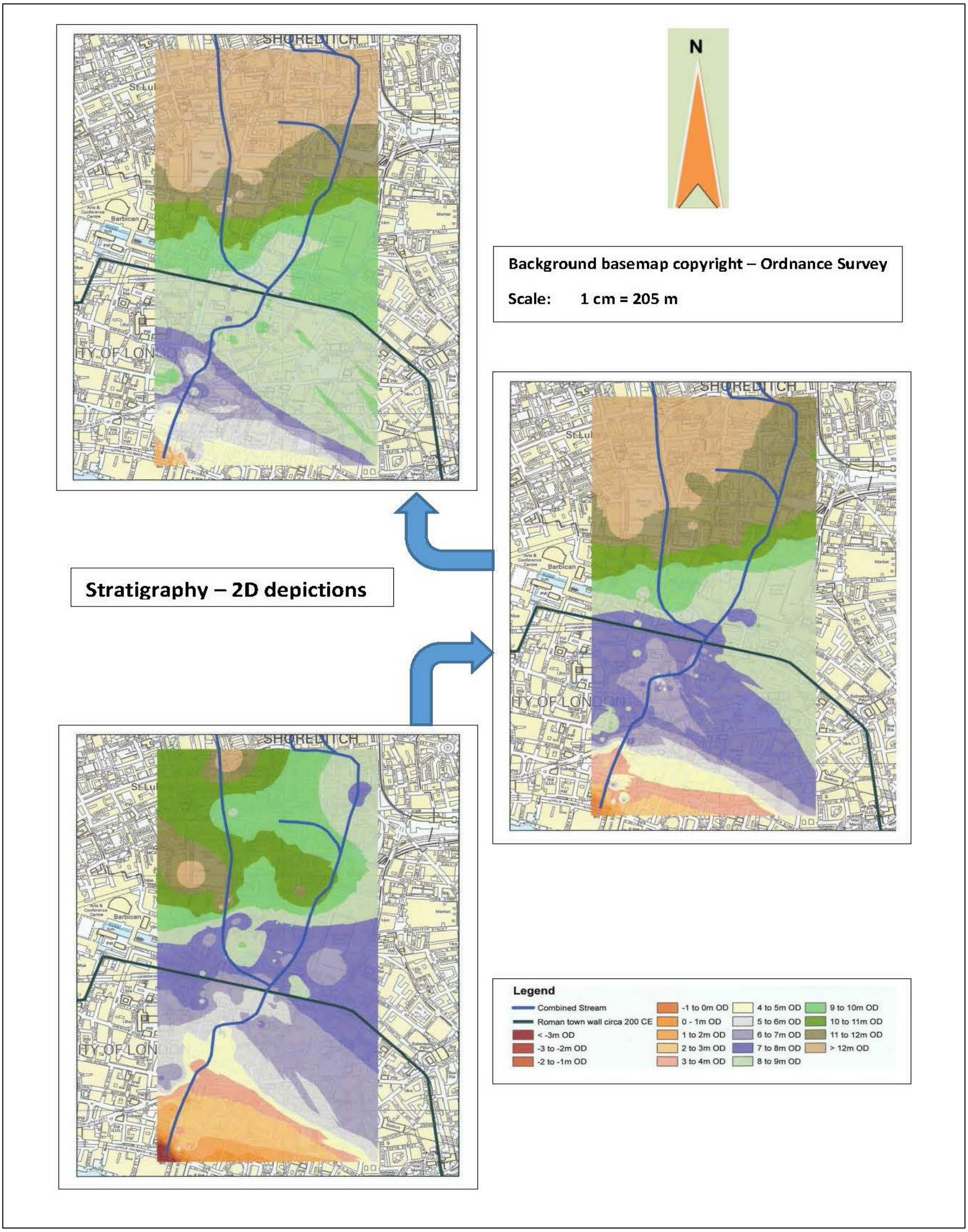


Figure 4-7 **Top Natural *(bottom left)***

Figure 4-8 **Top Pre-Roman *(middle)***

Figure 4-9 **Top Roman Archaeology *(top left)***

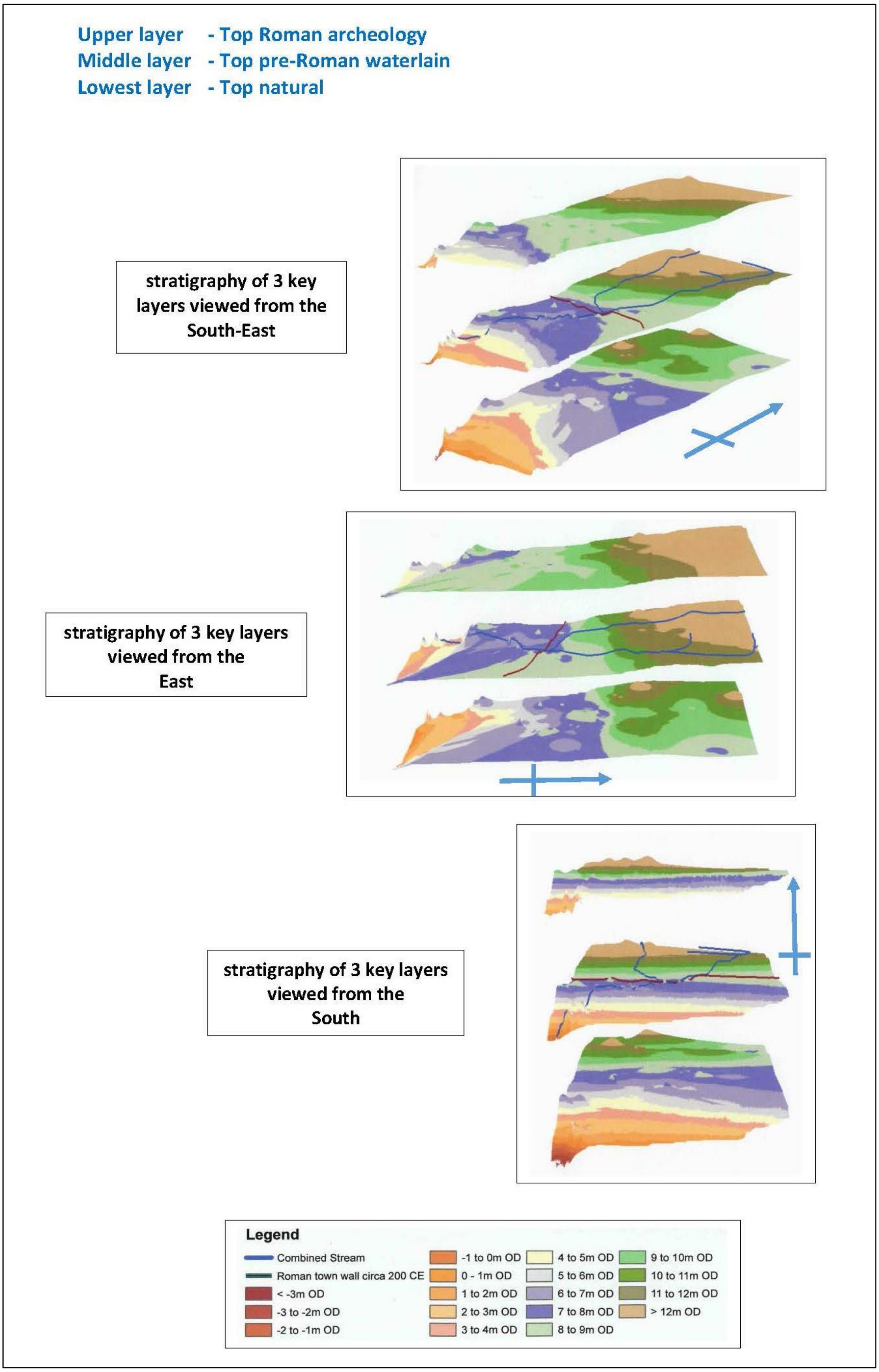
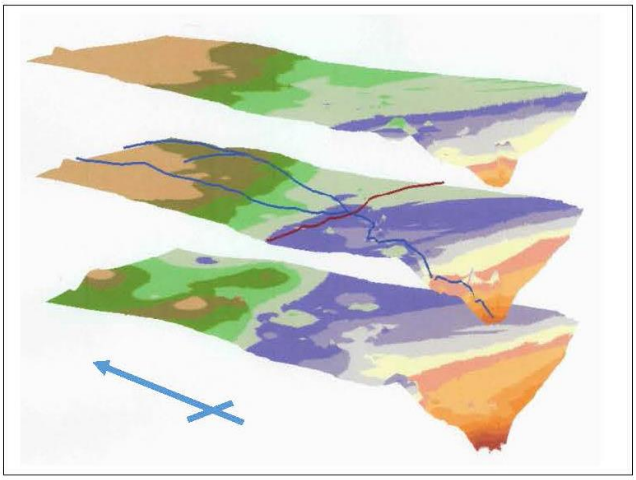


Figure 4-10 3D depiction of land surfaces from southeast *(top)*

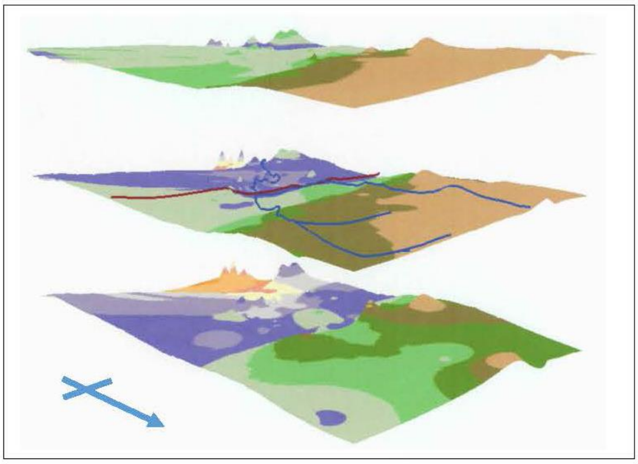
Figure 4-11 3D depiction of land surfaces from east *(middle)*

Figure 4-12 3D depiction of land surfaces from south *(bottom)*

Upper layer - Top Roman archaeology
Middle layer - Top pre-Roman waterlain
Lower layer - Top natural



stratigraphy of 3 key layers viewed from the South-West



stratigraphy of 3 key layers viewed from the North-East

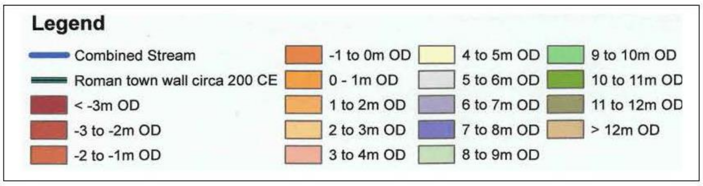


Figure 4-13 3D depiction of land surfaces from southwest *(top)*

Figure 4-14 3D depiction of land surfaces from northeast *(bottom)*

The principal points arising out of a comparison of the Figures are reported below and the implications of the topography of the three key horizons resulting from the stratigraphic analysis are also Interpreted and applied in the flood-risk analysis (Chapter 6).

- The route shown for the river has relevance to the Top Pre-Roman (TPR) and Top Roman Archaeology (Silberbauer and Logan, 2016) topographies, however, not for the Top Natural (T Nat) as the route taken by the river when T Nat was at the surface will have been quite different, as indicated by its contours. The river is shown on the T Nat map only to provide points of reference and aid comparison between all three maps.
- Top Natural shows two distinctly different landscapes either side of the line of the eventual town wall, almost certainly an unrelated coincidence. South of the line of the wall, the land slopes gradually towards the Thames, the slope in the thalweg being reasonably constant with a very shallow slope to the valley sides. North of the line of the wall, the landscape becomes one with a number of pronounced undulations, with shallow troughs and low hummocks.
- With the exception of a “knick-point” at Bucklersbury, with consequent abrupt fall in the ground surface, the Top Pre-Roman surface shows a smoother progression through the contours throughout the area studied when compared with Top Natural, particularly notable in the northern half of the area, where the undulations have been “ironed out”. In general, there is an average depth of superficial deposits of between 1.5 and 2.0m in Zones A, B and C and 0.3 to 0.5m in Zones D and E– varying proportions of gravel, sand and silt mixed with clay and some organic material, i.e. loam – laid down over the clay and gravel as the Thames migrated southwards.
- Of particular interest to the current research is the extensive, heart-shaped, shallow bowl depression in the land, extending from the wall to Lombard Street with its lowest point at Tokenhouse Yard/Draper’s Gardens. A low ridge of land on its southeastern flank, running west-northwest to east-southeast, would have drained storm run-off in a northerly direction, rather than in a southerly direction towards the Thames as would otherwise have been the case. With the Walbrook passing through this depression, at best the land within the depression would have been marshy but, in periods of heavy or prolonged rain, the area may have become a temporary lake. This is a large portion of the area referred to in this current research as the Middle URWV.

- The low promontory to the immediate east of the Walbrook at Cannon Street Station, found in the LYD88 and CCP04/CNV08 investigations, can be noted from the Top Pre-Roman topography, although the limited number of data points results in this being shown as three closely grouped hillocks rather than an area of generally higher ground.
- Given the limited number of data points available to the research, the depiction of the course of the Walbrook on the TPR map appears to be a reasonable match with the contours.
- When compared with that of the TPR, the TRA topography indicates that the Romans carried out a considerable amount of land raising activity during their period of occupation. Although some of this activity is apparent in the Lower URWV, it is most notable in the Middle URWV in the area that had formerly been the location of the extensive, shallow bowl depression, within the line of the town wall. In this area, the land appears to have been raised by between 1.5 and 2.5 metres, probably more in some localised low spots, to a general level of between 7.5 and 8.8m OD.
- By contrast, the physical topography of the land to north of the wall was altered little during the Roman period, the exception being a narrow strip of land along the line of the wall which, as for the Middle URWV, was again raised to between 7.5 and 8.5/9.0m OD.

The raising of the land to this level is further discussed, with respect to flooding by the Walbrook in the urban Middle Roman Walbrook Valley, in Sections 4.6.3, areas most at risk of flooding, and 4.7.3, Roman ground-raising activity. These have a major impact on the flood frequency analysis, reported in Chapter 6, and the river management and flood mitigation measures taken by the Romans discussed in Chapter 7.

4.5.2 Riverbed slopes – Urban Roman Walbrook Valley (URWV)

The Walbrook, from the point of confluence of the westerly and easterly streams at Blomfield Street through to its estuary with the Thames at Upper Thames Street, was converted to raster format. This enabled the course of the River Walbrook to be defined by the GIS software, by plotting the thalweg, i.e. the line linking the lowest points through the valley, for the Top Pre-Roman Waterlain layer. This course has been depicted in 3D from two directions that best illustrate the river as it wends its way through the landscape, viz from the southwest (Figure 4-15) and from the south (Figure 4-16).

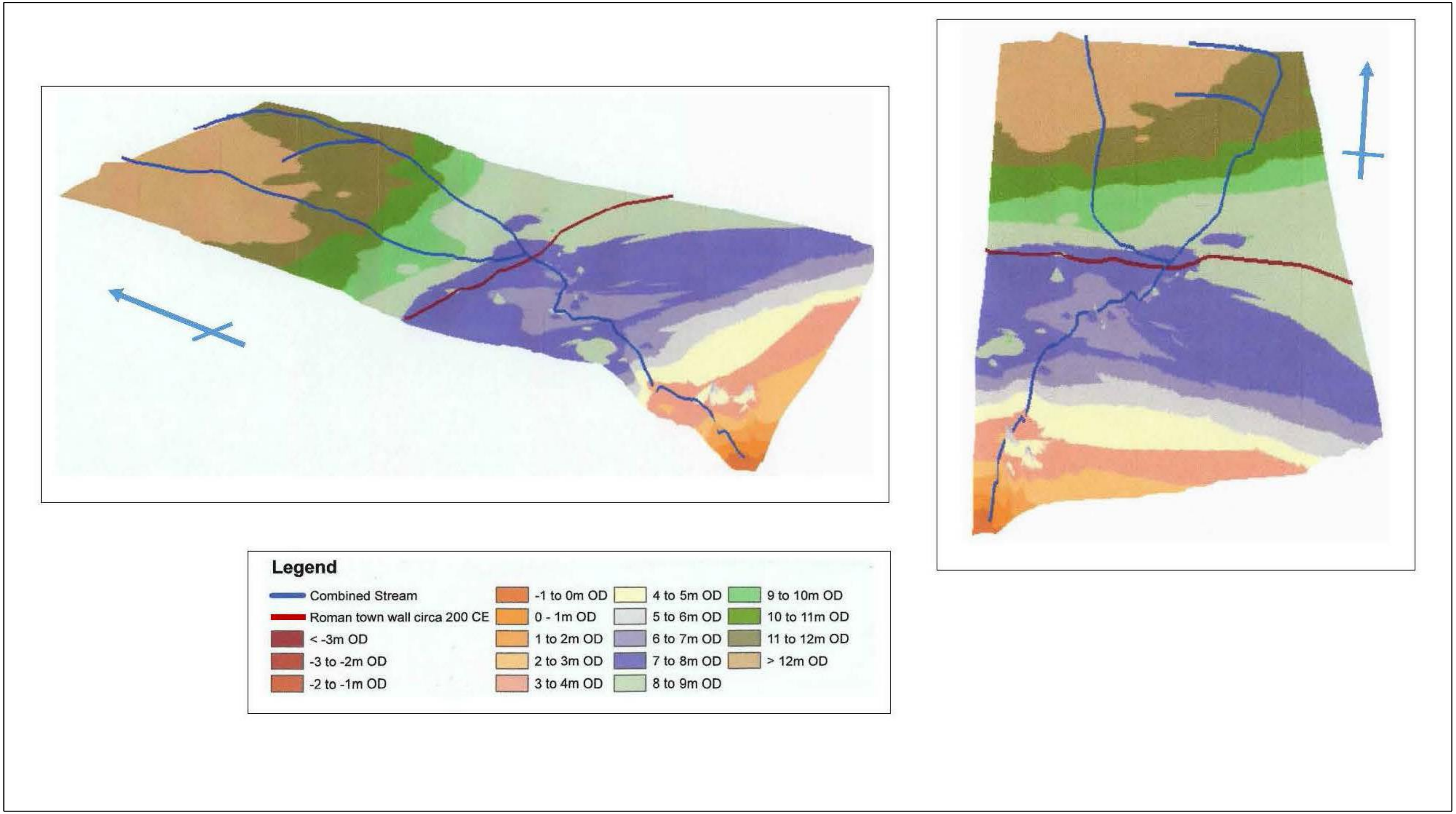


Figure 4-15 3D depictions of the Top Pre-Roman Waterlain surface showing the course taken by the River Walbrook viewed from south *(right)*

Figure 4-16 3D depictions of the Top Pre-Roman Waterlain surface showing the course taken by the River Walbrook viewed from southwest *(left)*

The course of the river as depicted on these two figures is, in reality, an illustration of the line of lowest ground level through the valley. Unfortunately, very few archaeological investigations have encountered the bed of the Walbrook's principal stream in the Roman period, too few to define a riverbed profile for the watercourse through the valley. The thalweg has therefore been used as a surrogate.

The GIS model was interrogated for ground elevation data along the line of the thalweg from the confluence of the western and eastern Walbrook streams in Blomfield Street and the banks of the Thames in the Roman period at Upper Thames Street. Ground levels were obtained at 20-metre intervals along its course. Assuming an average height from the top of the riverbank to its bed of 1 metre, the elevation of the riverbed at each of these points has been calculated. This elevation data, together with the precise location of each point along the thalweg, is reported in Table 4-6, from which riverbed slopes over distances of 20, 60, 100 and 160-metre intervals have been calculated. The line of the thalweg, and consequently the river, as well as the location of each of the elevation data points, is shown on Figure 4-17. Profiles for the riverbed are illustrated on Figure 4-18. Two profiles are shown, one derived using the data arising out of the GIS analysis and the other which "smooths" out the profile of the riverbed. From an inspection of the GIS-derived profile, it is apparent that it cannot be taken as representing a riverbed profile as, in parts, particularly from Lothbury through to the Thames, the river is shown as flowing uphill for parts of its course. This is because the bed profile data are derived from ground elevations. Further, from Figure 4-8, the contours of the Top pre-Roman layer, it can be seen that the river passes through a shallow depression in the ground surface between Draper's Gardens and Lothbury. Downstream of Lothbury, the land rises slightly through to Princes Street after which it falls away more steeply through to Bucklersbury and the Bloomberg Development. After a further slight undulation, the land again falls through to the Thames. In order to pass through the Bucklersbury "ridge", the Walbrook had to cut a valley through the section from Lothbury to the Bloomberg Development. The land surface shown by the GIS depicts a cross-section through the ridge not the valley between. Archaeological investigations upstream of Lothbury and on the Bloomberg Development have provided levels for the bed of the Walbrook. The second curve on the Figure 4-18 smooths out the anomalies in the GIS-derived curve and, using the control levels found in a few archaeological investigations at key points, provides the profile of the Walbrook's bed through the urban Roman area was employed in the hydrological elements of this research.

Table 4-6 The Walbrook through urban Roman London from Blomfield Street to Upper Thames Street

Riverbed slopes calculated at 20 metre, 60 metre and 100 metre intervals

RasterValu = Point Z = ground surface of pre-Roman waterlain layer (taken to equal level of river bed)
Point X and Point Y respectively easting and northing UK Ordnance Survey coordinates

					Distance Between Points		POINT_Z	river bed	River bed slope			
OBJECTID *	SHAPE *	RASTERVALU	POINT_X (easting)	POINT_Y (northing)	Individual (metres)	Cumulative	ground elevation (m OD)	elevation (m OD)	Every 20 metres (m/10,000m)	Every 60 metres (m/10,000m)	every 100 metres (m/10,000m)	every 160 metres (m/10,000m)
1	Point Z	7.156649	532946	181528	20	20	7.16	6.16	33.83			
2	Point Z	7.088985	532936	181510	20	40	7.09	6.09	6.93	13.59		
3	Point Z	7.075118	532926	181493	20	60	7.08	6.08	16.44	7.79	7.82	
4	Point Z	7.04224	532919	181474	20	80	7.04	6.04	-18.12	-0.56	14.61	32.92
5	Point Z	7.078483	532912	181456	20	100	7.08	6.08	67.81	16.56	27.61	60.08
6	Point Z	6.942861	532904	181437	20	120	6.94	5.94	71.93	46.58	41.24	-20.06
7	Point Z	6.798997	532896	181419	20	140	6.80	5.80	84.57	52.17	95.07	3.47
8	Point Z	6.629866	532884	181404	20	160	6.63	5.63	251.05	111.87	-45.32	17.51
9	Point Z	6.127771	532868	181391	20	180	6.13	5.13	-634.16	-127.70	-18.77	18.26
10	Point Z	7.396081	532851	181381	20	200	7.40	6.40	204.68	-143.16	-16.84	42.49
11	Point Z	6.986718	532833	181372	20	220	6.99	5.99	94.23	99.64	-52.30	40.06
12	Point Z	6.798248	532813	181370	20	240	6.80	5.80	73.76	56.00	127.69	-6.05
13	Point Z	6.650737	532793	181367	20	260	6.65	5.65	265.80	113.18	99.77	56.78
14	Point Z	6.119143	532774	181364	20	280	6.12	5.12	65.08	110.29	57.37	16.59
15	Point Z	5.98898	532754	181361	20	300	5.99	4.99	-117.76	-17.56	16.31	45.18
16	Point Z	6.224505	532735	181353	20	320	6.22	5.22	-131.58	-83.11	-60.21	10.97
17	Point Z	6.487669	532724	181338	20	340	6.49	5.49	-116.79	-82.79	-8.64	-36.34
18	Point Z	6.721241	532722	181318	20	360	6.72	5.72	322.94	68.72	-25.07	-62.93
19	Point Z	6.075361	532719	181298	20	380	6.08	5.08	-199.93	41.00	-21.29	-57.09
20	Point Z	6.475229	532717	181278	20	400	6.48	5.48	-112.65	-104.20	-27.46	-57.69
21	Point Z	6.700532	532715	181258	20	420	6.70	5.70	-147.65	-86.77	-106.26	-42.44
22	Point Z	6.995832	532713	181239	20	440	7.00	6.00	-71.04	-72.90	-93.54	-71.81
23	Point Z	7.137912	532707	181220	20	460	7.14	6.14	-136.37	-69.14	-69.97	-49.85
24	Point Z	7.410652	532699	181201	20	480	7.41	6.41	5.22	-43.72	-22.86	-25.46
25	Point Z	7.400217	532686	181187	20	500	7.40	6.40	87.91	31.04	-13.49	18.09
26	Point Z	7.224389	532670	181175	20	520	7.22	6.22	-24.21	21.23	30.28	43.82
27	Point Z	7.272815	532655	181162	20	540	7.27	6.27	82.49	19.43	69.39	125.07
28	Point Z	7.107834	532647	181143	20	560	7.11	6.11	200.75	94.41	78.76	209.49
29	Point Z	6.706337	532639	181125	20	580	6.71	5.71	134.79	111.85	186.33	326.05
30	Point Z	6.436757	532631	181107	20	600	6.44	5.44	513.60	216.13	305.94	228.08
31	Point Z	5.409564	532623	181088	20	620	5.41	4.41	680.56	398.05	469.87	217.99
32	Point Z	4.048445	532615	181070	20	640	4.05	3.05	1020.42	566.99	281.33	195.56
33	Point Z	2.007613	532607	181052	20	660	2.01	1.01	-807.95	70.82	178.96	184.15
34	Point Z	3.623505	532600	181033	20	680	3.62	2.62	1.75	-268.73	47.11	105.90
35	Point Z	3.62001	532593	181014	20	700	3.62	2.62	21.35	7.70	-148.28	5.74
36	Point Z	3.577307	532586	180996	20	720	3.58	2.58	43.44	21.60	-9.17	-95.83
37	Point Z	3.490419	532579	180977	20	740	3.49	2.49	-112.41	-22.99	-33.66	48.81
38	Point Z	3.715241	532573	180958	20	760	3.72	2.72	-120.69	-77.70	3.64	140.50
39	Point Z	3.956614	532567	180939	20	780	3.96	2.96	207.88	29.06	64.79	118.36
40	Point Z	3.540862	532561	180920	20	800	3.54	2.54	349.19	185.69	234.33	184.70
41	Point Z	2.842473	532556	180900	20	820	2.84	1.84	735.25	361.48	227.30	250.35
42	Point Z	1.371968	532551	180881	20	840	1.37	0.37	-155.82	193.14	300.57	279.91
43	Point Z	1.683616	532546	180862	20	860	1.68	0.68	574.21	139.46	313.28	181.49
44	Point Z	0.535206	532541	180842	20	880	0.54	-0.46	412.78	328.99	189.39	153.54
45	Point Z	-0.290348	532537	180823	20	900	-0.29	-1.29	115.80	176.19	85.45	37.20
46	Point Z	-0.521957	532534	180813	20	920	-0.52	-1.52	-760.98	-322.59	-77.47	85.45

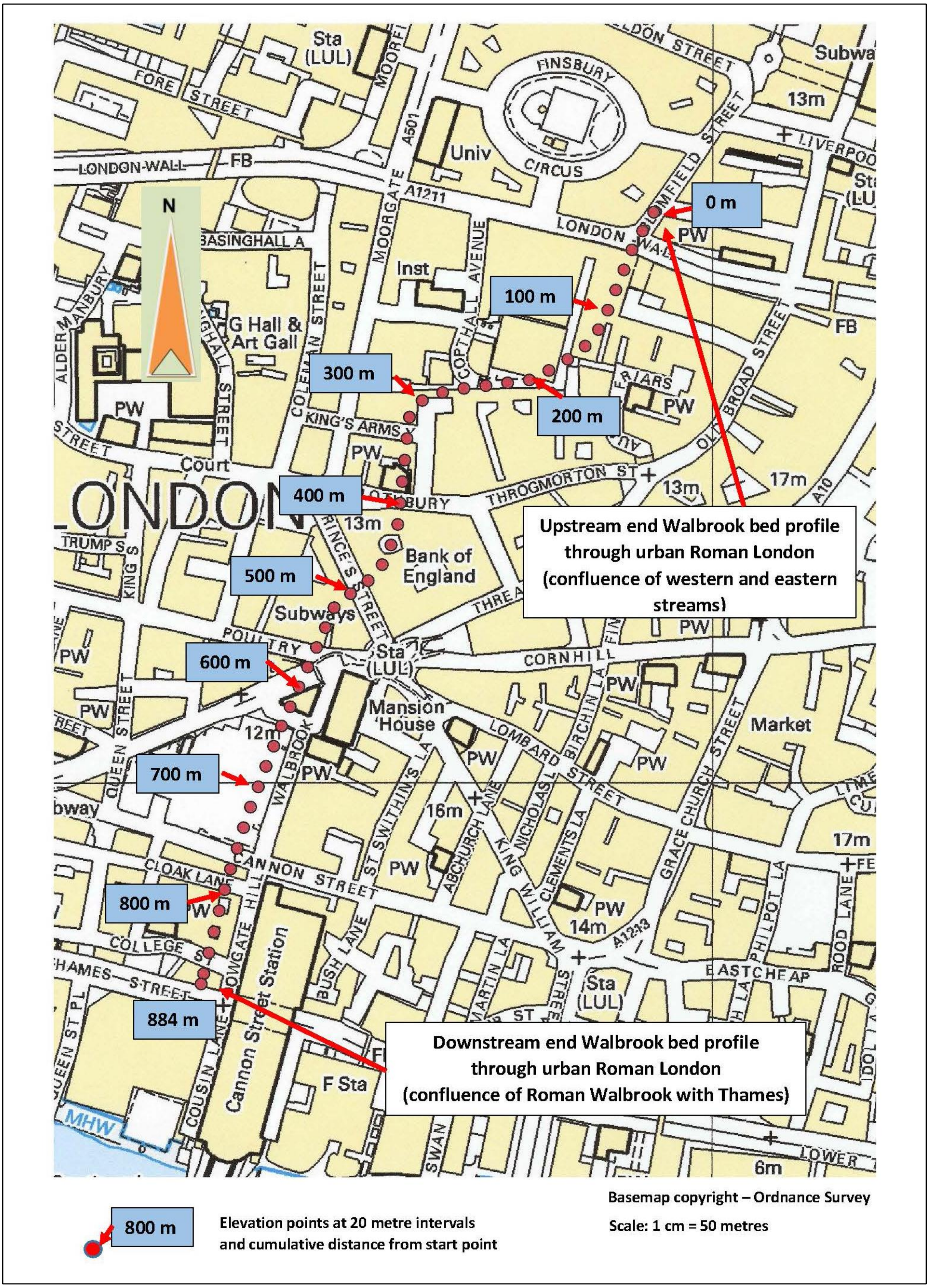


Figure 4-17 Line of the thalweg of the URWV and hence of the of the Walbrook, together with the location of the Z-points (elevations) used in the GIS analysis of riverbed slopes

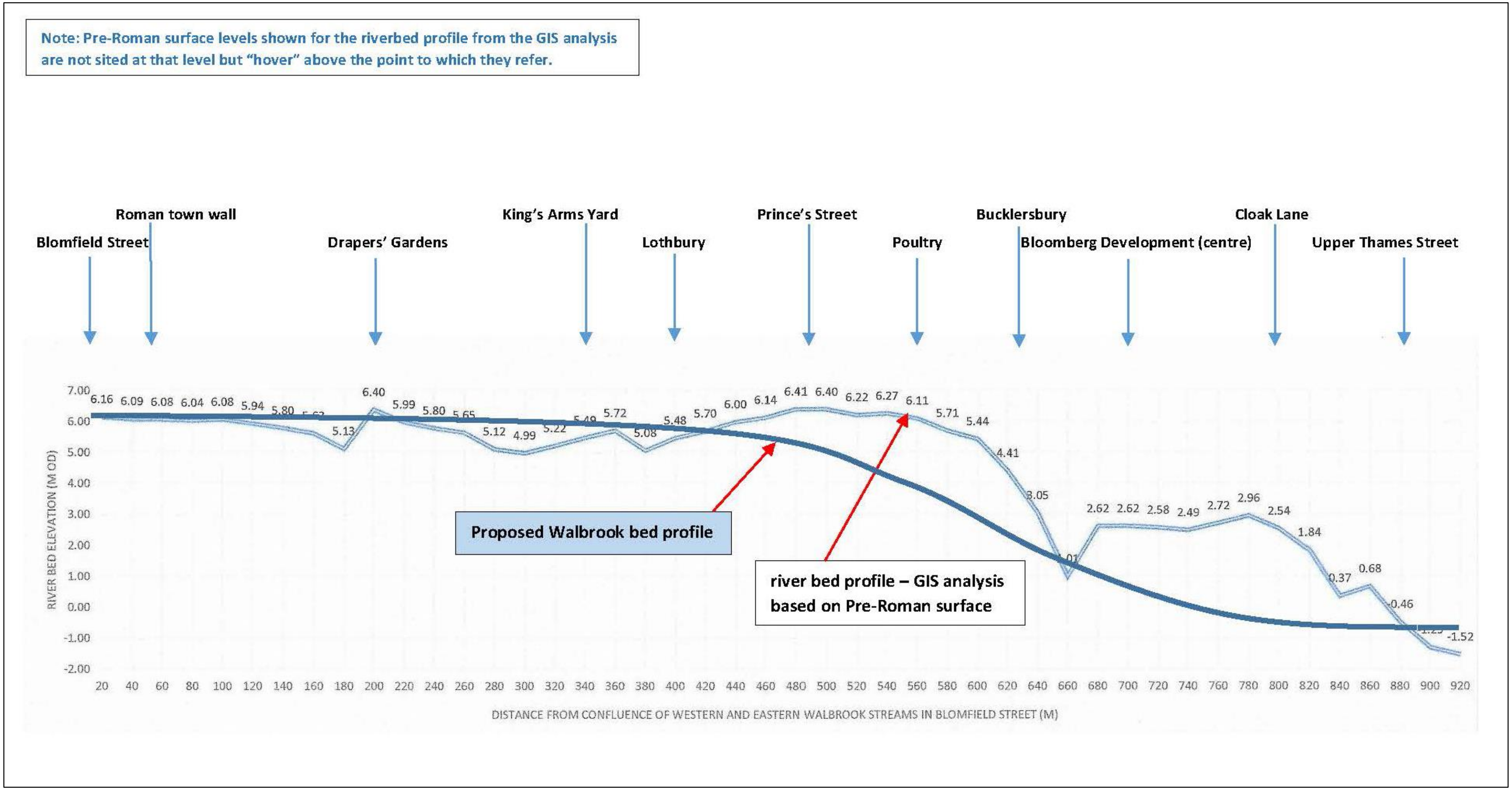


Figure 4-18 The River Walbrook through urban Roman London. The riverbed profile as derived from the GIS model analysis and as proposed

The urban Roman Walbrook can be divided into 5 distinct stretches each with its own slope to its bed between its upstream end, i.e. the confluence of the western and eastern streams, and the Thames at Upper Thames Street. These are shown in plan on Figure 4-19 and listed in Table 4.7 that also contains the data from which the bed slopes have been calculated. The riverbed slopes for these five stretches are shown on Figure 4-20.

The implications of the riverbed slopes are discussed in Chapter 6, Section 6.3 where the gradients of the riverbed are used in the flood-risk analysis to calculate the flow of the river at any point above which value its banks would be over-topped.

Table 4-7 Calculation of urban Roman Walbrook bed slopes over four of its constituent stretches

Stretch of urban Roman Walbrook	Distance (m)	Riverbed levels			Riverbed slopes
		Upstream	Downstream	Fall	
		(m OD)	(m OD)	(m OD)	(m/10,000m)
Zone D Blomfield Street to Lothbury	400	6.16	5.74	0.42	10.5
Zone C Lothbury to Bucklersbury	240	5.74	1.80	3.94	164
Zone B Bucklersbury to Cannon Street	120	1.80	0.30	1.50	125
Zone A Cannon Street to Upper Thames Street	130	0.30	-1.00	1.30	100

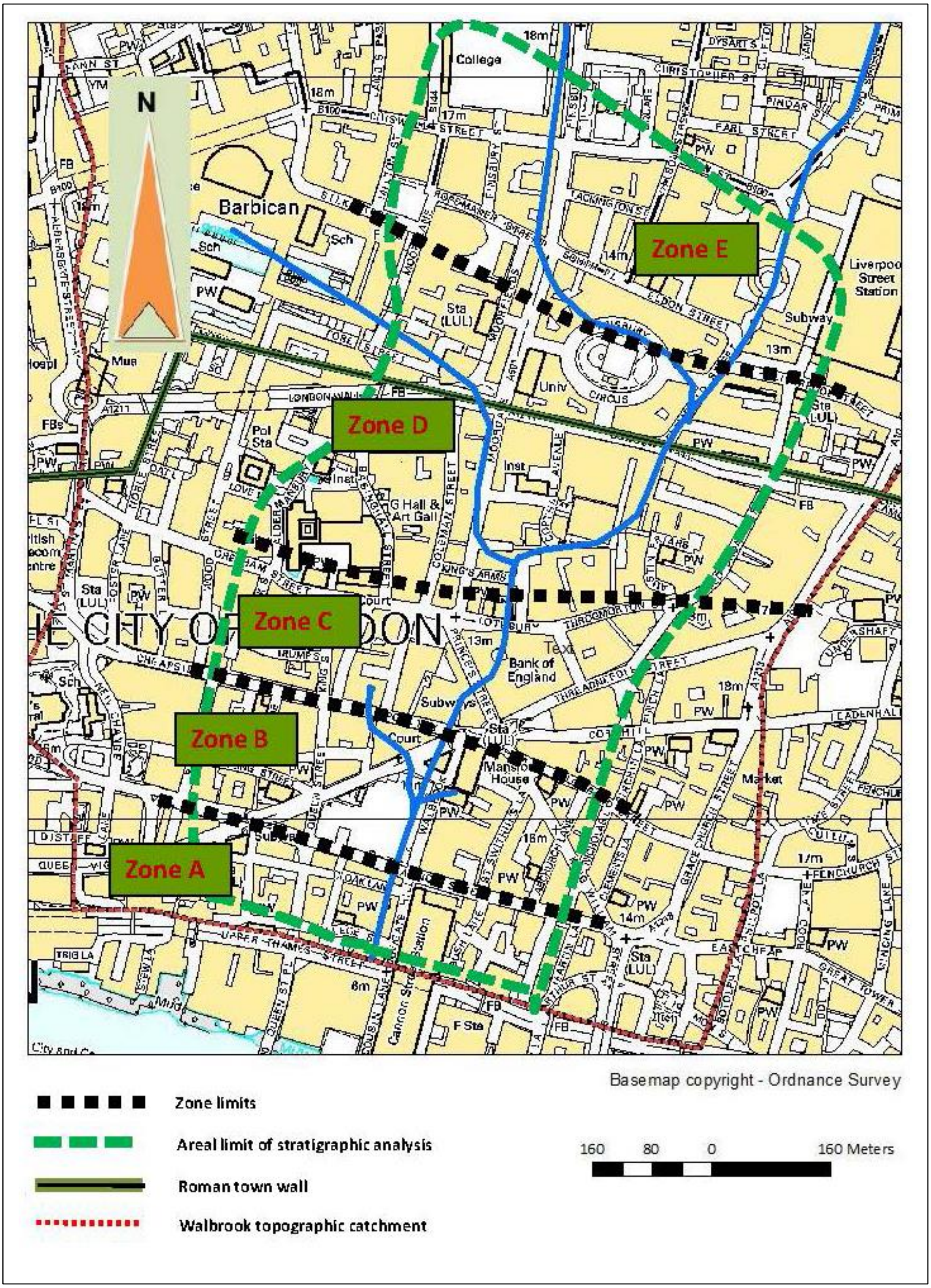


Figure 4-19 Limits of riverbed slope zones

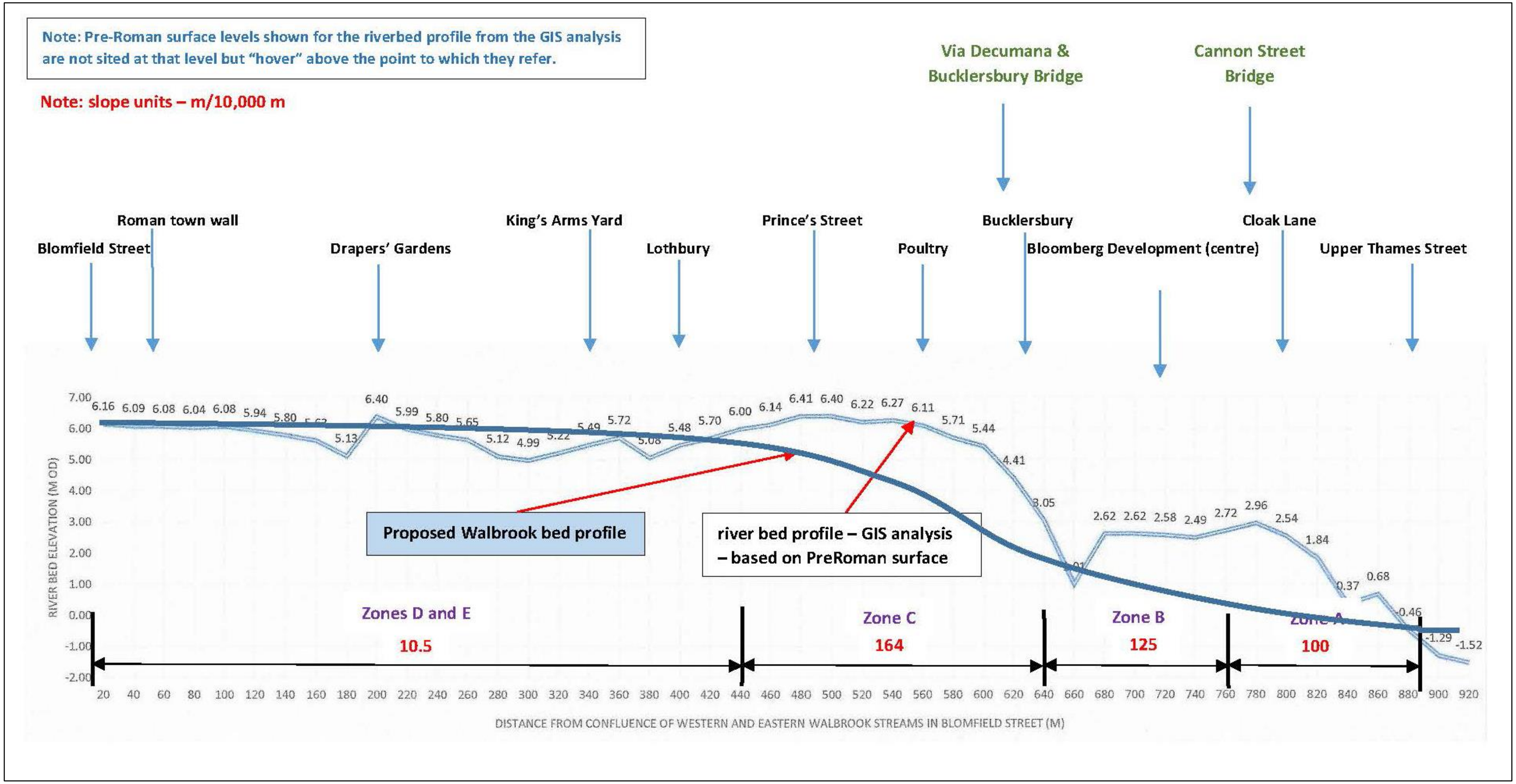


Figure 4-20 The River Walbrook through urban Roman London. Riverbed slopes

4.6 Geomorphology of the Urban Roman Walbrook Valley (URWV)

In the period preceding the arrival of the Romans, the processes affecting the geomorphology of the Greater Walbrook Valley were exogenic in nature.

The following aspects of geomorphology of the URWV as they relate to this research are based upon data drawn from the foregoing sections:

- Topography (Section 4.6.1)
- Pre-Roman Landscape (Section 4.6.2)
- Areas most at risk of flooding (Section 4.6.3)
- Potential for water-derived power (Section 4.6.4)

4.6.1 Topography

The surface designated Top pre-Roman (TPR) represents the natural topography of the URWV at the start of the Roman period. This ground surface can be identified in most City of London archaeological investigations by the presence of artefacts found just below or above this surface. It represents the uppermost ground surface of deposits laid down by the Walbrook on top of the bedrock geology, generally London Clay, and Pleistocene drift geology, over the millennia preceding arrival of the Romans, i.e. during the Early and Middle Holocene. This topographic surface is depicted in 2D in Section 4.5.1, Figure 4-8 and in 3D in Section 4.5.1, Figures 4-10 to 4-14. To expand on these, Figure 4-21 provides “birds-eye views” of the area respectively from the southwest and the south. Figure 4-22 is a cross-section, north to south, through the URWV and particularly highlights the shallow “bowl” depression in the land surface between Copthall Avenue, just south of the wall and Lothbury. Modern streets and landmarks are used to facilitate orientation along the urban Roman Walbrook.

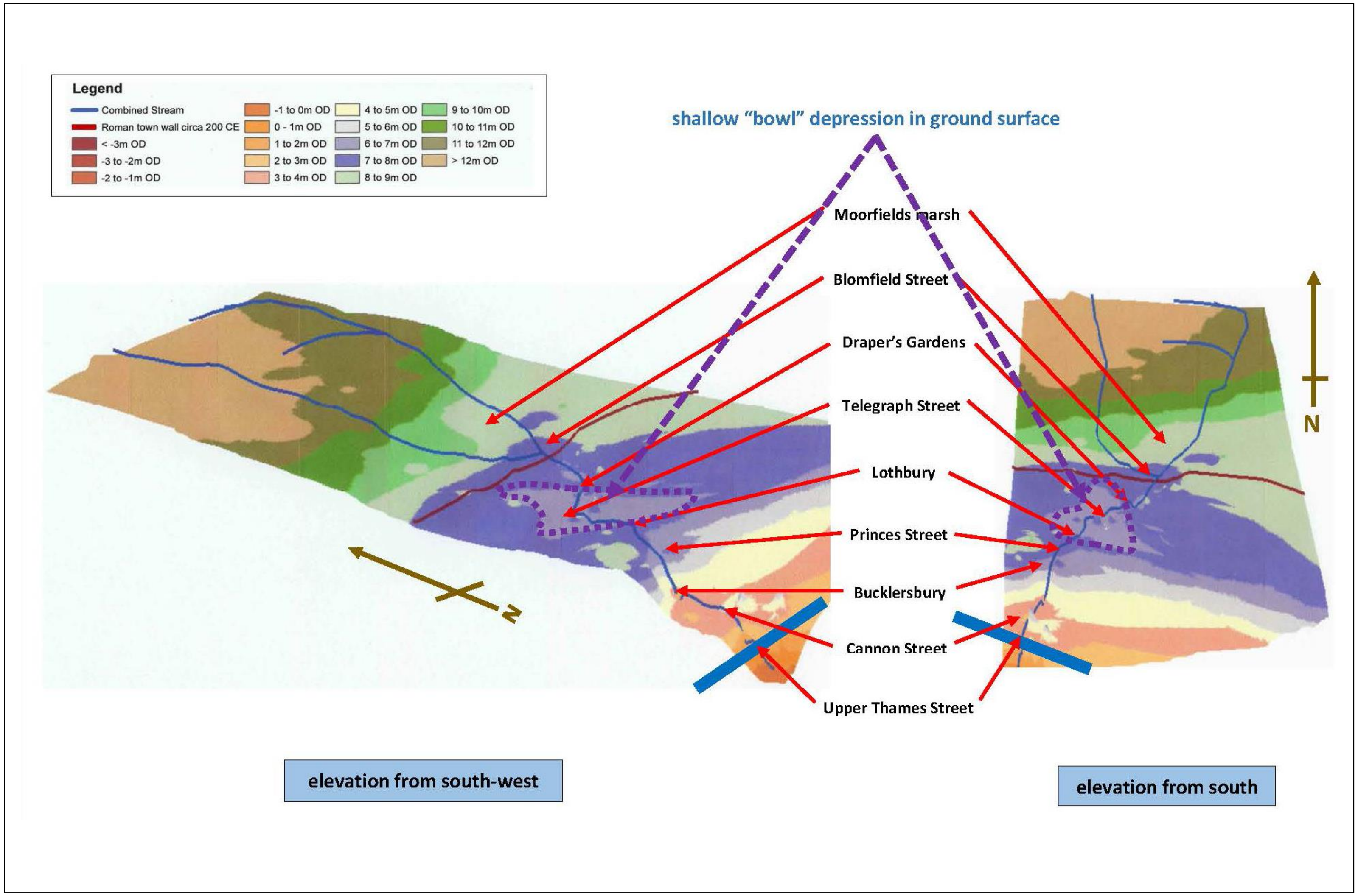


Figure 4-21 “Top pre-Roman” land surface of the URWV

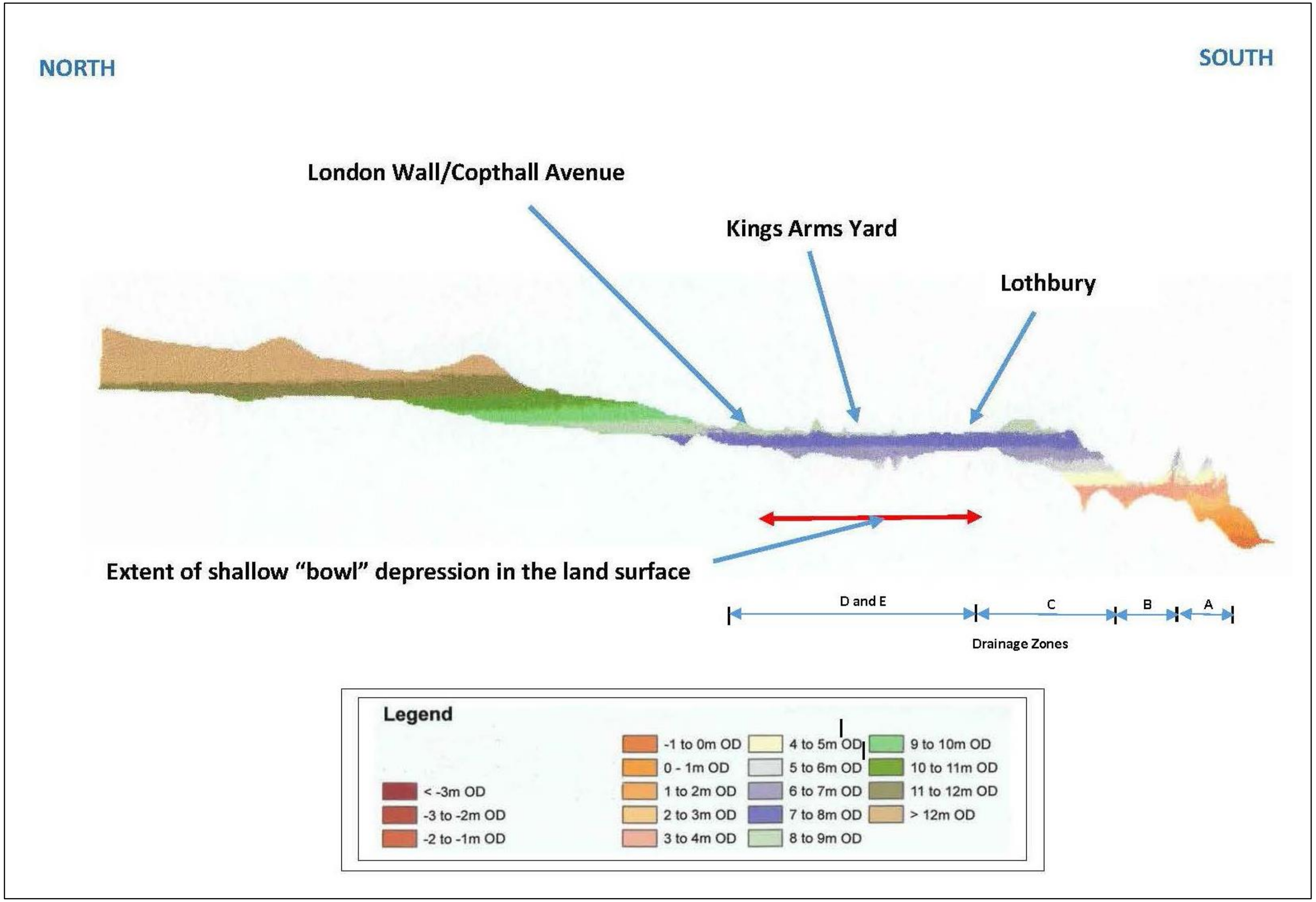


Figure 4-22 North-south cross-section through the URWV showing the location of the shallow "bowl" depression

Notable topographic points of interest can be identified from Section 4.5.1, Figures 4-7 to 4-14, Section 4.5.2, Figure 4-20 (the riverbed slopes for Zones A to D) and Figure 4-21, viz.:

- From Section 4.5.2, Table 4-7 and Figure 4-20, the bed of the pre-Roman Walbrook passes successively through stretches with significantly different bed slopes
  - a 400m long stretch, Zone D, from Blomfield Street to the southern side of Lothbury, having a barely discernible slope of 10.5m per 10,000m (0.1%);
  - a 240m stretch of steeper slope, Zone C, of 164m per 10,000m (1.64%), from immediately upstream of Lothbury, proceeding under the Bank of England, across Princes Street to Bucklersbury;
  - a 120m stretch with a shallower slope, Zone B, of 125m per 10,000m (1.25%), through the Bloomberg development to Cannon Street; and
  - a bed slope which eased a little over the final 130m long estuarine stretch, from Cannon Street to the confluence of the Walbrook with the Thames, having a slope of 100m per 10,000m (1.0%).
- A further area, Zone E, north of the town wall and the Roman urbanised area, known as Moorfields, was contiguous with Zone D; prior to construction of the wall, there would have been little difference in the topography of the two areas and Zone E would have had topographic and hydrological characteristics indistinguishable from those of Zone D.
- An extensive, heart-shaped, shallow depression in the ground surface, not much more than 1 metre below its general surroundings, was a major feature of Zone D, extending from Draper's Gardens south to Lothbury, northwestwards to the London Wall end of Copthall Avenue, west to Coleman Street, southwest to Old Jewry and as far as Throgmorton Avenue to the southeast.
- A narrow strip of land, bordering both banks of the Walbrook, extended the depressed land from Draper's Gardens northwards to just north of the town wall.
- A low east-west oriented ridge of land, which can be noted on Figure 4-22 along the line of Lothbury, marked the southern edge of the depression through which the Walbrook carved a steeper-sided passage through to Bucklersbury. The latter was the southern edge of the east-west ridge and the location of the bridge that carried the main east-west road of Roman London (POU05), the Via Decumana. In a draft of the report on the geo-archaeological work

carried out as part of the BZY10 investigation, this area was characterised as the location of a narrowing and steepening of the valley at Bucklersbury which dropped down to a more deeply-scoured, wider lower reach where the Bloomberg site is located. The change in slope here may be a "knick-point" in the valley formed by a fall in the base or sea level such as occurred at the end of the Pleistocene during channel incision. It is the point at which the southernmost line of the Taplow Gravel rests on the Kempton Park Gravel. The steeper gradient would have given the stream more erosive energy causing it to cut back upstream to Lothbury. (Ruddy, 2015).

- The draft geo-archaeological report for the BZY10 investigation also notes the existence of a drift-filled hollow (DFH) on the Bloomberg site filled with Pleistocene and Holocene sediment (Ruddy, 2015). This can be seen on Figure 4-22 as an inverted cone, prior to the BZY10 work thought to be an anomalous datum. Similarly, the report notes another DFH just offshore the Roman north bank of the Thames at the mouth of the Walbrook estuary. Data gathered by this current research also located this DFH, viz. the BGS boreholes Nos. 1065533 and 1065534, Section 4.5.1, Table 4-5, respectively located at the intersection of Cousins Lane and Upper Thames Street and Bell Wharf which showed Top Natural at approximately -8.50m OD, 6 to 7 metres lower than data from nearby sites.
- An area of land rose rapidly away westwards from Bucklersbury/Poultry, at an elevation exceeding 9.0m OD, well above the banks of the Walbrook channel that at this point were at 2.7m OD (ONE94; BOL94; POU05).
- There was a plateau at a higher level than the Walbrook valley floor, with a north-south oriented scarp slope on its western side immediately to the east of the Walbrook. This is represented in Figures 4-15 and 4-16 by the cluster of three high points resulting from isolated spot elevations (LYD88; CCP04/CNV08), upon which a high-status building stood, formerly known as the Governor's Palace. This building would have overlooked the Walbrook and Thames, respectively to its west and south.

Some general observations can also be made:

- protrusions above the general ground surface become less pronounced with time; in the progression from the natural drift geology to the overlying waterlain surface immediately prior to the arrival of the Romans this alteration will have been caused by natural processes, whereas the progression between the start and end of the Roman period is almost certainly due principally to re-shaping of the land surface by the Romans, in all probability for the most part prompted by a need to avoid flooding;

- land to the north of Finsbury Circus appears to have been at a generally higher elevation than that through the Circus itself and southwards. A gravel and sand terrace at Eldon Street had a surface that gently sloped across two investigation sites, ENS03 to BDC03, from northwest to southeast, from a level of c10.20m OD to 8.85m OD. Investigation work at FBY01 (Finsbury Square) found the natural Roman ground surface at 11.78m OD, approximately 220m to the north of Eldon Street, and at the VER90 site at 11.33m OD, 50m south of FBY01. This abrupt change in level may mark the boundary between the Hackney and Taplow terraces. There are 16th century references to a "High Field" in the Moorfields area which had its southern boundary at Worship Street about 150 metres north of the FBY01 site, a description suggesting that this portion of Moorfields was at a higher level than the land to the south (Ellis, 1798, 83; 156-183; 219; 225). It is probable, therefore, that flooding of Moorfields, due to the town wall, would have been restricted to land south of Eldon Street. It is claimed earlier in the same refference that the "Fin" of Finsbury is a corruption of "Fen", a possible reference to the marshy nature of the area.
- a raised area to the west of Poultry is a notable exception to the foregoing; here a small area appears to become more pronounced through the period of Roman occupation; although speculation, it may have been that ground-levelling activity in the vicinity preparatory to its progressive development may have led to a continuous accumulation of spoil material in the area and hence the progressively higher land surface; and
- recent archaeological investigation at the Bloomberg Development, BZY10, previously known as the Temple of Mithras site, has also found that the Walbrook Valley floor was relatively flat and low-lying to the west of the Walbrook but rose rapidly away from Queen Victoria Street westwards. Given the higher land to the north and east of the river, the view southwards from the bridge crossing the Walbrook at Bucklersbury would have been of looking down into a shallow amphitheatre-shaped area beyond which was a short estuarine stretch of the river opening out to the Thames.

These topographic points of interest, when combined with the slope to the riverbed at their location, dictate the natural topographic and hydrological character of that section of the Walbrook Valley that would be urbanised by the Romans immediately before their arrival.

4.6.2 Pre-Roman landscape

A description of the Roman London stretch of the Walbrook Valley as it may have been prior to the arrival of the Romans has been synthesised for each of the five zones, Sections 4.6.2.1 to 4.6.2.5, from points of interest identified from the topography of the Top pre-Roman surface and riverbed slopes derived from the stratigraphy. Vegetation cover of the Greater Walbrook Valley catchment is deduced and discussed in Chapter 5, Section 5.7.5.

4.6.2.1 Zone E - Moorfields to Finsbury Circus/Blomfield Street

This area covers more than half of the URWV. It had only a very gentle slope to the land, from northwest to southeast, as did the stretch of the Walbrook passing through it. Zone E contained the two Walbrook streams, both passing north to south before the western stream turned sharply east across the northern half of Finsbury Circus to join with the eastern stream. Whilst the two streams ran roughly parallel to each other along slowly converging paths, the western stream would have been at a slightly higher elevation than the eastern stream until the point of their confluence.

The land through which the two streams passed could be characterised as seasonal marsh being only occasionally below river level at times of continuous rain or storms. When not flooded, there would probably have been numerous “islands” of slightly higher land throughout the floodplain, forming secondary channels, some of which would have been just above water level even when the rest of the area flooded. The banks of the streams would have varied between 0.5 to 1.0 metres above the general bed of the river. Although the courses taken by both the principal western and the eastern streams would have been well-defined between definite banks in drier weather, they would have become progressively less-defined as runoff led to an increase in flows. Figure 4-23 indicates how the whole of Zone E may have appeared before general flooding covered much of the area as a consequence of the more extreme storms.

The banks of the river would have been flanked by waterlogged woodland, probably alder Carr, Figure 4-24, reeds and rushes, giving way to tall grasses, bushes and scattered trees, such as oak, hazel and alder (Scaife, 2011, 533-538) as the ground rose away from the marsh and was generally drier.

Figure 4-23 Marshy area, as parts of Zone E may have appeared in drier weather (internet image – stylepinner.com)

Figure 4-24 Alder Carr flanking a river - probably more dense than for Walbrook (Alamy stock photo)

A recent work which re-visited the findings from six archaeological sites which lie between Finsbury Circus and Eldon Street (Harward et al., 2015), particularly notes drainage southwards across the sites to a major “tributary” of the eastern stream. It is the view of this current work that the “tributary” referred to is the western stream link to the eastern stream, not a tributary. This conclusion has been arrived at in other research carried out in the second decade of the 20th C (Lambert, 1921, 55-112), The channel has also been uncovered in the course of the Crossrail work at Finsbury Circus. Zone E, although the location of the upper Walbrook cemetery (Harward et al., 2015) and of agricultural activity, remained virtually free of Roman land raising activity. The construction of the wall in 190 to 220 CE would have radically altered the visual character of the area as well as its hydrological character, as described in Section 7.4, creating a perennial marsh to the immediate north of the wall.

4.6.2.2 Zone D – Finsbury Circus/Blomfield Street to Lothbury

Zone D occupies the upper, and much of the middle, URWV, extending southwards for 440m along the Walbrook from the confluence of the western and eastern streams. The transition from Zone E to Zone D would hardly have been visible prior to the arrival of the Romans but for one significant topographical feature, the extensive heart-shaped, shallow depression in the ground. As described in Section 4.6.1, this straddled the Walbrook and extended from Draper’s Gardens south to Lothbury, northwest to the London Wall end of Copthall Avenue, west to Coleman Street, southwest to Old Jewry and as far as Throgmorton Avenue to the southeast. This depression would probably have been boggy in nature, at times almost dry and in wet weather would almost certainly have flooded to form a shallow pond. The bright green area in Figure 4-25 illustrates how such a feature may have appeared. In times of storm, the Walbrook would almost certainly have overtopped its low banks and frequently flooded the area. Less intense storms may well have created many temporary islands over the depressed area, whereas during the more extreme rainfall events, or when it had rained intensely for long periods, the area may have suffered extensive flooding, Figure 4-26.

A seminal work on this portion of the Walbrook Valley, which describes the investigation on a number of sites under the group reference KEY83, clearly shows the ill-defined nature of a series of sinuous tributaries roughly oriented in a southeasterly direction towards the Walbrook (Maloney, 1990; 26-28, 40 & Fig 44a).

Figure 4-25 Boggy, shallow, depression in the ground (bright green area), subject to frequent flooding (photo of unknown origin)

Figure 4-26 General flooding as a result of more extreme storms (alamy stock photo)

Apart from the depressed area in Zone D, it is difficult to be sure, when interpreting the archaeological records for Zone D, what form the remainder of the general physical topography took. Figures 4-23 and Figure 4-26 illustrate types of flooding that may have occurred when the general physical topography of the land was flat and criss-crossed by a myriad of inter-connected drainage channels or, alternatively, took the form of a corrugated topography or was flat with occasional high points.

Zone D was the location for much of the Roman land raising activity of the 1st and 2nd centuries. As illustrated by the statistics reported in Section 4.7.3, Tables 4-8 and 4-9, land was generally raised between 1 and 2 metres and, more exceptionally up to 4 metres. It is difficult to determine from archaeological investigations whether the land was only raised locally where housing was to be built or industry located or raised over large areas.

However, as already noted, it is apparent that the land was raised in most locations by stages, those settling the area never quite coming to terms with the full potential of the Walbrook to flood. It is probable, at least, that where there were small concentrations of dwellings and industry, and where principal roads crossed the area, a general campaign of land raising would have been undertaken.

Storm flows into the urban area would have been considerably reduced by culverting the Walbrook and its tributaries through the wall,, due to the throttling effect exerted by their limited cross-section. It is probable that a further degree of control would have been built into the flow management system by installing sluice gates at the entrances to each of the culverts. Construction of the town wall would therefore have resulted in a considerable reduction in the propensity of Zone D to flood and may have eliminated the phenomenon altogether. This situation is discussed further in Chapter 7, Section 7.4.1.

4.6.2.3 Zone C – Lothbury to Bucklersbury

The river falls through 3.94 metres in a relatively short distance, 240m between Lothbury and Bucklersbury. Zone C is therefore one of topographical transition for the river from the higher ground of the flat plain to the lower ground on the northern limit of Zone B. The slope of the riverbed was approximately 15 times steeper than through Zone D leading to a relatively confined, higher energy stretch of river channel.

At its northern limit, a low ridge passed from east to west across it, forming the southern boundary of the depressed area in Zone D. It contained a stretch of the Walbrook from Lothbury to Bucklersbury that carves a curving course down through it from north to south. The land rose sharply away on the west bank of the river and it is probable that the visual effect would have been to create a subsidiary, narrow valley through the section, the valley effect progressively increasing through to Bucklersbury. The ridge and “knickpoint” created by the river through it may mark the southern edge of the Taplow Gravel surface where it overlies the Kempton Park Gravel. It is at the southern limit of the area, that the Walbrook was bridged across the narrow valley in order to carry the town’s main road from the Forum in the east along Cheapside and out to the west.

It is unlikely that this stretch of the Walbrook would have been subject to flooding but even if the river had overtopped its banks under the most extreme of storm conditions, the narrowness of the valley and the steepness of its sides would have contained the inundation to a very small bankside area.

4.6.2.4 Zone B – Bucklersbury to Cannon Street (the Bloomberg Development)

Zone B, the Temple of Mithras site (WFG44 & 45), now known as the Bloomberg Development (BZY10), is a flatter area of land, when compared with Zone C, surrounded on its three landward sides by neighbouring land that was higher by 4 to 7 metres. The slopes around the perimeter were steep to the east and north and gentler to the west, the latter rising a further 6 to 7 metres to the catchment boundary which passed through St Paul’s. This higher surrounding land would have created an auditorium effect when viewed from the bridge across the Walbrook at Bucklersbury. To the east, above a steep, low scarp slope, was a high status building, formerly known as the Governor’s Palace. It was almost certainly sited to provide its occupants with a panoramic view across the Walbrook below to the western ridge around southwards over the Thames and eastwards to the bridge, the port and the Forum.

The Walbrook passes in a straight line through the eastern side of the Bloomberg Development from slightly east of north to slightly west of south for a distance of 120 metres.

Water from the Thames would have entered the Walbrook channel under spring high tides but only reaching the north end of the Bloomberg Development under the very highest of spring tides, which occurred at the start of the Roman occupation (see Section 5.7.7, Tidal levels in the Thames). For much of the Roman period, tidal inflow would have reached only the southern end of the Bloomberg Development. Only truly exceptional astronomic high tides combined with a spring tide would have raised the water in Walbrook to between 1.50 to 2.00 m OD a short way past the Bloomberg

Development less than 50m north of Bucklersbury. This would have been an extremely rare occurrence for much of the Roman period.

As it would have received rainfall draining from surrounding land, from a number of short tributaries found draining these areas, the lower, flatter area may have been marshy in its natural state. The following points have been drawn from an early draft of the report on the BZY10 investigation:

- environmental archaeological data found in the natural waterlain materials in course of the archaeological investigations have generally been characteristic of non-saline environments, indicating that any flooding of the area was not from a semi-saline Thames source but from drainage from surrounding areas;
- it is possible that the area may very occasionally have been subject to flooding, if a high tide had coincided with storm flows along the Walbrook; this is explored further in Chapter 6, Sections 6.3 and 6.4.3, and
- In its natural state, the area would have been at times boggy but for the greater part of the year would probably have been dry with bushes and reeds flanking the stream.

That the area was subject to flooding is suggested by evidence of land raising activity from an early date in the development of the town in order to accommodate industrial, craft and market activities. It is here that considerable amounts of stable waste were employed, together with a mix of anthropogenic and natural material, in reclaiming the land.

4.6.2.5 Zone A – Cannon Street to Upper Thames Street.

Zone A carries the estuarine stretch of the Walbrook. The bed of the river flattens slightly south of Cannon Street and this trend continues through to the Thames. As HWST was 1.50m OD at the beginning of the Roman period and the riverbed was at 0.30m OD, the Walbrook would have been tidal through the whole of this stretch and into the southern half of the Bloomberg Development. However, HWST fell to 0.00m OD by the middle of the 1st C and remained at this lower level until the 4th C. Under these conditions, the Walbrook would have been tidal only as far as Cloak Lane to the south of Cannon Street.

The Walbrook continued the line taken through the Bloomberg development until less than 50 metres from its confluence with the Thames. Over the remaining short, final stretch of the river it appears to have veered towards a southwesterly direction, as evidenced by findings from the DGH86 investigation. However, interpretation of evidence found in the course of the LYD88 Cannon Street Station investigation has led to the suggestion that the Walbrook had an easterly channel that ran down the side of that site. This division into two streams downstream of the Bloomberg Development would have created a delta with an island between the two streams. However, whereas the east bank of the Walbrook was located in the DGH86 excavation, none was found for an easterly branch of the stream.

There is evidence of flooding of the land to the east of the Walbrook in Zone A early in the development of the town and of remedial action in the form of building up the Thames embankment and drainage to avoid it. The impression given by the sparse evidence of Roman buildings or infrastructure in Zone A is of an open area of flattish land that, in its natural state, almost certainly was subject to flooding, particularly when high tides coincided with heavy rainfall.

Evidence of flooding is presented in Chapter 6, Sections 6.4.1 to 6.4.4, which deal respectively with Zones D to A.

4.6.3 Areas most at risk of flooding

The shallower the slope to a riverbed, the lower the velocity of flow in the river and hence, for a given channel cross-section, the lower the rate of flow that can be carried before its banks are over-topped. Therefore, from Section 4.6.2, the areas of the URWV at greatest risk of flooding are:

- land to either side of the river between the marsh at Moorfields up to and including Draper’s Gardens (Zones D and E);
- the shallow, heart-shaped, depressed area within Zone D with its southern boundary being the east-west ridge of marginally higher land at Lothbury (Zone D);

and, to a lesser extent,

- between Bucklersbury and Cannon Street, the area now known as the Bloomberg development (Zone B), and
- the riverside areas of the estuarine stretch nearest the Thames (Zone A).

The risk of flood events in these areas is explored further in Chapter 6, Section 6.4.

4.6.4 Walbrook Valley geomorphology and the potential for water-derived power

The potential of the Roman Walbrook to power one or more water mills is discussed in Chapter 8, Section 8.7. It had been suggested early in the research that the most likely location for such a milling operation would be by the banks of the Walbrook immediately south of Bucklersbury (Myers, 2012). It is therefore of some interest that investigations at the Bloomberg site (BZY10) appear to have unearthed evidence which could indicate a Roman milling operation at the northeast corner of the site. A typical overshot Roman waterwheel in the 1st and 2nd centuries had a diameter of 2 metres and the total fall in a river between the water offtake and the bed of the river at the mill would have needed to be between 2.6 and 3.0 metres. A mill that operated two wheels in series would have needed a fall of between 5.0 and 5.5 metres.

According to Figures 4-18 and 4-20, showing riverbed slopes, and riverbed elevation statistics in Table 4-6 supported by Figure 4-17, which showed the location for each of the data points, the riverbed elevation at the northeast corner of the Bloomberg site would have been approximately 2.0m OD. The offtake would have needed to be at a point upstream that would have had a bed level of between 4.6m OD and 5.0m OD. Due to there being a steeper bed profile between Bucklersbury and Lothbury, this would have been the case between a point just south of Princes Street and Lothbury, i.e. 180m and 260m upstream of the suggested location for a mill. An offtake at this point would have been sufficient to run a single-wheel mill installation.

Due to the shallow slope to the Walbrook's bed between Lothbury and Blomfield Street, it would appear from the riverbed profile that there would have been insufficient fall along the riverbed to power two wheels in series at the mill. Bed level at Blomfield Street would have been approximately 6.2m OD, 0.8 to 1.3m height short of that required to power two wheels. However, once the wall was constructed and if river flow through it were to have been controlled by sluice gates, water level upstream of the wall could have been artificially raised to create conditions sufficient for a second wheel in series. Land northwards of Finsbury Circus was typically at an elevation exceeding 8.50m OD and so raising water level to even 8.2m OD would not have led to flooding upstream of this area. However, since the land between the wall and Finsbury Circus and to the west over the area of the modern Moorgate London Underground station was at a lower level, this would have become a perennial marsh. (Archaeological evidence for a mill at Bucklersbury is presented in Section 8.7 and Appendix 8B).

4.7 Sedimentology of the Urban Roman Walbrook Valley (URWV)

4.7.1 Stratigraphy

Stratigraphic sections were constructed for 26 LAARC sites from their archaeological investigation reports, plans and sections. These 26 sites and their locations are depicted on Figure 4-27.

The stratigraphic sections form part of Appendix 4E – Stratigraphy, and are shown on Figures 4E-2 and 4E-3 and 4E-4 to 4E-10. They are grouped according to their respective riverbed zones, A to E. Individual stratigraphic sections show the three key horizons – viz. Top Natural (TNat), Top Pre-Roman Waterlain (TPR) and Top Roman Archaeology (Silberbauer and Logan, 2016) - the principal strata and notes relating to the strata as abstracted from site investigation reports. All 26 sites are within the URWV or its immediate vicinity in the northern rural suburb outside the line of the wall.

The following comments and conclusions are based upon the stratigraphic sections and comments in Appendix 4E supplemented by notes drawn from summaries of the individual site investigation reports, plans and sections as reviewed at LAARC (Full notes on each of the sites are reported in Appendix 2B):

1. Investigating archaeologists appear to have interpreted Top Natural as being deposits laid down prior to and during the formation of the Thames terraces.
2. In this respect, with the exception of SKN87/CKL88, for the most part, natural geology underlying the URWV is London Clay for eight Zone A and B sites. On only five of the eleven sites in Zone D was London Clay described as the natural strata. Gravel was described as

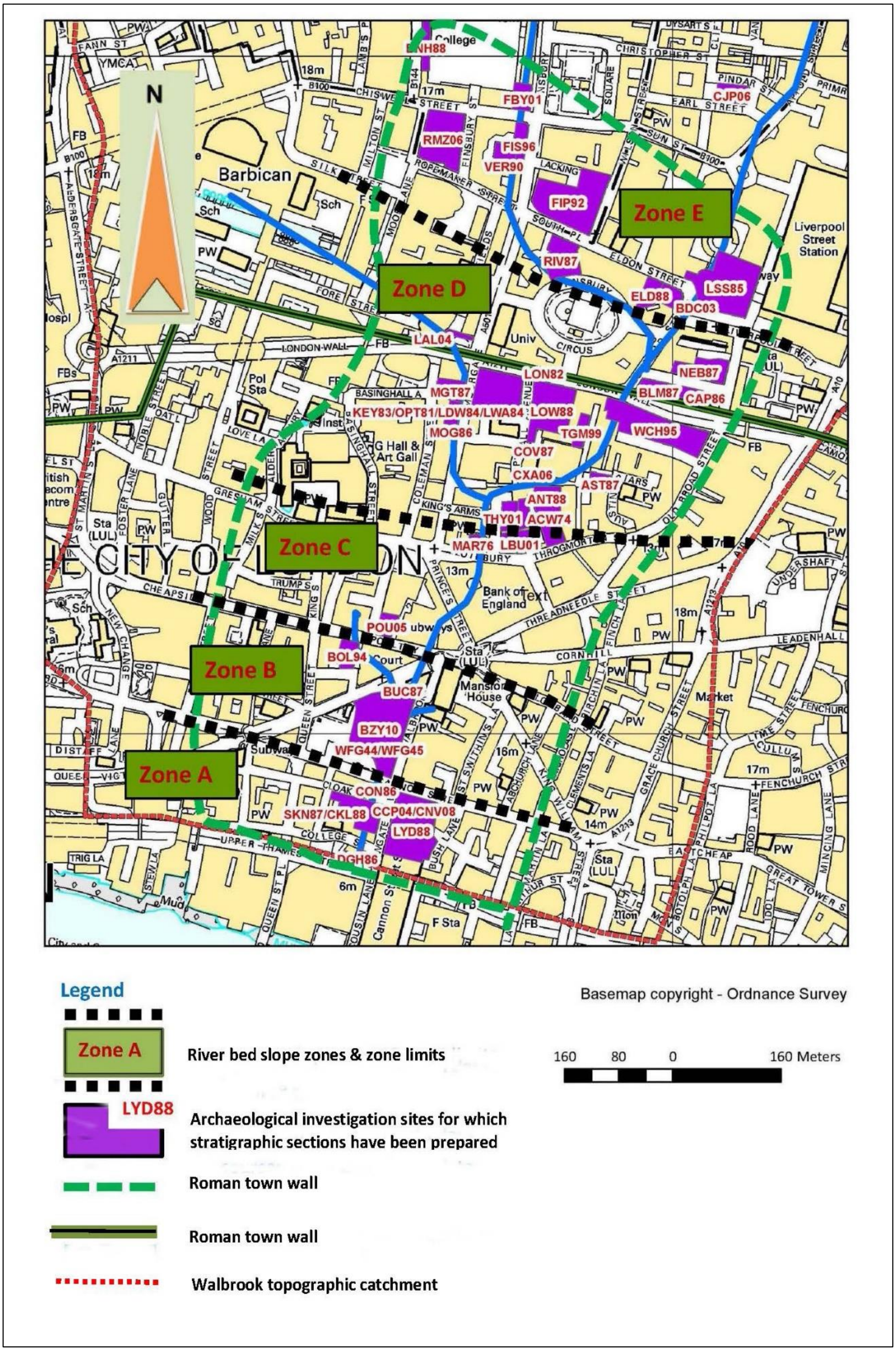


Figure 4-27 LAARC sites for which stratigraphic sections have been prepared

natural for the remaining six Zone D sites and all three of the Zone E sites. For the four Zone C sits, a transition zone, natural was found to be a mix of London Clay and gravel.

3. Overlying natural is a stratum of varying thickness principally composed of waterlain material, viz. gravel, sand, silt and clay, although a small proportion of the silt and clay may have been wind-blown deposits. In some cases, this stratum exhibited a small content of natural organic material. This layer will have been basic material from which the natural soil of the Greater Walbrook Valley was formed. Dependent upon the dominant constituent of these deposits, the soil at any point in the valley has been found to be a sandy, silty or clayey loam.
4. Only in a very few instances do the waterlain strata contain anthropogenic materials and, where these have been found, they are generally recorded as having been either deliberately deposited in a pit, trodden into the layer or mechanically driven into it.
5. Chronological resolution of the stratigraphic data drawn from the LAARC records has generally been reported to a lower standard than other data. For only four of the twenty-seven sites included in the research could the dating of strata, by dendrochronology, ceramics or coins, be considered reliable, viz. THY01 (6-8 Tokenhouse Yard, EC2), MGT87 (55-61 Moorgate, EC2), NEB87 (35-45 New Broad Street) and LSS85 (Liverpool Street and Broad Street Stations, EC2). A number of other investigations do provide some dating but it is often difficult to understand on what evidence the dating statements are based.
6. In absence of reliable dating, the finding of anthropogenic material in the stratigraphy overlying the "pure" waterlain strata has been considered to be evidence of Roman occupation. Absence of Roman anthropogenic material has been taken to indicate the top limit of the Roman stratum, i.e. Top Roman Archaeology.
7. Materials comprising the layers laid down in the course of the Roman occupation are, for the most part, the result of topographic landscape management through ground-raising activity by the Romans.
8. Thin bands of silt have been interpreted as evidence of frequent flooding, often stimulating eventual ground-raising activity, and these have been more noticeable in Zone D. However, with only one exception, no evidence has been found on other sites of individual, catastrophic flood events resulting in the deposition of significant layers of waterborne materials. That exception is BLM87, where an avulsion, evidenced by extensive crevasse-splay deposits in the form of an alluvial fan, was found in the eastern bank of the eastern Walbrook stream. Given

that the eastern stream had a virtually straight channel at this point, it required another force to create the avulsion. This site of the avulsion coincides precisely with the point at which the western Walbrook joins the eastern stream, and storm flow from the former could have caused the direct impact sufficient to cause the avulsion

9. The materials to raise land levels varied considerably between sites but evidence indicates the following were used:
    a. levelling - soil excavated locally from high points to fill depressions in the surface;
    b. natural superficial materials imported from elsewhere, most commonly gravels, sand, silt or clayey or sandy silt as well as brickearth and silty clay;
    c. waste material from quarrying activity in the general region;
    d. material of anthropogenic origin, in the main building debris, with frequent mention of ash and flakes or fragments of charcoal and shellfish, mainly oysters; stable waste was used in Zone B and in a few instances, solid wastes from craft and industrial activity have been found; and
    e. organic waste materials from animal husbandry, agriculture and horticulture practised by the Romans following tree-clearing activity in the catchment north of the urban area.

4.7.2 Nature of the soil

Within a catchment, such as that of the Walbrook, the soil is a product of weathering of rocks and abrasive activity when rocks in their original or weathered form are either wind-blown or conveyed by water draining over land and in streams. The “natural” geology of the Greater Walbrook Valley has been summarised in Section 3.3.4 and illustrated on Figure 3-4 as 84% gravels and sands, 6% silt, 5% London Clay and 5% as alluvium, the latter generally being found in the lower catchment. The degradation products of these superficial deposits, mixed in many different combinations, are the origin of the soil of the catchment.

From the stratigraphic sections in Apppendix 4E, it can be seen that the most common form of soil overlying the waterlain deposits of the URWV is a mix of silt, sand and clay in varying proportions, generally with a humic content. This type of soil is commonly called loam and, where found in the London area, is a good fertile medium for vegetation (Willats, 1937). Of the three principal soil constituents, silt is found in significant amounts of varying proportions in nearly all of the materials excavated in the course of archaeological investigations in the URWV. Silt is generally a product of the weathering and abrasion of sand and it is probably the high sand content of the upper Walbrook Valley that is the origin of the ubiquitous silt that may have been carried to the lower levels of the catchment by the stream or, to a minor degree, blown on the wind.

However, more than 90% of the catchment of the Greater Walbrook Valley lies outside of the URWV. It is this extra-urban area that was the gathering ground for both the base and storm flows entering urban Roman London. An assessment of the hydrological regime of the Greater Walbrook Valley in the Roman period will be influenced by the nature of the soil and hence of the probable vegetation. Data on soil within the catchment is limited to the Roman urban and suburban areas, where most of the archaeological work has been carried out. The potential of the Walbrook to convey clay, sand, silt and gravel is discussed in detail in Chapter 6, Section 6.6. However, clay having the smallest particle size of the main constituents of the soil of the Walbrook Valley and the most likely soil constituent to have been transported by streams to the lower catchment levels. The soils of the upper and middle regions of the Greater Walbrook Valley are therefore more likely to have a higher proportion of sand, silt and gravels than the soils of the lower, urban parts of the catchment. Clay has a tendency to reduce the permeability of soils and the soils of the upper and middle catchment, due to their lower clay content, would almost certainly have been more permeable than those found in archaeological investigations in the lower catchment. The organic content of the fertile loamy soils will also have been significant due to decomposition in-situ of plant material and leaf fall. This silty, clayey, sandy soil would have overlain gravels and sand for 84% of the catchment. The implications of this conclusion for the hydrological character of the catchment are discussed in Sections 5.6.2 and 5.7.3.

4.7.3 Roman ground-raising activity

Figure 4-28 shows the locations of the forty archaeological investigation sites from which stratigraphic data has been extracted in order to assess the nature and extent of ground-raising activity undertaken in the URWV. It also shows the limits of the five zones, A to E, used to differentiate stretches of the urban Roman Walbrook with differing hydrological characteristics. Data was abstracted from ninety-one trenches, trial pits and boreholes on the 40 sites. Table 4-8 reports the stratigraphic data relating to the three key research horizons, Top Natural. Top pre-Roman and Top Roman Archaeology, as drawn from the forty sites, categorised by their respective zones. The table summarises the thickness of the waterlain deposits and the thickness of the deposits dumped by the Romans when ground raising as well as a summary of the nature of the material used by the Romans to raise and re-shape the land at each of the archaeological sites reported.

To facilitate the reading of Table 4-8, it has also been reported in Appendix 4F which can be found on the DVD.

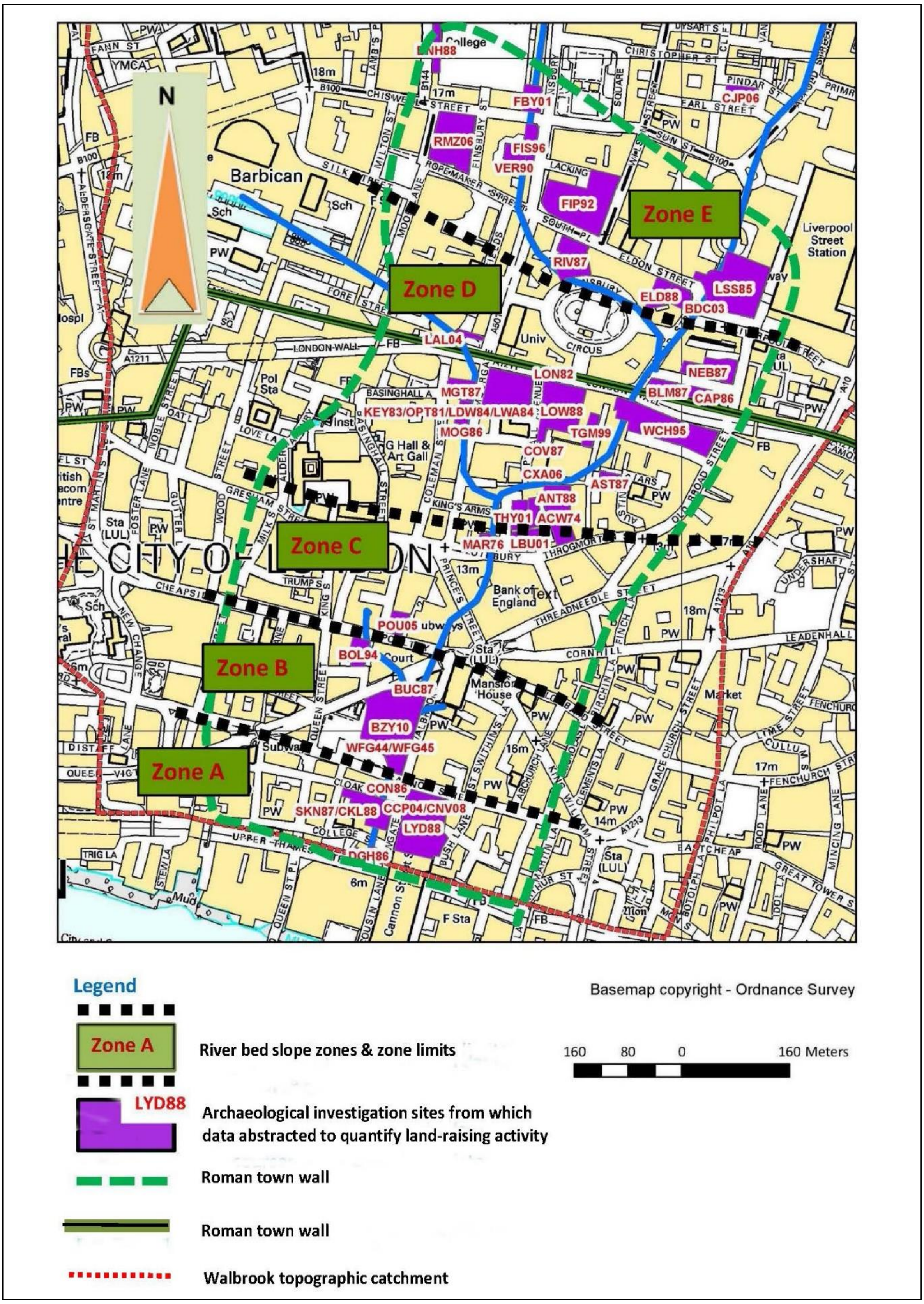


Figure 4-28 **Riverbed slope zones and archaeological investigation sites from which data abstracted to ascertain extent and nature of Roman ground-raising activity**

Table 4-8 Thickness of pre-Roman waterlain deposits and ground-raising deposits

Depths of pre-Roman waterlain ground and Roman made ground

Zone	Ref	Address	Easting	Northing	Top natural (m OD)	Depth waterlain (m)	Top pre-Roman waterlain (m OD)	Depth Roman made ground (m)	Top Roman Archaeology (m OD)	Range/average deposit depth (m) Pre-Roman waterlain	Roman made ground	Principal material used when raising ground level
A	DGH86	Dowgate Hill House, Dowgate Hill, London, EC4 (E-W section, S side site_	532526	180818	-2.10	1.32	-0.78	1.78	1.00			clayey silt; organic, peaty
	DGH86	Dowgate Hill House, Dowgate Hill, London, EC4 (Pile hole 2)	532512	180826	-4.85	4.05	-0.80	2.40	1.60			sandy silt, some pebbles, bone & shell
	DGH86	Dowgate Hill House, Dowgate Hill, London, EC4 (Test pit W)	532520	180822	-4.85	4.00	-0.85	2.45	1.60			silt; sandy silt; organic/anthropogenic
	LYD88	Cannon St Stn north, Upper Thames Street (Dowgate Hill, EC4 (Section 35(r))	532600	180817	-0.14	1.21	1.07	0.43	1.50	**0.2 to 4.1**	**0.3 to 3.9**	silty sandy clay; pebbles; building debris
	LYD88	Cannon St Stn north, Upper Thames Street (Dowgate Hill, EC4 (Section 43)	532575	180814	-0.02	0.65	0.63	0.87	1.50	**1.6**	**1.7**	peaty silt; gravel/sand; clayey silt & silty clay
	SKN87 & CKL88	Skinner's Hall Kitchen, 8-9 Cloak Lane, London, EC4 (Trenches B & W)	532547	180885	0.87	0.28	1.15	3.91	5.06			clayey silt; gravel & sand; building debris
	CON86	76 Cannon Street, London, EC4	532570	180915	2.74	0.26	3.00	2.74	5.74			no data
	CCP04/CNV08	Cannon Place, London, EC4 (Trial pit 1)	532583	180836	5.15	0.20	5.35	0.85	6.20			clayey sandy silts; demolition debris
	CCP04/CNV08	Cannon Place, London, EC4 (Trial pit 5)	532625	180844	4.15	2.30	6.45	0.30	6.75			demolition debris
B	WFG44&WFG45	Bucklersbury House (Temple of Mithras), London, EC4	532552	181005	0.29	1.78	2.07	1.13	3.20			loamy clay; brickearth
	WFG44&WFG45	Bucklersbury House (Temple of Mithras), London, EC4	532545	181007	2.13	1.37	3.50	2.05	5.55			loamy clay; brickearth
	BZY10	Bloomberg Place, London, EC4	532609	181052	1.00	0.60	1.60	0.90	2.50			anthropogenic, including stable manure
	BZY10	Bloomberg Place, London, EC4	532601	181058	2.00	1.80	3.80	3.90	7.70	**0.3 to 3.4**	**0 to 3.9**	anthropogenic, including stable manure
	BZY10	Bloomberg Place, London, EC4	532618	181050	1.80	3.40	5.20	2.00	7.20	**1.5**	**1.7**	anthropogenic, including stable manure
	BZY10	Bloomberg Place, London, EC4	532600	181008	2.30	1.30	3.60	0.00	3.60			anthropogenic, including stable manure
	BUC87	Dockland Light Rail Shaft, Bucklersbury, (near Queen Victoria St), London, EC4	532593	181068	3.87	0.26	4.13	3.17	7.30			brickearth; sandy silt; demolition/organic
	BOL94	Bolsa House, 76-80 Cheapside, London, EC2 (borehole 1; N end basement)	532516	181136	7.30	1.10	8.40	1.35	9.75			anaerobic sandy & clayey silt; pebbles/ragstone
	BOL94	Bolsa House, 76-80 Cheapside, London, EC2 (borehole 2; S end Bolsa House)	532541	181098	6.80	1.60	8.40	0.60	9.00			sand/pebbles; clayey silt; charcoal/shells/mortar
C	POU05	36 Poultry, London, EC2 (Test pit 3)	532575	181169	7.00	2.10	9.10	0.70	9.80			silt; charcoal/burnt daub
	POU05	36 Poultry, London, EC2 (Test pit 8)	532574	181150	7.00	2.10	9.10	0.80	9.90	**1.00 to 2.67**	**0.70 to 1.80**	road? Layers sand & compacted gravel; charcoal/oysters
	LBU01	41 Lothbury, London, EC2 (Borehole 2)	532796	181313	5.50	2.67	8.17	1.80	9.97	**2.0**	**1.1**	silty clay
	MAR76	St Margaret Lothbury Church, Lothbury, London, EC2	532723	181300	5.00	1.00	6.00	1.00	7.00			no data
	ANT88	9-10 Angel Court, London, EC2 (Section 1; near W wall, NW corner of building)	532750	181336	6.10	0.10	6.20	3.27	9.47			sandy sit; gleyed clay & silt; charcoal
	ANT88	9-10 Angel Court, London, EC2 (Section 2; near N wall, NW corner of building)	532757	181342	4.50	0.05	4.55	4.67	9.22			organic silty clay dumped over marsh
	ACW74	1-8 Angel Court, 30-35 Throgmorton Avenue, London, EC2 (Trench A; NE end site)	532821	181361	7.08	0.07	7.15	1.37	8.52			brown & grey silty soil; nails/glass/shell/anthropogenic
	THY01	6-8 Tokenhouse Yard, London, EC2 (Trench 2, SE corner site)	532784	181309	4.09	0.59	4.68	3.13	7.81			silty clay, occasional peat
	THY01	6-8 Tokenhouse Yard, London, EC2 (Trench 1, NE corner site)	532776	181333	4.09	0.98	5.07	3.51	8.58			silty clay some gravel & peat
	THY01	6-8 Tokenhouse Yard, London, EC2 (Borehole 1)	532753	181317	4.93	2.89	7.82	0.50	8.32			sandy clayey silt; anthropogenic
	THY01	6-8 Tokenhouse Yard, London, EC2 (Borehole 2)	532767	181315	5.24	2.25	7.49	1.75	9.24			sandy clayey silt; anthropogenic
	THY01	6-8 Tokenhouse Yard, London, EC2 (Borehole 3)	532767	181331	5.25	1.90	7.15	1.90	9.05			organic silt; sandy gravel
	AST87	22-25 Austin Friars, London, EC2 (Section 3 - SW corner of site)	532877	181361	6.80	0.80	7.60	1.20	8.80			gravel & sand; sandy silt
	AST87	22-25 Austin Friars, London, EC2 (Section 8 - mid E side of site)	532902	181367	8.33	0.46	8.79	0.78	9.57			clayey silt; pebbles; charcoal/oysters/mortar
	AST87	22-25 Austin Friars, London, EC2 (Section 11 - NW corner of site)	532800	181380	6.04	1.44	7.48	1.58	9.06			sandy, clayey silt; ash/charcoal/decayed timber
	CXA06	2 Copthall Avenue, London, EC2 (Borehole 2)	532794	181396	5.56	0.38	5.94	1.86	7.80			sandy & clayey gravel; gravelly clay
	CXA06	2 Copthall Avenue, London, EC2 (Borehole 25)	532784	181396	6.09	0.29	6.38	1.42	7.80			no data
	CXA06	2 Copthall Avenue, London, EC2 (Borehole 27)	532790	181398	5.53	0.88	6.41	1.39	7.80			sandy clayey silt; gravel; charcoal/oysters/mortar
D	COV87	10-12 Copthall Avenue, London, EC2 (borehole 1)	532843	181385	7.02	0.70	7.72	0.68	8.40			silty clayey sand
	COV87	10-12 Copthall Avenue, London, EC2 (borehole 2)	532849	181398	6.94	0.68	7.62	0.78	8.40			clay, occasional pebbles
	TGM99	8-10 Throgmorton Avenue, London, EC2 (trial pit 1; S end of site)	532856	181428	5.45	2.05	7.50	1.60	9.10			sandy silt (brickearth); building debris/charcoal/oysters
	TGM99	8-10 Throgmorton Avenue, London, EC2 (trial pit 8; N end of site)	532868	181464	5.20	2.30	7.50	1.35	8.85			sandy silt (brickearth); building debris/charcoal/oysters
	WCH95	72 & 74-78 London Wall, London, EC2 (Borehole A, Trench 1)	532949	181480	5.34	1.94	7.28	1.90	9.18			silt; silty clay; sandy silt; anthropogenic
	WCH95	72 & 74-78 London Wall, London, EC2 (Area 1 - average levels)	532951	181471	5.96	1.13	7.09	1.91	9.00			silt; silty clay; sandy silt; anthropogenic
	WCH95	72 & 74-78 London Wall, London, EC2 (Area 2- average levels)	532948	181462	5.37	1.93	7.30	1.62	8.92			silt; silty clay; sandy silt; anthropogenic
	WCH95	72 & 74-78 London Wall, London, EC2 (Area 3 - average levels)	532959	181444	6.92	0.70	7.62	1.48	9.10			silt; silty clay; sandy silt; anthropogenic
	WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2 (Area 1; pile 177)	532948	181475	5.62	1.13	6.75	2.27	9.02			no data
	WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2 (Area 1; pile 184/185)	532964	181469	6.92	0.75	7.67	1.00	8.67			no data
	WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2 (Area 2; pile 169)	532944	181462	5.14	1.50	6.64	2.80	9.44			no data
	WCH95	Winchester House, 72 & 74-82 London Wall, London, EC2 (Area 3; TC1 &TC3)	532946	181450	7.02	0.45	7.47	1.60	9.07	**0 to 2.89**	**0.10 to 4.67**	no data
D	LOW88	52-63 London Wall, 20-56 Copthall Avenue, London, EC2 (Section through Road 2)	532820	181470	6.50	0.78	7.28	1.22	8.50	**0.8**	**1.5**	road raiding; highest flood deposits at 8.12 m OD
(contd)	MOG86	49-53 Moorgate, 72-74 Coleman Street, London, EC2 (Area M)	532677	181465	8.92	0.16	9.08	0.12	9.20			sandy silt & pebbles; charcoal
	MGT87	55-61 Moorgate, London, EC2 (Trench G; NE side site)	532685	181510	7.10	0.20	7.30	1.60	8.90			clayey silt; charcoal/shells
	MGT87	55-61 Moorgate, London, EC2 (Trench H; mid N side site)	532670	181510	7.20	0.10	7.30	1.56	8.86			silty clay; brickearth; charcoal/shells
	MGT87	55-61 Moorgate, London, EC2 (Trench F-F; behind NNE-SSW revetments 1 & 2)	532682	181494	6.50	0.50	7.00	1.48	8.48			silty clay with gravel; glassmaking waste
	MGT87	55-61 Moorgate, London, EC2 (Trench F-F (2N); river side NNE-SSW revetments)	532684	181499	6.50	0.50	7.00	1.48	8.48			sandy, clayey silt; brickearth; organics
	MGT87	55-61 Moorgate, London, EC2 (Trench F-F (25); river side NNE-SSW revetments)	532683	181489	6.50	0.50	7.00	1.48	8.48			sandy, clayey silt; brickearth/demolition

Table 4-8 (continued) Thickness of pre-Roman waterlain deposits and ground-raising deposits (continued)

Zone	Ref	Address	Easting	Northing	Top natural (m OD)	Depth waterlain (m)	Top pre-Roman waterlain (m OD)	Depth Roman made ground (m)	Top Roman Archaeology (m OD)	Range/average deposit depth (m) Pre-Roman waterlain	Roman made ground	Principal material used when raising ground level
	MGT87	55-61 Moorgate, London, EC2 (Trench B; SW corner site, E of trench A)	532658	181495	6.55	1.00	7.55	1.45	9.00			brickearth; silty clay; demolition waste
	KEY83 + 4 sites	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court, London, EC2	532737	181481	5.28	0.56	5.84	2.64	8.48			organic sandy sitly clays; anthropogenic
	KEY83 + 4 sites	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court, London, EC2	532734	181481	5.50	1.04	6.54	2.22	8.76			organic sandy sitly clays; anthropogenic
	LAL04	London Wall/Moorgate, London, EC2 (Trench 1)	532678	181580	8.20	0.00	8.20	1.20	9.40			sandy clay; clayey silt; building debris/ragstones
	LON82	London Wall, Junction with Blomfield Street, London, EC2	532810	181530	6.80	0.85	7.65	0.18	7.83			sandy gravels; silty organic clay; charcoal/oysters
	BLM87	Blomfield House, 85-86 London Wall, London, EC2 (Trench A; E end of site)	532992	181505	7.40	0.20	7.60	0.10	7.70			clayey sit; freshwater molluscs
D	BLM87	Blomfield House, 85-86 London Wall, London, EC2 (Trench B; SW end of site)	532954	181512	6.80	0.20	7.00	1.25	8.25			sandy silt; silt; gravel; over marsh
	BLM87	Blomfield House, 85-86 London Wall, London, EC2 (Trench C; W end of site)	532958	181517	6.89	0.21	7.10	0.70	7.80			sandy silt; silty clay; crevasse splay deposits
	BLM87	Blomfield House, 85-86 London Wall, London, EC2 (Trench E; NE end of site)	532961	181526	7.25	0.05	7.30	1.05	8.35			silt, gravel & organics; crevasse splay deposits
	CAP86	Capel House, 54-62 New Broad Street, London, EC2 (Trench B)	533012	181511	7.60	0.15	7.75	0.85	8.60			gravel; pebbles; organic clay
	CAP86	Capel House, 54-62 New Broad Street, London, EC2 (Trench E)	533067	181500	8.65	0.05	8.70	0.35	9.05			sandy gravel; silty clay
	NEB87	35-45 New Broad Street, London, EC2 (Test pit 13)	533041	181552	8.80	0.03	8.83	0.35	9.18			sandy gravel; silty clayey sand
	NEB87	35-45 New Broad Street, London, EC2 (Test pit 16)	533039	181505	9.08	0.12	9.20	0.34	9.54			sandy gravelly & sandy silty clay; mortar
	NEB87	35-45 New Broad Street, London, EC2 (Test pit 18)	533018	181533	7.86	0.14	8.00	0.78	8.78			sandy silty & gravelly clay
	BDC03	6 Broad Street Place, London, EC2 (Test pit 3)	532990	181645	6.50	1.60	8.10	0.80	8.90			brickearth; gravel & sand; silt
	BDC03	6 Broad Street Place, London, EC2 (Test pit 5)	533015	181650	6.46	2.44	8.90	-0.05	8.85			silty sand
	BDC03	6 Broad Street Place, London, EC2 (Test pit 6)	533005	181625	6.45	1.70	8.15	0.34	8.49			sand & silt; sandy silt
	RIV87	River Plate House, 7-11 Finsbury Circus, London, EC2 (Room/Area D)	532839	181698	9.13	0.64	9.77	1.27	11.04			silty clay; charcoal/anthropogenic
	RIV87	River Plate House, 7-11 Finsbury Circus, London, EC2 (Room/Area A)	532832	181704	9.21	0.14	9.35	0.12	9.47			sandy, clayey silt; marsh deposits
	RIV87	River Plate House, 7-11 Finsbury Circus, London, EC2 (Room/Area F)	532838	181686	8.80	0.40	9.20	0.25	9.45			brickearth; sandy, clayey silt; marsh dep.
	LSS85	Liverpool St Station, Broad St Station, London, EC2 (Section 7 - 8.7 m from E limit)	533048	181619	7.20	0.33	7.53	1.82	9.35			silty clay & clay; freshwater snails
	LSS85	Liverpool St Station, Broad St Station, London, EC2 (Section 7 - 7.5 m from E limit)	533049	181619	7.18	0.63	7.81	1.49	9.30			silty clay & silt; decayed organics/plants
	ELD88	Liverpool House, 15-17 Eldon Street, London, EC2 (Test pit 1)	532978	181673	8.07	0.03	8.10	0.67	8.77			sandy silty clay overlain by marsh deposits
	ELD88	Liverpool House, 15-17 Eldon Street, London, EC2 (Test pit 2)	532990	181668	8.13	0.10	8.23	0.30	8.53	**0 to 2.44**	**0 to 1.82**	sandy silty clay overlain by marsh deposits
	ELD88	Liverpool House, 15-17 Eldon Street, London, EC2 (Area A)	532963	181635	8.20	0.10	8.30	0.14	8.44	**0.3**	**0.4**	sandy silty clay overlain by marsh deposits
E	ELD88	Liverpool House, 15-17 Eldon Street, London, EC2 (Area B)	532972	181632	7.87	0.13	8.00	0.33	8.33	(excluding undated		sandy silty clay overlain by marsh deposits
	FIP92	Dominion Buildings, Island Site, Finsbury Pavement, London, EC2 (Test pit 6)	532805	181770	8.74	1.27	10.01	0.00	10.01	marsh deposits, river		post Roman marsh deposits overlay brickearth
	FIS96	127-139 Finsbury Pavement, London, EC1 (Trench 1, Section 11)	532780	181895	12.28	-0.99	11.29	0.99	12.28	channel & quarry)		no data (natural N-S channel; Walbrook western channel?)
	RMZ06	Ropemaker Street/Finsbury Street, Islington, EC2 (Bay 6)	532685	181845	10.80	0.00	10.80	0.00	10.80			no Roman deposits
	RMZ06	Ropemaker Street/Finsbury Street, Islington, EC2 (Bay 20)	532683	181827	9.15	0.00	9.15	0.00	9.15			no Roman deposits
	RMZ06	Ropemaker Street/Finsbury Street, Islington, EC2 (Bay 30)	532664	181834	10.35	0.00	10.35	0.00	10.35			no Roman deposits
	FBY01	1-2 Finsbury Square, London, EC2	532766	181961	11.78	0.00	11.78	0.00	11.78			no Roman deposits
	VER90	Veritas House, 119-125 Finsbury Pavement, London, EC2 (Trench VII)	532752	181866	12.33	-1.00	11.33	1.00	12.33			brickearth (depression due to quarrying)
	BNH88	Gavrelle House, 2-14 Bunhill Row, London, EC1 (Section 2)	532640	181990	13.65	0.05	13.70	0.20	13.90			silty clay
	CJP06	30 Crown Place, Hackney, London, EC2 (Test pit 6)	533067	181932	11.29	0.00	11.29	0.00	11.29			brickearth overlain by medieval deposits
	CJP06	30 Crown Place, Hackney, London, EC2 (Test pit 8)	533107	181929	10.70	0.00	10.70	0.00	10.70			brickearth overlain by medieval deposits
Average overall depths						**0.86**		**1.26**				

Table 4-9 categorises, within specified ranges of thickness, the depth of dumped deposits found in each of the trenches, trial pits and boreholes according to the zone in which they occur.

Table 4-9 Number of sites with dumped deposits within specified ranges of thickness

Zone	Total no. of sites	Total no. of trenches & pits boreholes	Numbers of archaeological sites with dumped deposits within the stated range of thickness					
			0 to 0.5 m	>0.5 to 1.0 m	>1.0 to <2.0 m	>2.0 to <3.0 m	>3.0 to <4.0 m	>4.0 m
A	5	9	2	2	1	3	1	0
B	4	9	1	2	2	2	2	0
C	8	18	1	3	10	0	3	1
D	12	33	6	5	18	4	0	0
E	11	22	15	4	3	0	0	0
Totals	***40***	***91***	***25***	***16***	***34***	***9***	***6***	***1***

The following observations are based upon Tables 4-8 and 4-9:

1. The average overall depth of ground-raising deposits made by the Romans in the URWV for Zones A to D (29 sites) was 1.52 metres, whilst for Zone E (11 sites), which remained mainly rural through the Roman occupation, the average depth of deposits was just 0.4 metres.
2. The range of ground-raising that took place in each of the four urban zones was of a similar magnitude, ranging from none to a maximum depth of 4.7m, with average thickness in the zones ranging from 1.1 (Zone C) to 1.7m (Zones A and B). In Zone D, the area where the extent of land raising activity was greatest, the average depth was 1.5m.
3. As Zone C was unlikely to have suffered flooding due to the steeper slope to the riverbed over this stretch, the uniformity of magnitude of ground raising in Zones A to C found in the archaeological investigations might indicate that it was not just undertaken to raise land above flood levels. It may also have formed part of construction activity to bring ground to a uniform level for buildings and roads.
4. The thickness of dumped deposits did not exceed 2.0m in 82% of all of the sites and did not exceed 1.0m in 46% of the sites nor exceed 0.5m in 27% of the total.
5. The average depth of waterlain deposits for each of the zones, A to D, i.e. the strata laid down over natural prior to the arrival of the Romans, ranged from 0.3 to 2.0 m. This is similar to, but less than, the depth of the deposits made by the Romans in the course of their ground-raising

activity within each of the zones, i.e. 0.4 to 1.7m. However, the waterlain deposits were laid down over many millennia whilst the Roman deposits were built up over a period of just 350 years. This is an indication of the intensity of the Roman effort to raise the general level of the land, particularly as much of that ground-raising activity was carried out in the first 150 years of occupation, prior to the building of the town wall.

6. Conservatively, assuming that the deposition of waterlain deposits mainly took place since the beginning of the present interglacial from 11,700 years BP, the annual deposition of waterlain deposits in the five zones ranged from zero to 0.4 mm, which could be characterised as equivalent to a very thin annual covering of silt.
7. Due to the limited areal extent of all but a very few archaeological investigations in the City of London, it is not possible to say whether ground raising was carried out over an area extending beyond the site investigated. However, it is more probable that the surface levels recorded are indicative of localised ground-raising activity, i.e. to raise individual buildings and specific lengths of road above flood level – or what, at any particular moment, may have been considered to be the maximum flood level.
8. There are indications that ground-raising activity never quite succeeded in avoiding further flooding, e.g. LOW88, at the intersection of Copthall Avenue and London Wall. Here a road laid on a brushwood base to pass over a marsh experienced a number of visible flood events from an elevation of 7.32m OD up to 8.20m OD, the road being raised several times over that depth. Another example is that of THY01, on the eastern side of Tokenhouse Yard. Here the land surface was shown to have been progressively raised at least 4 times to a total depth exceeding 3m up to the end of the 2nd C or early 3rd C. Typically, raised land had a final Roman elevation between 7.8 and 8.6m OD.
9. In order to minimise the cost of a land-levelling exercise, it is common practice to source materials for filling low ground from nearby areas at a higher level than the required finished ground level. Those seeking to raise ground levels in the URWV would, almost certainly, have followed this practice as far as was practical. However, much of the superficial material available, in Zone D in particular, would have been of marshy origin and unsuitable as a foundation to buildings; it is therefore probable that a good proportion of material used in ground-raising was imported from other parts of the urban area.

10. Materials used to raise ground levels appear to have been of both natural and anthropogenic origin. In the main, the most predominant appears to have been loam, varying considerably in its constituent proportions of sand, silt and clay together with some organic content, the latter most probably being of plant origin. This natural material may, in part, have been unwanted excavated material from operations quarrying for brickearth, sand and gravel for use in the construction of buildings. In contrast, possibly when unwanted in construction, brickearth was dumped as were various mixes of sand, gravel and pebbles, domestic solid waste and stable manure (a large amount of the latter appears to have been dumped in the NE corner of the Bloomberg site (BZY10). On occasion, particularly in Zone D in those areas along the Walbrook where industries and crafts were sited, some of the material dumped was the solid detritus from glassmaking, metal and leatherworking.

4.8 Environmental Archaeological Evidence

In the last 20 to 25 years, environmental archaeological analysis has played an increasingly important role in determining the flora, fauna and general environmental conditions associated with botanical remains, pollen, insect remains and other invertebrates, parasites, diatoms, molluscs and fish bones. The environmental conditions under which the taxa would either have grown or been imported by humans, wind or flowing bodies of water are used to build an understanding of the general period of the context in which they were found. With respect to archaeological investigations carried out in the URWV (Urban Roman Walbrook Valley), six investigations involved detailed environmental archaeological analysis and are of particular interest in this respect, viz.

- Bloomberg Development (BZY10) – non-estuarine lower RWV
- No. 1 Poultry and vicinity (ONE94) – southern middle urban RWV
- 6 – 8 Tokenhouse Yard (THY01) - northern middle urban RWV
- Moorgate Telephone Exchange (MTX11) – upper urban RWV
- 17-31 Moorfields, Moorgate Station, EC2 (XSP10) & Finsbury Circus (Crossrail), EC2 (XRZ10) – upper urban RWV

4.8.1 Bloomberg Development (BZY10)

(Scaife, 2014, 123-130) (Stewart and Smith, 2014, 152-157)

The environmental archaeological data that follows for this site has been taken from an early draft of the report on the investigation and may be subject to change following further interpretation of the findings. Being a draft, page numbers for this reference would not be useful. Suitable deposits were sub-sampled and submitted for micro-morphological analysis and assessment for pollen, diatom, Ostracoda and foraminifera.

The report notes that there is little or no future potential for the diatom and ostracod remains from these anthropogenic to marginal deposits but the pollen does provide good potential for investigation of the palaeo-vegetation to waste component.

The micro-morphological sampling and analysis was related to a core taken at or near the Walbrook channel, the situation being referred to as a "dump". It showed a dominant loamy sand soil formed in the alluvium, which was presumed to be of Romano-British Age. There were pebbles, gravel and coarse alluvial soil clasts throughout the samples. Ensuing inundations took place in a swampy, low-energy environment, although at times the deposits dried out and eventually the deposits become humic silty clay. These deposits contained wood and broad-leaved tree bud remains, thought to have originated from trees upstream along the banks of the Walbrook.

The underlying natural was London Clay over the whole site. Along the Walbrook channel, its upper surface is at between – 0.50m OD and 0.50m OD, but rises to 1.00m OD on the eastern extremity of the site. The clay was overlain on the edge of the site by Taplow terrace gravels and eroded gravels in the Walbrook floodplain. These gravels were found at between 0.50m OD and 4.50m OD. On the western fringes of the site, the gravels are overlaid with brickearth, a late Pleistocene windblown/alluvial deposit. Along the channel, the clay was overlain by reworked gravels, sands and silt with silt bars lining the sides of the channel. Pollen indicates that the banks were stabilised by growths of alder Carr. Deposits over the gravel and clays of the site are generally fine-grained clays and silts with slightly coarser-grained sand and gravels with signs of wetland peat formation.

A Devensian drift-filled hollow was located to the south of the site and provided an environmental record from early pre-history although of little archaeological interest with respect to the site.

Rising sea levels from about 2,600 BP backed up the Thames, led to the tidal limit moving upstream of the Walbrook and a backing up of the river to the southern half of the site. This led to higher groundwater levels and to more frequent flooding by the Walbrook. It is considered that this gave rise to a water-meadow environment over the site dominated by herbs and grasses, seasonal flooding leading to a silty soil. With the start of the Roman period, the floodplain continued to receive natural deposits but was increasingly subject to land management by dumping within which deposits were significant amounts of human artefactual material. The dumped material included highly organic silts with building materials and wood remains, domestic and stable waste. Periods of intentional dumping were interspersed with short periods of inundation.

Ground surface in the Roman period rose gently to the west up the slopes of Ludgate Hill but more steeply to the east where there was a promontory with a top surface at 4.50 to 5.40m OD (found on the LYD88 site). It would appear that the Walbrook has carved out the valley from west to east and two tributaries from the northwest enter and join the Walbrook on its west bank at mid-site.

Charred plant remains were common, wood charcoal being the most common, although there was evidence also of charred cereal grains and wheat chaff. Straw and bran mixed with wild flower seeds associated with damp meadows indicated stable waste that had been dumped over the whole site. Fruit seeds found included those of *prunus* (plum and cherry), *spinosa* (sloe), *malus pumila* (apple) *pyrus* (pear) and *ficus* (fig), less common were *vitis* (grape), *morus* (mulberry) and *(rubus)* blackberry. Apple endocarp was also found as were the shells from *corylus* hazel, *juglans* walnut and *pinus* (pine), with pinecones and pine scales. Herbs such as *coriandrum* (coriander) and *foeniculum vulgare* (fennel) were found and, more exotically and rarely, *capsicum* (pepper). Olive stones were another indication of imported foodstuffs. Beet, carrot and brassica leaf vegetables such as cabbage were indicative of vegetable cultivation.

There were remains of beetles and a type of cockroach. Many species of the former are associated with stored grain in various stages of decay. The latter are associated with damp, dark humid areas full of rubbish and other settlement wastes. The presence of houseflies and dung beetles were typical of decaying settlement waste. However, the low numbers of water fleas, which prefer clean water supplies, would suggest that the area suffered significant pollution.

An assessment of animal bones indicated only a small assemblage of wild game, approximately 3% of the total – including wild duck, woodcock, crane, hare, rabbit, roe and red deer. Similarly, fish bones were only a small part, 4%, of the total – eel, salmon family, cod, haddock, plaice and flounder. Large and medium-sized mammals formed almost 80% of the total bones found – cattle, sheep, goat and pig - and there were signs of "split and smashed" butchery, typical of the Walbrook area, in nearly a third of the total.

4.8.2 No. 1 Poultry and vicinity (ONE94)

(Hill et al., 1998) (Hill and Rowsome, 2011) (Scaife, 2011, 533-538)

In contrast with sites in the upper and the northern half of the middle URWV, the Poultry site was interesting as it permitted an analysis of the environmental evidence without the skewing effects of dominant wetlands communities (e.g. alder Carr).

A large range of plant remains due to water-logging was found, including weed seeds, fruit and nuts, cereal bran mosses and occasional pods and flowers. The fruit remains included rare species, apples and pear stones. The seeds of wild plants dominated by weeds indicative of waste-ground, although other habitats such as grassland and riverine land were also present. Charred straw found was probably animal fodder, bedding or possibly thatch.

With respect to the pollen found, there was a paucity of tree taxa relative to herbs. In the pre-Roman period, alder occupied the lower slopes adjoining the Walbrook with oak, hazel, holly and beech in the drier middle and upper slopes. However, the paucity of tree pollen would indicate that the trees were more in sporadic clumps rather than dominant woodland. *Alnus* (alder) was the only tree pollen found in significant quantities, possibly due to the proximity of the Walbrook where alder may have fringed the river or formed localised Carr. Small concentrations of willow were also found associated with the lower valley alder. There were also very low numbers of exotics such as walnut, a Roman introduction to the London region, and a single spore of fir, another introduction. Their carriage to the site on the wind cannot be ruled out particularly as, originally, the area would have been open and exposed.

Herbs were numerous and diverse, dominated by grasses with docks, sorrels, clover, buttercup and daisy. English plantains were probably associated with the waste or disturbed ground associated with settlement. Immediately pre-Roman, the area had the appearance of abandoned agricultural land, with little evidence of arable cultivation. In the early Roman period, however, cereal pollen and weeds associated with cultivated land were present possibly indicating arable activity and/or local crop processing. Sedges, rushes and certain wild flowers were indicative of damp meadow conditions and bracken spores were a further indication of a grassland habitat. Burnt cereal grains were consistent in their context with the effects of the Boudican fire.

Cereal pollen grains found beneath the Via Decumana could have been imported but could also indicate that the soil was arable prior to the road construction, although these were only found in one area and grasses dominated the strata beneath the Roman road.

With respect to diet and economy, a considerable weight of hand-collected and numbers of wet-sieved bone were found, 250 kg from the Roman levels – cattle, sheep, pig and goat – which, from the chop-marks and knife-cuts, appeared to be mainly associated with butchery. There was also a limited recovery of chicken, goose, duck, dog, horse and cat bones as well as a small component of fish, wildfowl and game.

Diatom analysis showed all diatom taxa were from a freshwater environment, none were from estuarine or marine environment, indicating no contact with the Thames. It is probable that the diatoms found were those that had inhabited shallow-water habitats, ponding or puddles but they were not of the type resulting from flooding. No ostracods were found. Insect remains were typical of dense urban settlement – beetles associated with degradation of domestic waste and rubbish, woodworm associated with rotting timber and insects and spider beetles typical of unheated earthen-floored buildings with wooden or wattle and daub walling. Flies were of the type associated with fresh and rotting excrement and rubbish as well as stable waste. Dominating the taxa indicator groups were those associated with decayed stored grain, possibly rubbish and sweepings from nearby grain storehouses – and possibly a mill on the BZY10 site.

4.8.3 6-8 Tokenhouse Yard (THY01)

(Branch et al., 2012, 60-75)

In the prehistoric to Roman period, freshwater mollusc taxa found in the fill of a former stream were indicative of a wetland habitat, the environment being one of pools rather than moving water. Other species could indicate that the pools were subject to periodic drying and yet others of marsh and grassland. This would support the finding of this research that the area within which the site is located is in a shallow, bowl-like depression that would have consisted of many ponded areas, the ponds probably owing their existence to seasonal flooding. Pollen samples were mainly non-arboreal but with occasional pollen of oak, ash and willow indicating isolated dry areas of woodland and wet scrubland. The isolated woodland was considered to have been remote from the site on the edges of the valley and this was further reinforced by the findings of earlier work at Copthall Avenue sites (Maloney and De Moulins, 1990). These findings are reinforced by the nature of the seeds and plant remains analysed. There was little to indicate economic and dietary habits of early Roman inhabitants of the site.

The pre-Roman and early Roman landscape of this part of the upper URWV is therefore marshland, consisting of grasses, rushes and sedge swamp, bordered the stream, whilst the valley sides comprised areas of grassland, waste ground and scrubland, with clear indication of early Roman occupation.

A few decades into the Roman occupation, 58 to 85 CE, cereal pollen was found showing local cultivation or the processing and storage of cereals. Beetle and bug taxa from this period found in a drain are indicative of the source being dry probably from a building and the species of beetle and weevil remains found supported the supposition that grain was stored in the area.

From 85 to 100 CE, seeds and stones were found from a greater variety of fruits and nuts – wild cherry, grapes, sloe, plum, hazelnuts and blackberry and seeds of weeds commonly found in cultivated fields – and cereal pollen indicated its continuing cultivation. In addition to the wide variety of fruit, there were also seeds of herbs, e.g. coriander. Two tree taxa, oak and beech, were present and the remains of worked timber were also found. The taxa found supported the suggestion that the ground remained damp. From samples taken from contexts dated to 100-110 CE, the environment continued to be one of non-arboreal plants, grassland, waste ground and cultivated land.

After the initial period, it appears that there were successive deposits to raise the land surface, the deposits being a complex mix of materials of anthropogenic and natural origins. The area remained damp and muddy throughout the Roman period. Contexts indicated that there were flood events between 85 and 90 CE, between 140 and 160 CE and 180 and 220 CE, showing that attempts to avoid flooding by raising the land were only partially successful.

Charcoal fragments in later contexts, 140 to 160 CE, are of oak, hazel and willow or poplar, although oak dominates. Willow and poplar are indicative of watercourses and damp woodland. The food of the inhabitants included marine shellfish. The landscape was composed of a mix of isolated scrubland, grassland, waste ground and areas of damp ground or marsh and this continued through to 220+ CE. Later samples showed pollen of birch, lime and elm expanding on the species found as charcoal fragments – but their numbers still indicative of only isolated woodland.

The diet and economy of the Roman inhabitants of this part of urban Roman London was based upon cereals, animal husbandry, wild fruits and nuts, imported fruit and shellfish. Local timber was used as fuel and for construction. It is unclear as to whether the crops cultivated locally included cereals or whether the grain was brought in and stored. Nor can it be confirmed from the environmental investigation work whether the buildings on site were for human habitation, for stables or other animals or for both, although dung beetles found were indicative of animal husbandry. The investigators speculate that some of the oak may have come from managed sources.

4.8.4 Moorgate Telephone Exchange, EC2Y (MTX11)

(Lewis, 2016, 171-177)

This site is adjacent to and immediately to the north of the town wall. The plant remains found in the Roman sequence were mainly of wild plants and the seeds of wetland plants were an indication of seasonal flooding. A waterlain clay layer overlay the site, dated post construction of the wall, indicating that the area was regularly flooded and the seeds of fully aquatic plants larval cases of caddisfly would suggest that the water was standing for some time.

4.8.5 17-31 Moorfields, Moorgate Station, EC2 (XSP10) & Finsbury Circus (Crossrail), EC2 (XRZ10)

(Pfizenmaier, 2016, 211-216)

Recent work on Crossrail stations at Moorgate (XSP10) and at Finsbury Circus (XRZ10) have provided additional evidence, in part of an environmental nature, confirming the development and use of land that would be cut off from the urban area by the town wall from the end of the 2nd C. The area was crossed by a series of ditches and channels, some natural, some constructed all oriented to flow in a

NNW to SSE direction. The underlying geology included gravels capped by patches of discoloured or weathered brickearth and a thin homogeneous layer of waterlain clay indicating intermittent flooding. The channels yielded evidence of aquatic and wetland plants as well as a significant amount of blinks, found in areas that are wet in winter but also seasonally dry. Aquatic invertebrate remains strengthened the impression of seasonally-filled channels. From early on in the Roman period, spelt wheat remains were present indicating cultivation and dry-land plants indicating managed meadows and pastures in the general vicinity. There is evidence that the area was most intensively-used through the 2nd C, particularly the middle half of the century. Cultivation in this period was supported by finds of charred crop-processing waste. This consisted mainly of cereal chaff from spelt wheat and a few cereal grains and seeds of brome. The mix of wet and dry ground plants in the channels indicated that the area was subject to flooding. Over-bank flooding was dated to have occurred between 120 and 200 CE. A complete lack of features dated to the 3rd or 4th C and the commencement of the accumulation of peat supports the current hypothesis that the marsh that became Moorfields was begun during or soon after construction of the town wall. There were a number of small finds in the ditches – bone hairpins, a copper needle and a bone needle – but it is unclear whether these were generated by casual rubbish disposal or wash-out of grave goods from the northern Walbrook Roman cemetery to the immediate north of the Finsbury Circus site. Gravel-quarrying pits were found on the Finsbury Circus site that contained pottery dated to 120-160 CE. The pits were sealed by a group of highly-fragmented animal bone, possibly waste from bone-processing, possibly grease extraction, following butchery.

4.8.6 Environmental archaeological evidence – synthesis and summary

During the Pleistocene and for much of the prehistoric Holocene, the Greater Walbrook Valley was a thickly wooded environment, dominated by lime trees. As a warmer climate settled in, most of the lime trees were replaced by alder along the valley floor on and close to the banks of the Walbrook and higher up on the drier slopes by oak and hazel. By the start of the Roman period, oak was the dominant tree taxa away from the river. The lower valley at least appears to have been cleared at some point in the Bronze or early Iron Ages for small-scale, localised arable farming. The middle and lower slopes of Ludgate Hill were terraced and drained to reduce flooding from tributaries of the Walbrook and to facilitate farming activity. However, it is unclear from the environmental archaeological evidence whether this was carried out before the arrival of the Romans or shortly after.

Following the Boudican revolt, the area to the west of the Walbrook crossing became more densely developed, buildings being of timber or wattle and daub construction. There is evidence of substantial grain storage facilities around the western end of the bridge and large amounts of waste products from food preparation supports the interpretation of a building as a tavern/eating house on the ONE94 site. A bread oven was found at the NE corner of the BZY10 site. Although not remarked in the environmental assessment, the ONE94 site appears to have reverted to a more open, undeveloped character in the 3rd C with substantial, high-status buildings replacing the previous simpler, more densely-packed constructions.

In the pre-Roman period, the Walbrook valley in what was to become the upper and middle urban areas of the valley were naturally flat and marshy, subject to seasonal flooding and, less frequently, major flooding events. The river was slow-flowing in dry periods with numerous side channels and cross-connections between them and the two main streams. Following flooding, many lakes and pools of water would be left behind. There is evidence of early Roman occupation of the area that is characterised by a progression of phases of land raising by dumping interspersed with flooding by the Walbrook, indicating that the inhabitants were never completely successful in their attempts to avoid flooding.

The lower URWV was a seasonal marsh by the start of the Roman period and the area was subject to a considerable amount of ground-raising activity using a variety of natural and anthropogenic deposits, most notably significant quantities of stable waste.

Outside of the town wall, there are indications that the area was subject to seasonal flooding prior to its construction. However, from the early decades of the 3rd century, the lack of any archaeological features in the upper urban Roman Walbrook Valley and evidence of water standing for long periods, indicate that the Moorfields marsh and peat accumulation was a direct result of the construction of the town wall.

Chapter 5 Palaeo-hydrology of the Roman Walbrook

5.1 Introduction

Hydrological analysis of a river to determine its base flow and storm flow regimes requires acquisition and development of data specific to its catchment. This is a relatively straightforward process for an existing river, particularly where its present condition is to be modelled. It becomes a more difficult task for a river that has not flowed for about 500 years, as is the case with the Walbrook, rendered even more complex when the catchment descriptors that must be determined are those of 2,000 years ago and for which there is no record of any contemporaneous written account.

The hydrological characteristics of rivers that flow through urban developments and rural catchments are completely different. Pre-Roman, the Walbrook catchment, apart from some very small settlements, would have been rural (Morris, 1982, 82; 91). Apart from urban Roman London, covering between 5 and 10% of the catchment, the area would have remained rural and agricultural in character. Today, the whole of the ancient catchment of the Walbrook is completely urbanised. Unfortunately, there is no contemporary description of the Walbrook or its catchment for the Roman period. One of the challenges of the research, therefore, was to re-create the character of the catchment of this pristine stream.

A conceptual hydrological model of the Greater Walbrook Valley has been produced on the basis of the content of Chapters 3 and 4, and is shown in Figure 5-1. This shows two situations, until and after the construction of the wall in 220 CE.

Urbanisation of a small portion of the Walbrook's catchment by the Romans and their increasing use of a portion of the catchment for farming activity will have progressively altered the drainage characteristics of the river basin. To understand the impact of the river on Roman London, it is therefore necessary to model the catchment at the time immediately prior to the occupation, when the catchment would have been almost in its natural state, as well as when it would have been a mix of agricultural and urban development together with some natural rural countryside.

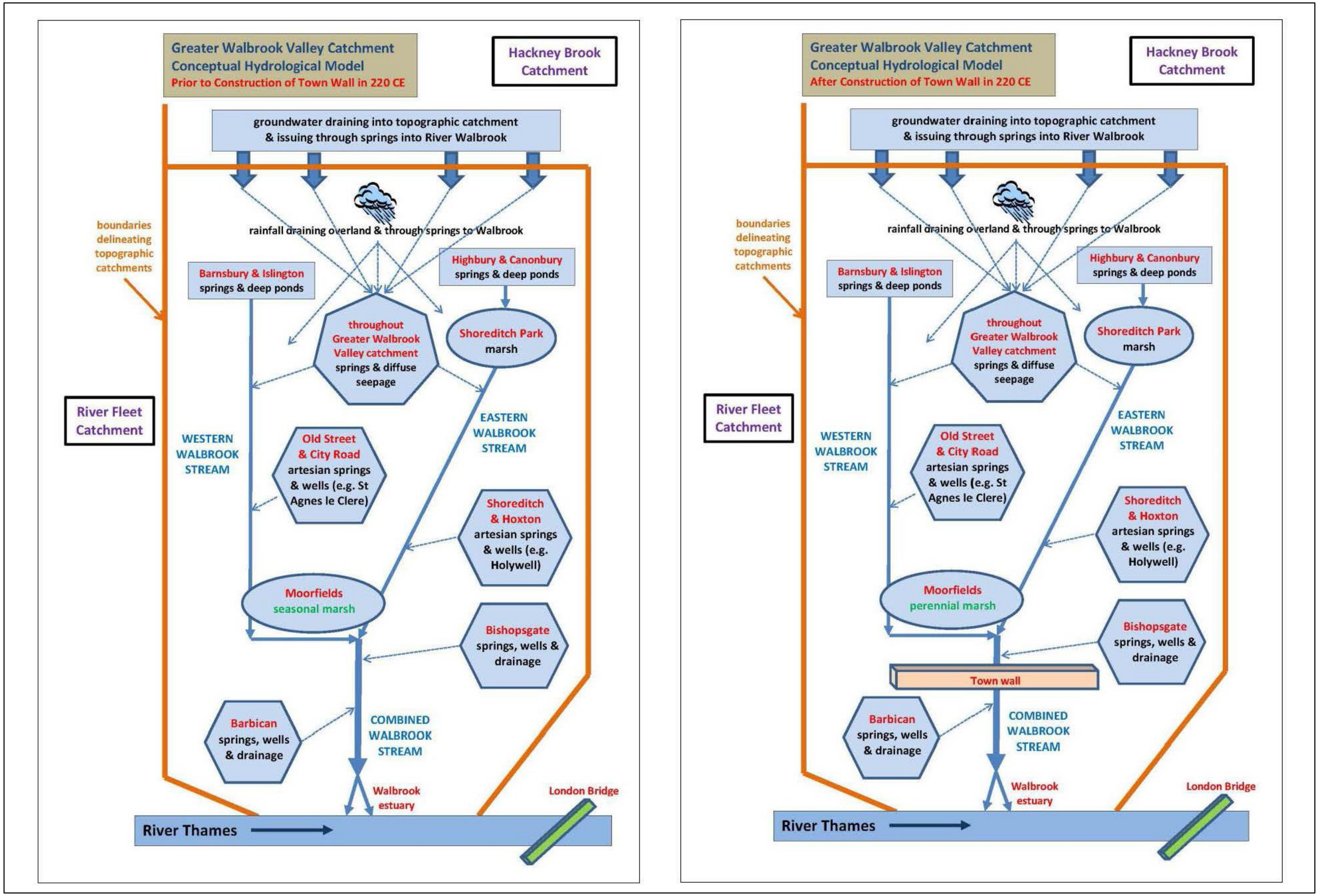


Figure 5-1 Conceptual hydrological model of the Greater Walbrook Valley Catchment

Prior to this present research, in absence of a value for its base flow, identified use of the Walbrook's waters in the Roman period could only have been those evidenced through archaeological investigation. However, by developing a reliable range of base flow rates, this research has been able to identify potential uses for the river that have not yet been proven through archaeological investigation. That is not to say that such usage actually took place, only that it would have been feasible to use the river for these purposes.

5.2 Objectives

The objectives of the palaeo-hydrology research component were to determine for the Greater Walbrook Valley (GWV) in the Roman period:

1. the boundaries and extent of both the surface water runoff catchment and the groundwater collection catchment;
2. the full extent of the Walbrook river system;
3. the natural characteristics of the GWV required to carry out a hydrological analysis of its catchment both immediately prior to the arrival of the Romans and during their occupation;
4. the reliability and magnitude of the base flow of the river in dry weather; and
5. taking account of rainfall intensity and storm duration for the Greater Walbrook Valley, the magnitude of storm flows that would have been generated in the river, as it flowed through the area that was to become, and eventually was, urban Roman London, for storms having return periods ranging from an annual occurrence to once in 500 years.

The work involved and the research findings related to the first two of these objectives have been described in Chapter 3.

Storm flow estimation has been developed in such a manner that the results could be used in the flood-risk analysis, which forms the subject of Chapter 6.

5.3 Methodology

The data required in order to estimate the base flow in a river, i.e. its flow after prolonged periods of dry weather, and flows at times of storm, differs very little between the methods for their estimation. However, particularly with respect to modelling storm runoff, the nature of the data required can vary between different types of proprietary software. The choice of software to be used in the storm runoff analysis, considered the most appropriate to the very particular circumstances of the research, was therefore made at the start of the process.

Steps in undertaking the hydrological analysis of the Greater Walbrook catchment were as follows:

1. Alternative proprietary software for calculating storm rainfall runoff was assessed and a preferred software model chosen for modelling the catchment (Section 5.4).
2. Data required for the chosen storm runoff software were identified (Section 5.5).
3. A sensitivity analysis was undertaken to identify which parameters used in the adopted storm runoff software would exert the greatest influence on the calculation of runoff rates (Section 5.5 and Appendix 5-A).
4. The data were then acquired and the hydrological characteristics of the Greater Walbrook catchment, its descriptors, were developed for estimation of both base and storm flows. Modern data sources were used for those descriptors that would not have altered since the Roman period (Section 5.6). For those descriptors that would have altered since the Roman period, data were developed from the results of archaeological investigations and published material relating to the Greater Walbrook Valley or surrogate situations having geological, soil and climate conditions similar to those of its catchment (Section 5.7).
5. In parallel with the foregoing step, the mapping features of GIS software were used to record and depict on a 1:10,000 scale Ordnance Survey map base, on separate layers, the following aspects of the research and of the characteristics of the Walbrook and its valley:
    a. Walbrook-related catchment and sub-catchment boundaries, i.e. topographic and groundwater
    b. catchment geology
    c. Walbrook stream watercourses
    d. the Roman town wall
6. Using the spatial analysis features of GIS software, the following statistics have been derived:
    a. the area occupied by each of the Walbrook catchments and sub-catchments
    b. the lengths of each of the constituent streams of the Walbrook system

c. the areas of each of the principal categories of superficial deposits and outcroppings of natural geology of the Walbrook catchment, i.e. gravels, alluvium and London Clay.

7. A value for the reliable, perennial base flow in the river was estimated using a surrogate river analysis. This was carried out using modern river flow gauge data collected for periods of up to 100 years, for base flow and storm data for modern rivers within the Thames catchment having similar size and geology to those of the Walbrook. (Section 5.8).
8. Using the chosen software and data developed for it, storm rainfall runoff was calculated for a range of intensity, duration and storm return periods and related flows in the river developed for critical locations in the URWV (Section 5.9).

Fig 5-2 depicts the methodology for the palaeo-hydrology service component of the research.

5.4 Choice of Storm Runoff Modelling Software

The quantification of storm flow runoff is not a precise exercise, even where catchment descriptors can be quantified with acceptable accuracy. There are many reasons for this – unevenness of any surface over a large area means that its accurate modelling of the time taken for rain falling on one part of a catchment to drain to another part is not possible. In addition, vegetation cover is not normally uniform over a large area, nor is the nature of the soil and the moisture content of that soil at the start of a storm, the so-called Antecedent Moisture Condition (AMC). The direction of travel of a storm over a catchment also influences runoff patterns and, in the course of a storm, the intensity of rainfall at any time will differ across a catchment. Storm flow runoff calculated using even the best of hydrological models should only be considered an estimate.

Lack of data specific to the Greater Walbrook Valley during the late Iron Age and early Roman period combined with difficulties inherent in accurately assessing storm runoff rates – means that the storm flows in the Walbrook generated in the course of this research should only be considered a best estimate. They provide an order of magnitude rather than absolute values. However, as no work has been done previously on this important factor, the generation of rates of flow in the Walbrook at times of storm, whilst only an estimate, will be an improvement on the current situation.

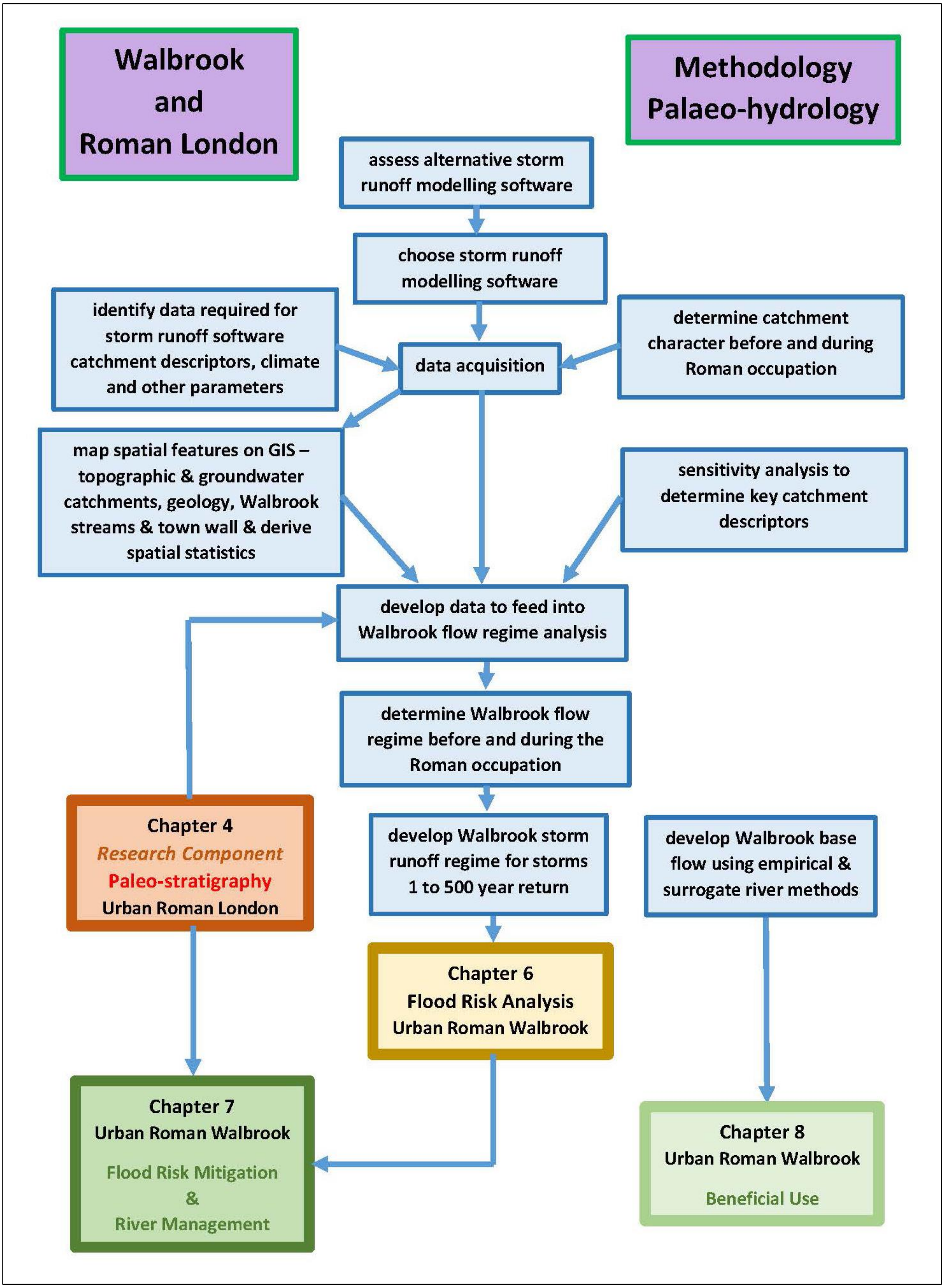


Figure 5-2 Methodology of the palaeo-hydrology service component

It was originally intended that storm runoff estimation software developed and used in the UK might be adopted for the current research. However, the Revitalised Flood Hydrograph method used in British practice (Kjeldsen et al., 2005) has two weaknesses with respect to the requirements of this research, viz.

- it relates to catchments as they are today and is not readily adaptable to the catchment descriptors derived for the natural undeveloped, pre-Roman catchment or as they would have evolved during the Roman period;
- users are not convinced that it can satisfactorily model small catchments such as the Greater Walbrook Valley; and
- does not readily lend itself for use in a sensitivity analysis of catchment descriptors.

The development of the UK's flood modelling approach is set out in Appendix 5B.

The unit-hydrograph method of modelling hydrological rainfall-runoff lies at the base of most modern approaches to storm flow estimation. A search was undertaken for storm runoff modelling software, based upon the unit-hydrograph method with the flexibility to apply catchment descriptors specific to the catchment being analysed. The HydroCAD software, developed in the United States, responded to this specification.

The software is an integrated solution for the analysis, design, and documentation of complete drainage systems using standard hydrograph techniques, i.e. it has as its foundation the same technology as the UK software. In contrast to the UK's Revitalised Flood Hydrograph software, it is flexible in that it can be adapted to reflect specific catchment characteristics, e.g. types of soil, soil saturation and mixes of different types of vegetation and surface permeability, whether rural or urban. The HydroCAD software can be tailored to accept rainfall intensity, duration and return period data from any source (HydroCAD, 2011: 27-34).

First developed in 1977, HydroCAD has been updated to reflect the latest concepts in hydrology. It is based upon the US standards for the sector, Technical Release 20 (Natural Resources Conservation Service, 1982) on watershed technology in general and Technical Release 55 (Cronshey and Nrcs, 1986). The latter is specifically devoted to small watersheds and is therefore appropriate for the

Walbrook catchment. Both standards were issued by the Soil Conservation Service of the United States, Department of Agriculture, now renamed the National Resource Conservation Service (Cronshey and Nrcs, 1986).

The software can be used to assess which hydrological characteristics have a significant effect on the magnitude of storm flows and which do not. It therefore lends itself well to a sensitivity analysis to identify which catchment descriptors and other hydrological factors most affect the outcome of an analysis. The parameters involved in applying the software have been listed in Section 5.5, developed in Sections 5.6 and 5.7 and the results of their application in the HydroCAD software are reported in Section 5.9.

5.5 Data Requirements – Palaeo-hydrology

In undertaking the literature search and review for the palaeo-hydrology component of the research, two different types of data were identified:

- those hydrological elements for which data relating to the current situation of the Greater Walbrook catchment is available and appropriate; and
- all other hydrological elements for which data relating to the current environment could not be considered representative of the Great Walbrook Valley conditions of the period being researched.

How much of the rain falling on a catchment, or sub-catchment, drains from its land surface and the rate at which it drains to and along a stream, are dependent upon the interaction of many factors but the dominant ones, as categorised above, are:

1. *Data gathered from modern published sources, specific to the Greater Walbrook Valley and still relevant to the immediate pre-Roman and Roman periods*
    a. topographic catchment – Greater Walbrook Valley (Section 3.2)
    b. superficial geology and the groundwater catchment (Section 3.3)
    c. modern surrogate river flow gauge records (Section 5.6.1)
    d. natural soil of the catchment (Section 5.6.2)
    e. climate and storm rainfall statistics (Section 5.6.3)

2. *Data which has to be developed from literature and archaeological sources as no contemporaneous record exists for the Greater Walbrook Valley before and during the pre-Roman period*
    a. the river – its streams and its main tributaries (Section 3.4)
    b. catchment topography – urban Roman London and immediate environs (Section 5.7.1)
    c. average slope of the riverbed (Sections 4.5.2 and 5.7.2)
    d. soil, with respect to the permeability of the land surface (Section 5.7.3)
    e. antecedent moisture condition (AMC), the state of saturation of the land at the start of a rainfall event (Section 5.7.4)
    f. landscape – vegetation and settlement (Section 5.7.5)
    g. HydroCAD landscape Curve Numbers (Section 5.7.6 and 5.9.1)

Apart from geology, rainfall and some elements of the Walbrook catchment topography, there is a lack of published material on the foregoing characteristics of the Greater Walbrook catchment, as well as on the river itself, for the Roman period. Qualitative descriptions and, wherever possible, quantitative values for these characteristics have been developed from material published on areas having a similar character to that of the Greater Walbrook Valley.

A few of the parameters used in hydrological analysis exert a significantly greater influence over the results than others. In order to understand which parameters exert the greatest influence when using the HydroCAD software, a sensitivity analysis was carried out. The details and outcome of this analysis are reported in Appendix 5A. The outcome can be summarised as follows:

- Curve Number (CN) value, a parameter which reflects the type of ground cover combined with soil type, has by far the greatest effect on the magnitude of storm runoff calculated, e.g. a value of 52 halves the rate of runoff compared to a value of 73 and reduction of CN to 32 reduces runoff to an insignificant level;
- increasing the Antecedent Moisture Content (AMC), the degree of soil saturation preceding a storm, to a value of 4 (frozen or totally saturated soil) from 3 (partially saturated), increases runoff by 50% and is therefore highly significant;
- reducing the length of overland flow by a half led to a 33% increase in flows in the river;

- the nature of vegetation cover is significant, e.g. a wooded area generates 16% less runoff in the river than short grass pasture (a factor reflected in the value of Curve Number adopted;
- land slope across the catchment towards the river is less significant than the foregoing but its effect is enough to warrant care in determining the value of this parameter, a doubling of the slope adopted resulted in an 18% increase in runoff; and, interestingly,
- the state of the river channel, reflected in the value of the hydraulic constant, Manning's Number, as well as the length and slope of the river, exerts little influence on the storm flow rate at the point investigated for frequency of flooding.

The significance of the main parameters – Curve Number, Antecedent Moisture Content, length of overland flow and the nature of vegetation – are reflected in the following sections on data development.

5.6 Data from Modern Published Sources

5.6.1 Modern surrogate river flow gauge records

It is not possible to conduct a flow gauging exercise to determine mean base flow in the Walbrook as it has not flowed as a river for more than 400 years. A technique has been developed to overcome this difficulty by means of a surrogate river analysis.

Identification of a single river in the same hydrological region as the Walbrook having a catchment of similar size with the same, or materially similar, hydrological, geological, topographical and vegetation characteristics did not prove possible. Even had such a river been identified, it would have been necessary to carry out river flow gauging and accumulation of rainfall data over many years for any comparison with the real Walbrook to have been credible.

Fortunately, public authorities in the UK with responsibility for managing the country's rivers have collected flow data over many years at more than 1,500 gauging stations throughout the country. Data from these gauging stations has been processed and then reported in the UK Hydrometric Register (Marsh and Hannaford, 2008).

The UK Hydrometric Register is a catalogue of river flow gauging stations in the United Kingdom together with a summary of their catchment hydrometric and spatial statistics. Its primary objective is to provide a range of reference and statistical information to enable basic hydrometric data to be used more effectively. It is structured to allow the selection of appropriate datasets for particular projects. The Register provides a range of data on the rivers reported upon, covering a considerable period in most cases. The data categories having greatest relevance to the present research include:

- River and gauging station names.
- Gauge location by Ordnance Survey reference.
- Size of catchment area contributing flow to the gauging station.
- Base Flow Index (BFI) – a measure of how much of the base flow is contributed through stored sources, principally springs.
- Period for which measurements taken – most stations possessing more than 20 years of records, some more than 100 years.
- Flow data – mean, median annual flood, peak and 7-day minimum flows as well as flow rates exceeded 5% and 90% of the period for which records kept.
- Geology of the catchment and its vegetation or use, e.g. rural, farmland, wooded, pasture, urban and industrial.

For the purposes of reporting hydrometric data in the Register, the UK has been divided into 12 regions. One of these, the Thames Region, would have been the one in which the River Walbrook would have been located and reported upon were it to be flowing in the present. Data from this region has been used in the surrogate river analysis as it has a similar climate and geology to the Walbrook catchment. The hydrometric data of 157 gauging stations on 88 rivers are reported for the Thames Region (Marsh and Hannaford, 2008; 97-112). However, there is considerable variation in the size of their individual catchment areas, from 9,948 km^2 to just 1.4 km^2. Base Flow Indices have an even greater variation, varying from 0.98 to 0.17, the higher value indicating that virtually all of the base flow, at the gauging station to which it relates, originates from stored groundwater.

Not all of the data reported under the Thames Region are therefore appropriate when used as comparators for the ancient Walbrook. Some data may be inappropriate due to the large size of a catchment, some because of their superficial geology and others due to the nature of their land use.

A "sieving" of the data was carried out using catchment size and Base Flow Index. Rivers and their gauging stations that passed this sieving process were further examined with respect to their geology and land usage to ensure that they were compatible with an undeveloped Walbrook catchment.

Catchment Size. The total area of Great Walbrook Valley is 4.70 km². There are only 5 gauging stations with contributory catchments of a similar size.

Base Flow Index. For the most part the headwaters of the rivers and their catchments in the Thames Region are characterised by chalk and gravels. However, although many of the catchments exhibit a predominance of chalk and/or gravels, sometimes with glacial drift superficial deposits, parts of the region at lower levels are also characterised by clay and some areas are heavily urbanised. Clay and urbanisation result in low BFI values, notwithstanding the nature of their underlying geology. Catchments having chalk and gravels as their principal superficial geology and deposits both give rise to rivers with high base flows derived from point source and diffuse springs. Such catchments have high BFI values. 84% of the Walbrook catchment is covered with gravel deposits of various classifications overlying London Clay. The clay occasionally outcrops to create numerous springs. As a result, a BFI value in excess of 0.8 could be expected of the Walbrook catchment.

Data were examined and analysed for groups of gauging stations. This was done to determine likely flows in the natural Walbrook as well as to identify any trends relating to catchment size and BFI values.

In order to determine any trends relating to BFI values, the following groups were examined:

- Gauging stations having BFIs of 0.9 and greater
- Gauging stations having BFIs of 0.8 and greater but less than 0.9
- Gauging stations having BFIs of 0.75 and greater but less than 0.8
- Gauging stations having BFIs of 0.2 and greater up to 0.4

In order to determine the likely flows in the Walbrook, the following grouping was examined:

- gauging stations having catchments with a land area less than 5.0 km²

- five gauging stations complying with the size criterion, had BFIs varying from 0.63 to 0.96, with an average value of 0.86, weighted by their respective catchment areas.

The tables for each of the individual groups of UK Hydrometric Register hydrological data are reported in Appendix 5C. The surrogate river analysis, using this data, is reported in Section 5.8.

5.6.2 Natural soil of the Greater Walbrook Valley

Data on the soil underlying the modern Greater Walbrook catchment were obtained using the Soils Site Reporter facility of the National Soil Resources Institute, managed by Cranfield University, which was accessed online (www.landis.org.uk/services/sitereporter.cfm). Apart from a narrow strip of loamy and clayey soils flanking the north bank of the Thames, the whole of the Greater Walbrook catchment, from the source of the river above the Angel, Islington, is described as covered by loamy soils. Both types are considered to have naturally high groundwater levels. As has been described in Section 3.3, the catchment is mainly underlain by gravel and sand deposits mixed with clay and silt and frequently overlain by brickearth, a clayey alluvium, similar to loam but a finer, homogenous, windblown deposit.

A loamy soil is one described as being a mix of sand, silt and clay, frequently with some humus content, where the main inorganic constituents are evenly balanced, although one or two of them may predominate. Loamy soils generally have a higher concentration of nutrients than sandy soils and are therefore, in the main, more fertile. However, the Soils Site Reporter indicated that the Greater Walbrook Valley loams have only low to moderate fertility. The Institute classifies the soils as supporting a land cover of arable grassland (meadows) and woodland whilst many other sources state that loams are well suited to growing market garden produce and for gardening. However, the loam in the pre-Roman London area would probably have contained a higher than average proportion of silt and clay and therefore would probably be more difficult to work than a well-balanced loam. The soil will hold and transmit moisture and so should facilitate the feeding of groundwater in the underlying sand and gravels.

Loamy soils on a gravel sub-surface, with particular reference to those of the London region, are known to be good soils, fertile, well drained, but not too dry, and relatively easy to work, occur on the terrace gravels. (Bird, 1996, 220).

References to the soils of the terrace gravels describe their free-draining nature:

> *"The North Thames Terraces ……….. cut by occasional river valleys …….. characterised by free-draining and easily worked soils …………. brickearth deposits, overlying the gravels …… a ready source of building materials ……"* (Baxter, 2011, 69).

To summarise the soil and superficial deposits of the rural, pre-Roman and Roman Greater Walbrook Valley would have been:

- a loamy soil, with low to moderate fertility, best suited to arable grassland (meadows) and woodland; and
- superficial deposits of gravel and sand, mixed with some silt and clay, overlying London Clay; in just a few places, at discontinuities in the gravel terraces, the loamy soil would have been directly underlain by London Clay.

The nature of the soil is assessed for its permeability for the purposes of the HydroCAD software in Section 5.7.3.

5.6.3 Annual rainfall, storm statistics and climate

Annual rainfall

The Met Office, formerly the Meteorological Office, is the only reliable source of rainfall data for the United Kingdom. Rainfall statistics are published for gauging stations around the country and the nearest published station data to the Greater Walbrook Valley is their station at Greenwich. Weather data statistics are reported in Figure 5-3 for two periods covering a total of 40 years, 1961 – 1990 and 1971 – 2000. Further statistics are available online for the period 1981-2010.

The annual rainfall for the three rolling 30-year periods, 1961-1990, 1971-2000 and 1981-2010 are of the same order of magnitude, respectively 585.5mm, 583.6mm and 557.4mm.

Storm statistics - Rainfall intensity, duration and return periods

The volume of water reaching a river as the result of a storm is dependent upon the duration of the storm and the pattern of rainfall intensity throughout the storm. The return period for a specific storm is the occurrence of a particular combination of duration and rainfall intensity. If the rate of flow in the river generated by that storm were to result in flooding, then its return period is also an indicator of how frequently the river may be expected to flood.

The rainfall intensity, duration, return period relationship is therefore fundamental to generation of surface runoff rates and a flood frequency analysis. This relationship can be quantified through analysis of rainfall records over a long period and is specific to a location.

The Flood Estimation Handbook (FEH) (Reed et al., 1999) is appropriate to specific catchments as they are today but, as explained in Appendix 5B, is insufficiently flexible for adaptation to the circumstances of the current research. However, the Handbook does include a dataset, based on the extensive, long-term rainfall records of the Meteorological Office, which permits the relationship for rainfall intensity, duration and return period to be determined quantitatively for any area of the UK. This data is stored on a CD-ROM which accompanies the Handbook.

Met Office

Greenwich 1961-1990 averages

Greenwich (7 m AMSL)

	Max Temp	Min Temp	Days of Air Frost	Sunshine	Rainfall	Days of Rainfall >= 1mm	Wind at 10 m
Month	[° C]	[° C]	[days]	[hours]	[mm]	[days]	[knots]
Jan	7.3	1.9	9.1	42.2	50.4	11.3	N/A
Feb	7.6	1.9	7.8	61.3	34.0	8.1	N/A
Mar	10.3	3.2	4.3	102.6	44.8	10.1	N/A
Apr	13.0	4.9	1.5	139.2	44.8	10.1	N/A
May	16.9	7.9	0.1	186.0	49.1	9.5	N/A
Jun	20.2	11.0	0.0	189.0	49.3	7.7	N/A
Jul	22.2	13.2	0.0	182.3	44.0	7.4	N/A
Aug	21.8	12.9	0.0	179.8	49.9	8.1	N/A
Sep	19.3	10.8	0.0	138.0	55.3	8.5	N/A
Oct	15.5	8.2	0.2	103.5	54.4	8.9	N/A
Nov	10.6	4.6	3.2	57.3	54.9	9.9	N/A
Dec	8.3	2.7	8.0	34.7	54.5	10.0	N/A
Year	14.4	7.0	34.1	1417.2	585.5	109.5	N/A

Met Office

Greenwich 1971–2000 averages

Greenwich (7 m AMSL)

	Max Temp	Min Temp	Days of Air Frost	Sunshine	Rainfall	Days of Rainfall ≥ 1mm	Wind at 10 m
Month	[°C]	[°C]	[days]	[hours]	[mm]	[days]	[knots]
Jan	7.9	2.4	7.4	45.9	51.9	10.9	N/A
Feb	8.2	2.2	7.4	66.1	34.0	8.1	N/A
Mar	10.9	3.8	2.9	103.2	42.0	9.8	N/A
Apr	13.3	5.2	1.1	147.0	45.2	9.3	N/A
May	17.2	8.0	0.1	185.4	47.2	8.5	N/A
Jun	20.2	11.1	0.0	180.6	53.0	8.4	N/A
Jul	22.8	13.6	0.0	190.3	38.3	7.0	N/A
Aug	22.6	13.3	0.0	194.4	47.3	7.2	N/A
Sep	19.3	10.9	0.0	139.2	56.9	8.7	N/A
Oct	15.2	8.0	0.3	109.7	61.5	9.3	N/A
Nov	10.9	4.8	3.0	60.6	52.3	9.3	N/A
Dec	8.8	3.3	6.9	37.8	54.0	10.1	N/A
Year	14.8	7.2	29.1	1461.0	583.6	106.5	N/A

Figure 5-3 Weather data for Greenwich, London

This CD-ROM has been accessed and a printout of storm data obtained for the Greater Walbrook valley for storms with return periods ranging from 2 to 500 years. Rainfall intensity-duration data were thus derived for the standard return periods of 2, 5, 10, 20, 50, 100, 200 500 years for an area centred on OS grid reference TQ 32750 82850. Rainfall intensity-duration data were further estimated graphically to provide storm data with an annual occurrence. The chosen OS grid reference relates to an area (Vestry Street, Shoreditch) close to the intersection of Old Street and City Road, approximating to the centre of the River Walbrook catchment. The data are reported in Table 5-1 and Figure 5-4. It is one of the principal advantages of the HydroCAD software over the FEH approach that storm data appropriate to the Greater Walbrook catchment can be used in the computation of storm runoff.

Monthly rainfall intensity

The rainfall intensities associated with their return periods, as reported in Table 5-1, are annual statistics. Average monthly rainfall intensities are significant when estimating storm runoff to rivers as the most intense storms tend to occur in the summer when storm cloud

Table 5-1 Rainfall intensity, duration and return data for the Greater Walbrook Valley

Greater Walbrook Catchment

Rainfall Intensity - Duration Data for a Range of Storm Return Periods

Data generated for OS grid reference - TQ 32750 82850 (intersection of City Road and Old Street)

An areal reduction factor of 0.978 has been applied to point rainfall

Storm Duration			Storm Return Periods							
minutes	hours	days	2 year rainfall mm	5 year rainfall mm	10 year rainfall mm	20 year rainfall mm	50 year rainfall mm	100 year rainfall mm	200 year rainfall mm	500 year rainfall mm
15	0.25	0.010417	8.27	12.56	16.56	21.6	30.46	39.41	50.93	71.46
30	0.5	0.020833	10.46	15.56	20.25	26.06	36.12	46.14	58.89	81.24
45	0.75	0.03125	11.98	17.61	22.73	29.03	39.84	50.51	63.99	87.41
60	1	0.041667	13.18	19.21	24.65	31.32	42.68	53.83	67.82	92.01
75	1.25	0.052083	14.19	20.55	26.25	33.2	45	56.52	70.93	95.71
90	1.5	0.0625	15.07	21.7	27.63	34.82	46.99	58.82	73.57	98.83
105	1.75	0.072917	15.86	22.73	28.84	36.25	48.73	60.82	75.86	101.53
120	2	0.083333	16.57	23.65	29.93	37.53	50.28	62.61	77.89	103.91
135	2.25	0.09375	17.22	24.49	30.93	38.69	51.69	64.22	79.73	106.06
150	2.5	0.104167	17.82	25.27	31.85	39.76	52.98	65.7	81.4	108.01
165	2.75	0.114583	18.39	26	32.7	40.75	54.17	67.06	82.94	109.8
180	3	0.125	18.92	26.68	33.5	41.67	55.28	68.32	84.37	111.46
195	3.25	0.135417	19.42	27.32	34.25	42.54	56.32	69.51	85.71	113
210	3.5	0.145833	19.89	27.92	34.96	43.36	57.3	70.62	86.96	114.45
225	3.75	0.15625	20.34	28.5	35.63	44.13	58.23	71.67	88.14	115.81
240	4	0.166667	20.78	29.05	36.27	44.87	59.11	72.66	89.26	117.1
255	4.25	0.177083	21.19	29.57	36.88	45.57	59.94	73.61	90.32	118.32
270	4.5	0.1875	21.59	30.08	37.46	46.25	60.74	74.51	91.34	119.48
285	4.75	0.197917	21.97	30.56	38.02	46.89	61.51	75.38	92.3	120.58
300	5	0.208333	22.34	31.03	38.56	47.51	62.24	76.2	93.23	121.64
315	5.25	0.21875	22.69	31.47	39.08	48.11	62.95	77	94.12	122.66
330	5.5	0.229167	23.04	31.91	39.59	48.68	63.63	77.76	94.97	123.63
345	5.75	0.239583	23.37	32.33	40.07	49.24	64.29	78.5	95.8	124.57
360	6	0.25	23.7	32.74	40.54	49.78	64.92	79.22	96.59	125.47
375	6.25	0.260417	24.01	33.13	41	50.3	65.53	79.91	97.36	126.34
390	6.5	0.270833	24.32	33.52	41.44	50.8	66.13	80.57	98.1	127.19
405	6.75	0.28125	24.62	33.89	41.87	51.3	66.71	81.22	98.82	128
420	7	0.291667	24.91	34.25	42.29	51.77	67.27	81.85	99.52	128.79
435	7.25	0.302083	25.2	34.61	42.7	52.24	67.81	82.46	100.2	129.56
450	7.5	0.3125	25.47	34.95	43.1	52.69	68.34	83.05	100.85	130.31
465	7.75	0.322917	25.74	35.29	43.49	53.13	68.86	83.63	101.5	131.03
480	8	0.333333	26.01	35.62	43.87	53.56	69.37	84.19	102.12	131.73

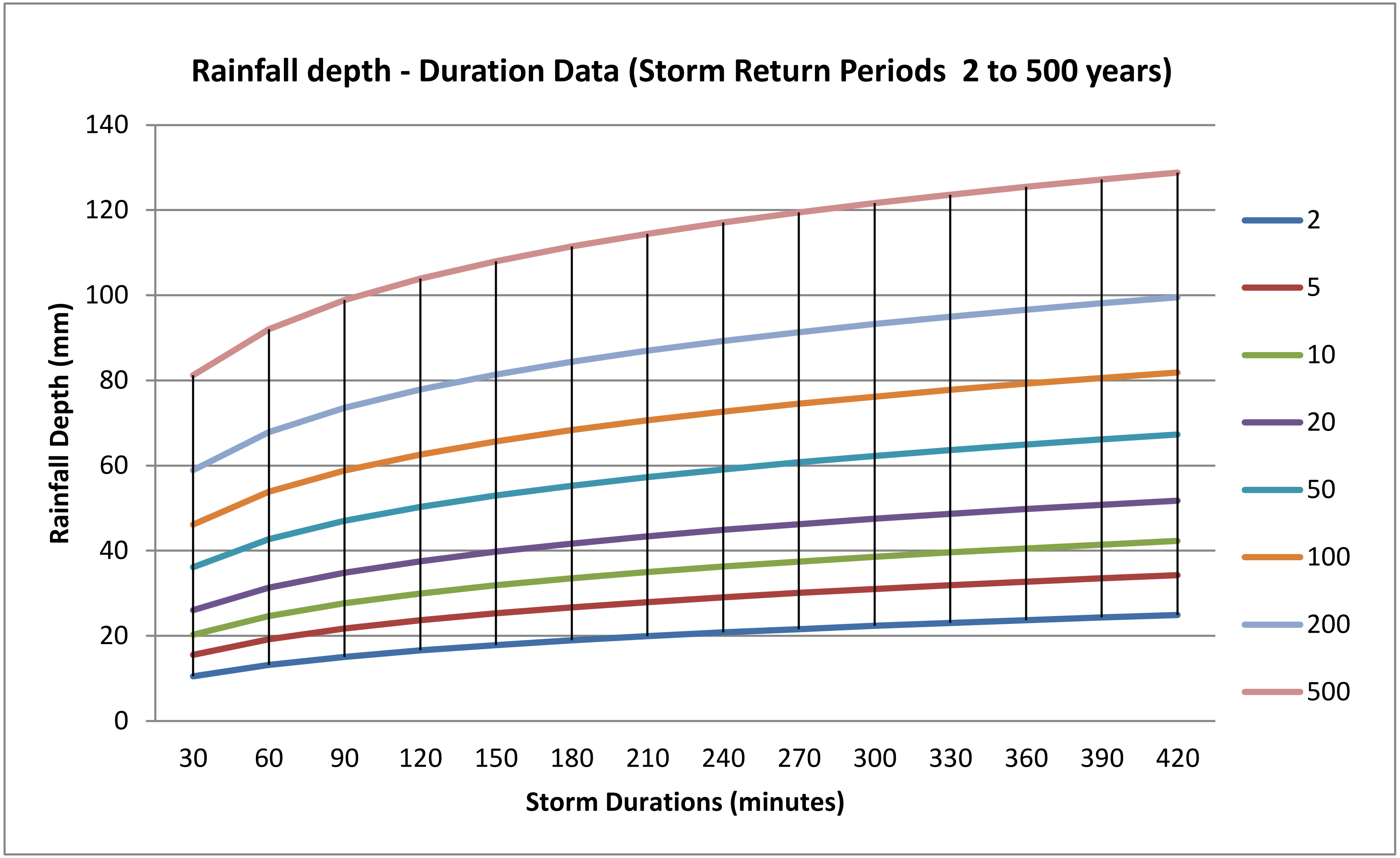


Figure 5-4 **Diagrammatic representation of rainfall intensity, duration and return data for the Greater Walbrook Valley**

Table 5-2 **Average Monthly rainfall statistics (source: Meteorological Office – Greenwich Park weather station)**

Month	1961-1990 Rainfall (mm)	1961-1990 Days of rain	1961-1990 Average rainfall intensity (mm/day)	1971-2000 Rainfall (mm)	1971-2000 Days of rain	1971-2000 Average rainfall intensity (mm/day)	1981-2010 Rainfall (mm)	1981-2010 Days of rain	1981-2010 Average rainfall intensity (mm/day)
January	50.4	11.3	4.5	51.9	10.9	4.8	41.6	11.4	3.6
February	34.0	8.1	4.2	34.0	8.1	4.2	36.3	8.5	4.3
March	44.8	10.1	4.4	42.0	9.8	4.3	40.3	9.8	4.1
April	44.8	10.1	4.4	45.2	9.3	4.9	40.1	9.0	4.5
May	49.1	9.5	5.2	47.2	8.5	5.6	44.9	9.2	4.9
June	49.3	7.7	6.4	53.0	8.4	6.3	47.4	7.4	6.4
July	44.0	7.4	5.9	38.3	7.0	5.5	34.6	6.3	5.5
August	49.9	8.1	6.2	47.3	7.2	6.6	54.3	8.1	6.7
September	55.3	8.5	6.5	56.9	8.7	6.5	51.0	8.6	5.9
October	54.4	8.9	6.1	61.5	9.3	6.6	61.1	10.9	5.6
November	54.9	9.9	5.5	52.3	9.3	5.6	57.5	10.9	5.3
December	54.5	10.0	5.5	54.0	10.1	5.3	48.4	9.5	5.1
Annual	*585.5*	*109.5*	*5.3*	*583.6*	*106.5*	*5.5*	*557.4*	*109.4*	*5.1*

formation is at its greatest. As demonstrated by the average monthly rainfall intensities derived from the rolling 30-year statistics and reported in Table 5-2, the most intense storms can be expected more frequently during the summer months, June to October, averaging 6.0mm/day compared with 4.5mm/day for the rest of the year (1981-2010 statistics). However, the ground surfaces are, typically, significantly drier during the warmer summer months than during the winter months and therefore better able to absorb rain falling upon it, reducing runoff to a river. The most intense storms of summer may therefore not generate the highest rates of storm flow in the river. The significance of this to storm runoff estimation is in relation to the Antecedent Moisture Condition (AMC), discussed in Section 5.7.4.

Climate in the Roman period

As no statistics exist for the Roman period for the relationship between rainfall intensity, storm duration and frequency of storm occurrence, it is intended to use modern data as reported in Table 5-1 and Figure 5-4. Climate in southern Britain in the Roman period is therefore of interest to the research principally for the possible effect that it may have had on rainfall intensity and frequency of occurrence of storms of particular intensities. However, in absence of Roman era climate data, proxy data has to be used to develop an understanding of how the climate compared with that of today.

Various types of palaeo-climatic proxy data, considered to be sensitive to temperature change, have been used to develop temperature data for the past, including tree rings, ice cores and coral growth. A study carried out in the USA reviewed previous climate research projects by others of historic climate reconstructions for the Northern Hemisphere that included part of the Roman period, 200 to 500 CE (Mann et al, 2008, 13252-13257). Although they accepted that their conclusion were likely to be less accurate for the Roman period, they considered that temperatures were up to 0.5°C lower than for the period over which modern rainfall statistics have been compiled. However, for any specific point in time, there was a variation between predictions of up to 0.3°C. The findings of this study are supported by an overview of mid- to late Holocene climate change (Beer and Wanner, 2008, 1791-1828).

A more recent study (Esper et al., 2012, 862-866), was based on tree-ring data from northern Scandinavia and orbital forcing data. The results of this study for the last 2,000 years are shown in Figure 5-5. (Beer and Wanner, 2008, 1791-1828)The early Roman era is considered to have been slightly warmer than today. However, it is of interest to note that temperatures have then begun a period of cooling to approximately the same as those of today by the time of the arrival in Britain of the Romans. Temperatures then fall by about 0.3°C to about 250 CE, then fall a further 0.3°C and rise by about 0.5°C over a period of 50 years to the start of the 4th C at which point they plateau to beyond the date of their departure from Britain. Therefore, the climate in the northern Hemisphere appears to have cooled slightly through the period that the Romans occupied Britain but not by a significant amount.

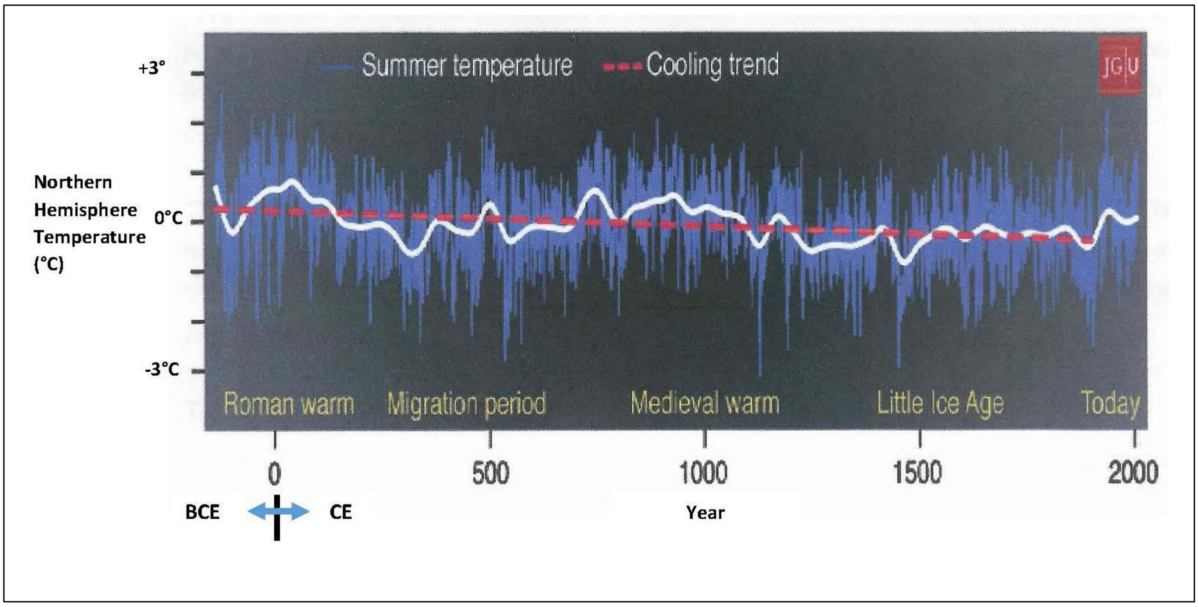


Figure 5-5 Temperature variation from 100 BCE to present day (after Esper, 2012, 862-866)

Vimes were introduced to Britain by the Romans (Association of English Wine Producers, 2016). However, Tacitus, writing at the end of the 1st C BC labelled the British clime "horrible" and unsuited to growing vines. The English wine industry has experienced a considerable resurgence in recent years, indicating that the climate does not have to be warmer than today in order to produce grapes for wine-making.

A slight cooling might have led to a reduced intensity of summer storms and conversely, the later slight warming may have resulted in storms of slightly greater intensity. However, as the variations in temperature from those of the last 200 years appear to have been small, it has been assumed that the climate of the London area of Roman Britain was similar to that of today and that the rainfall relationship shown in Table 5-1 and Figure 5-3 are valid for use in the current research.

5.7 Data Developed from Literature and Archaeological Investigations

5.7.1 Topography – Moorfields northwards

The Greater Walbrook Valley catchment immediately prior to the arrival of the Romans and for the period of their occupation can be divided into five main topographic areas for the western stream of the Walbrook:

a. the Islington ridge, which extends from the Angel, Islington through to Canonbury, to the City Road/Britannia Walk intersection;
b. City Road/Britannia Walk to Old Street/Great Eastern Street;
c. Old Street/Great Eastern Street to Finsbury Circus/Blomfield Street (the full extent of Moorfields – Lower, Middle and Upper);
d. London Wall to immediately beyond the western side of the Bank of England; and
e. Bank of England to Upper Thames Street.

For the Walbrook's eastern stream, the first extra-urban topographic divisions would have been:

i. the Islington ridge southwards to Shoreditch Park, up to the northern boundary of the Cranston Estate;
ii. the Cranston Estate through to the northern end of Curtain Road at Rivington Street; and
iii. Rivington Street/Curtain Road to Finsbury Circus/Blomfield Street.

From Moorfields outside of the town wall into the city to Upper Thames Street, there was a very significant alteration in the topography of the area from the start of the Roman period through the medieval period and well into the 17th century. This alteration in level varied significantly between locations but was a product of the same factors - in-situ accumulation of the fabric of demolished buildings, most of which deteriorated rapidly and were replaced within a period of one or two generations, the dumping of urban rubbish and natural infill. The latter was most obvious in the Moorfields marsh, where there were thick accumulations of peat. The processes that led to the formation of peat were almost certainly triggered by the completion of the town wall in the first decades of the 3rd century which, as described in Section 7.4, created the conditions under which the marsh was formed.

On departure of the Romans, the culverts carrying the Walbrook through the wall would have rapidly blocked and the marshy conditions worsened for nearly 500 years after which the abandoned city within the walls was re-occupied. Although the culverts were re-opened on re-occupation, the city's wards were not diligent in their duties to maintain the Walbrook channel and the marsh continued in existence for another 500 years. The conditions for peat formation were therefore in place from the beginning of the 3rd century through to the middle of the 15th century, a total of about 1,250 years. Archaeological investigations outside of the wall but close to it (Royal Commission on Historical Monuments, 1928; 86-87) have indicated that the depth of peat formed over this period was between 2.0 and 2.5 metres, which would have raised the channel of the Walbrook by a similar amount.

This raising of land levels over the area of Moorfields is demonstrated in archaeological investigations, e.g. VER90, FIS96 and FBY01 (Section 4.7.3), these three sites being in the Finsbury Square/Finsbury Pavement area. At this location, the medieval bed of the western stream of the Walbrook was found at a consistent level of 10.30m OD which corresponds well with the culvert found through the wall in the 19th century at All Hallows Church on London Wall, which had an invert at approximately 10.00m OD (Royal Commission on Historical Monuments, 1928). The Roman culvert, found less than 100m west of this at Blomfield Street, was at a level of 7.50m OD. This significant increase in surface level of Moorfields and hence the Walbrook, which fed it from the north, may well have influenced a raising of the general ground level above Old Street, its influence possibly extending as far north along City Road as Shepherdess Street.

This goes some way to explain the difference in elevation between Old Street at a level of 14.00m OD and the land in the general vicinity of the marsh north of the wall, which in the Roman period varied in elevation between 7.50 and 8.50m OD.

The Moorfields area has been defined as the area between Old Street and Great Eastern Street in the north, the town wall in the south, Deepditch in the east, the course of the eastern stream of the Walbrook, and Mallow Field in the west, around the modern Mallow Street (Bird, 1922, 88-90). This area has itself been considered historically to have three distinct areas, Lower, Middle and Upper Moorfields (Ellis, 1798, 83; 156-183; 219; 225). Worship Street, which runs west to east, formed the boundary between Upper and Middle Moorfields. Upper Moorfields consisted of High Field or Finsbury Field, i.e. “high” relative to the fields and marsh south of Worship Street. Lower Moorfields, the area of perennial marsh until the start of the 15th century, extended from the wall to Finsbury Pavement and Middle Moorfields lay between Finsbury Pavement and Worship Street.

There appears to have been a steeper slope to the land over the 300 metre wide area of transition, known as Middle Moorfields, than to the north or south. The topography of Moorfields is also described in Chapter 4, Section 4.6.2. In contrast to the re-shaped topography of the Greater Walbrook Valley catchment from Moorfields to the Thames, the topography of the area of the catchment lying to the north of the Old Street/Great Eastern Street intersection has altered little over the last 2,000 years. By far the greater part of the City of London remained within the confines of the Roman wall throughout the Medieval period, with the exception of limited ribbon development along principal roads outside but flanking the wall, principally on its north and east sides. The population of London began to increase through the late Tudor period but housing to cater for this hugged the wall either side of Moorfields or was accommodated further west around the Strand and Westminster. The population of London hovered between 100,000 and 150,000 through the 17th C, its growth affected by the Great Plague of 1665-66. It took until the middle of the 18th C for the boundary of London to reach as far north as Old Street, by which time the population was nearing half a million. City Road was only extended north to the Angel Islington from its intersection with Old Street in the second half of the 18th C. Industrialisation led to a mass migration from rural areas to the cities in the second half of the 18th C and many districts around London, particularly to the east and west experienced rapid urbanisation. By the start of the 19th C, the population of London had reached 1 million. With respect to the Study Area, this fuelled a further extension of London to Islington, Hackney and Highbury. The extension of the boundaries of the urbanised area of London from the Roman period to the beginning of the 19th C are shown on Figure 5-6. The areas outside of these boundaries remained principally rural in character, although there were some small villages that became foci of later development with whole districts taking on their names. The area between the medieval city and the early 19th C boundary was also used for (Curl, 2010)

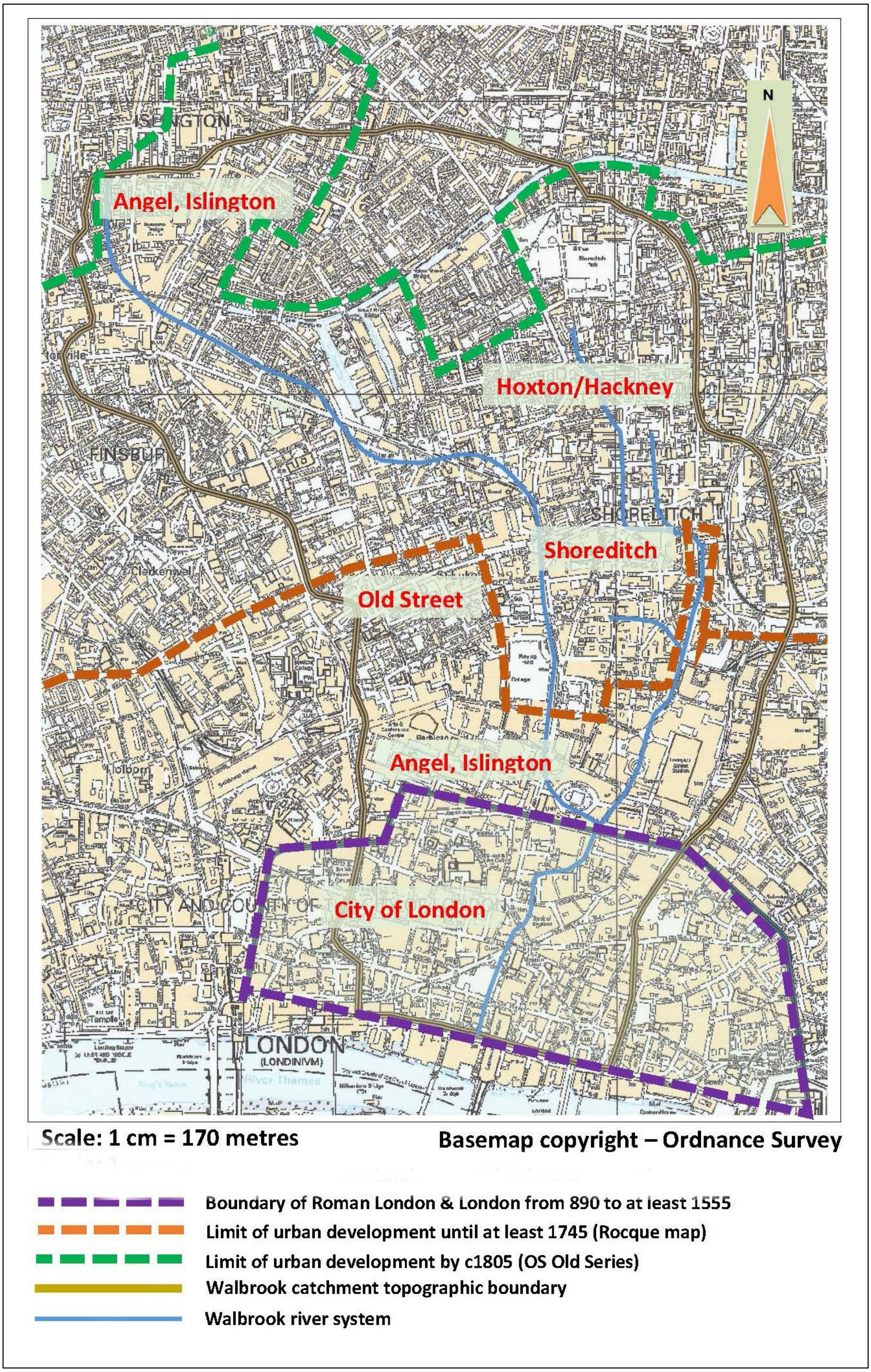


Figure 5-6 **Growth of London from the Roman period to beginning of the 19th C**

recreation by Londoners who would take countryside walks to a number of spas that were established within the Walbrook and Fleet catchments, e.g. in the former, the Peerless Pool at the City Road/Old Street junction and White Conduit House above the Angel, Islington (Curl, 2010, 79-85). Apart from those areas re-developed following the bombing of WWII, much of the housing and other infrastructure of today in the area north of Old Street through to Islington and Highbury were constructed on the original ground surface in the second half of the 18th C and the first half of the 19th C. The level at which the Regent's Canal was constructed in the early 1800s across the Greater Walbrook Valley is another indication that the topography has changed little over the flatter area between the canal and Old Street since its former rural existence. A late 17th C cobbled lane, Silbury Street, between Vestry Street and East Road, immediately north of Old Street still exists. Three oreholes at East Road, BGS references 1064584-6, show natural stratigraphy, gravel and sand underlain by London Clay, at the general level of the land to the north of Old Street.

The area between Old Street and the town wall, Moorfields, was one of transition between these two areas of quite different topographic evolution.

In summary, the area between the Thames and Moorfields experienced changes in level of between 3 and 9 metres from the start of the Roman period to the present day. In contrast, the area north of the Old Street/ Great Eastern Street intersection remained virtually unchanged from its original, rural contours, notwithstanding its complete urbanisation, which took place from the middle of the 17th C and was completed in the 19th C.

5.7.2 Average slope of the Walbrook riverbed - Blomfield Street northwards

The slope of a riverbed has a significant influence on the velocity of flow in a river. This has impacted upon the current research in two ways:

- time taken for storm flows to arrive at any point in the catchment of interest with respect to flood frequency (the greater the velocity, the shorter the time for concentrating flow at a particular location and the more intense the storm creating the flows); and
- capacity of a river channel to carry flow before its banks are over-topped and flooding occurs.

The average slopes of the riverbed from Blomfield Street southwards to the Thames have been developed in Chapter 4, Section 4.5.2. The bed slopes in this case are the dominant factor in determining whether flooding would have occured within urban Roman London.

This section concentrates on the development of the average slopes of the beds of the western and eastern streams of the Walbrook upstream of Blomfield Street. The riverbed slopes over these stretches of the stream are one of a number of factors that affect the magnitude of the flow arriving at a particular location.

Figure 5-4 provides a pictorial representation of the riverbed profiles for the two streams from their respective headwaters to Blomfield Street, together with the background statistics used to produce these. The statistics were drawn from the following sources:

- a modern Ordnance Survey map at a scale of 1:10,000
- archaeological investigation reports (VER90, FIS96, FBY01 – all at Finsbury Square/Finsbury Pavement – and LSS85 at Eldon Street/Blomfield Street);
- excavation of the wall at All Hallows Church in 1905, (Royal Commission on Historical Monuments, 1928).

As noted in Section 5.7.1, the topography of the upper reaches of the Greater Walbrook Valley have altered little over the last 2,000 years, today's land contours as recorded by Ordnance Survey have been taken as a surrogate for determining the slopes of the riverbed in these area. This applies to the catchment upstream from Britannia Walk/City Road for the western stream and upstream of Old Street/Great Eastern Street for the eastern stream. For the stretches downstream of this point, over which the topography has altered significantly, the aforementioned archaeological and literature sources have been used. The profiles of the western and eastern streams along their respective thalwegs to Blomfield Street are shown in Figure 5-7. The slope of the riverbeds of the eastern and western streams are developed in Table 5-3 based upon stream lengths and falls in elevation shown in Figure 5-7. No discernible watercourse has been identified for the eastern stream of the Walbrook north of Shoreditch Park to the watershed at the Canonbury and Highbury ridge. It is probable that the issues from springs in this area, particularly those in the vicinity of the priory at Canonbury were carried southwards in many small ditches to the head of the eastern stream at the Cranston Estate.

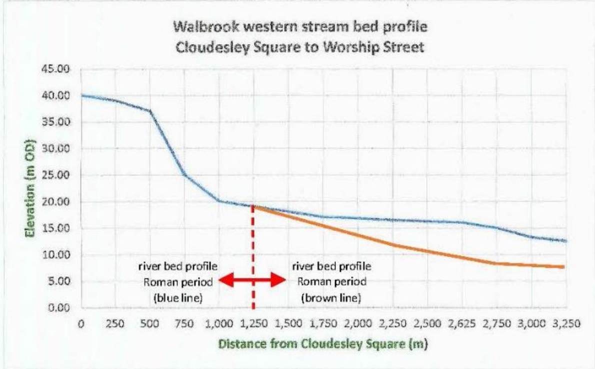
Upper Greater Walbrook Valley - Western & Eastern Streams

Stream Bed Profiles

Notes:
1 metre below land elevation today adopted as a surrogate for upper catchment river bed profile in Roman period
Values in bold brown font are river bed levels in Roman period from archaeological investigations, literature and BGS boreholes
The Finsbury Square elevation is derived from the Medieval bed level (10.30 m OD) less 2 metres accumulation of peat on the Moorfields marsh

Western Stream

Location	Distance from headwaters (m)	Land elevation today less 1 metre (m OD)	River bed profile in the Roman period (m OD)	Research evidence from Roman period
Cloudesley Square	0	40.00	40.00	
Ritchie Street	250	39.00	39.00	
Chapel Market/Liverpool Road	500	37.00	37.00	
Elia Mews (near NW end)	750	25.00	25.00	
Nelson Place	1,000	20.00	20.00	
City Road/Graham Street	1,250	19.00	19.00	
City Forum	1,500	18.00		
Shepherdess Street (Eagle pub)	1,750	17.00		
Britannia Walk/City Road	2,000	16.75		
Old Street (Silicon Roundabout)	2,250	16.50	**12.00**	BGS 1066133
Bunhill Fields Cemetery entrance	2,500	16.25		
Worship Street	2,625	16.00		
Finsbury Square (midway along square)	2,750	15.00	**8.30**	VER90; FBY01; FIS96
Moorgate (50 m south of South Place)	3,000	13.25		
Blomfield Street/Finsbury Circus	3,250	12.50	**7.75**	RHCM 1928, p87



Eastern Stream

Location	Distance elevation headwaters (m)	Land elevation today less 1 metre (m OD)	River bed profile in the Roman period	Research evidence from Roman period
Cranston Estate/Bury Street	0	18.00	18.00	
New North Road	250	17.00	17.00	
Buttesland Street/Pitfield Street	500	16.50	16.50	
Old Street/Great Eastern Street	750	16.25	16.25	
Rivington Street/Curtain Road	1,000	16.00	16.00	
Hewett Street/Curtain Road	1,250	14.00		
Primrose Street/Curtain Road	1,500	13.50		
Broadgate Development (N of Circle)	1,750	13.00		
Eldon Street/Blomfield Street	1,825	12.75	**8.00**	LSS85
Blomfield Street/Finsbury Circus	2,000	12.50	**7.75**	RHCM 1928, p87

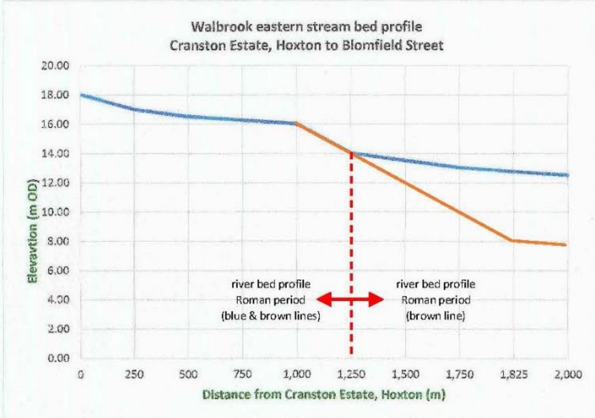


Figure 5-7 Riverbed slopes – upper Greater Walbrook Valley

Table 5-3 Greater Walbrook Valley – Riverbed Slopes Upstream of Blomfield Street

Greater Walbrook Valley
River Bed Slopes Upstream of Blomfield Street

Stream & Individual Stretches	Length	Bed elevation		Fall in	Slope of the river bed	
		upstream	downstream	elevation		
	(m)	(m)	(m)	(m)	(1 in ?)	(m/10,000m)
Western Stream						
Cloudesley Square to Chapel Market/Liverpool Rd	500	40.00	37.00	3.00	167	60
Chapel Market/Liverpool Rd to Nelson Place	500	37.00	20.00	17.00	29	340
(Cloudesley Square to Nelson Place)	***1,000***	***40.00***	***20.00***	***20.00***	***50***	***200***
Nelson Place to Britannia Walk/City Rd	1,000	20.00	13.75	6.25	160	63
Britannia Walk/City Rd to Finsbury Square	750	13.75	8.30	5.45	138	73
Finsbury Square to Finsbury Circus/Blomfield St	500	8.30	7.75	0.55	909	11
(Nelson Place to Finsbury Circus/Blomfield St)	***2,250***	***20.00***	***7.75***	***12.25***	***184***	***54***
Eastern Stream						
Cranston Estate to Rivington St/Curtain Rd	1,000	18.00	16.00	2.00	*500*	*20*
Rivington St/Curtain Rd to Eldon St/Blomfield St	825	16.00	8.00	8.00	103	97
Eldon St/Blomfield St to Finsbury Circus/Blomfield St	175	8.00	7.75	0.25	700	14
(Cranston Estate to Finsbury Circus/Blomfield St)	***2,000***	***18.00***	***7.75***	10.25	***195***	***51***

5.7.3 Soil with respect to permeability

For the purposes of the HydroCAD software, soil is classified in relation to its permeability (HydroCAD, 2011: 149). Four hydrologic soil groups have been identified by the US SCS (United States Soil Conservation Service, now the National Resources Conservation Service), each indicating a minimum rate of infiltration for bare soil, i.e. unrelated to its vegetation or other cover type, after prolonged wetting. The four groups, A to D are listed in Table 5-4 together with their permeability ratings and typical soils.

Table 5-4 Soil groupings and their permeability ratings (HydroCAD, 2011; 149)

Soil Group	Permeability rate (mm/hour)	Permeability description	Typical soils (see note)
A	>7.6	high	sandy loam
B	3.8 to 7.6	moderate	sandy clay loam; silty clay loam clay loam (larger catchment Zones B & C)
C	1.3 to 3.8	low	sandy clay; silty clay (smaller catchment Zones A & D)
D	0 to 1.3	none to very low	clay

Note: typical US soil references - (University College Santa Cruz, 2010, (Unit 2.1, page 20, Table 26)) (Dese, 2010, 1)

Superficial deposits underlying the soils has been determined as 84% gravel with the balance composed equally of clay, silt and alluvium. This would suggest that beneath the soil layer, the superficial deposits would have had a high degree of permeability. The stratigraphy records of the archaeological sites included in this research (Chapter 4, Section 4.7.1) demonstrate that the surface layers of soil at the time of the Roman invasion of 43 CE were generally composed of a silt, clay and sand, sometimes mixed with pebble or gravel. This finding is reinforced by modern sources of soil data in the London area (Section 5.6.2). The latter would generally contain small amounts organic material, almost certainly decomposed vegetation. The soil could therefore best be classified as an easily-worked silty, clayey, sandy loam, described in a soil survey of the London region as excellent deep loams (Willats, 1937). The conclusion drawn in Chapter 4, Section 4.7.2, based upon stratigraphic data, is that the silt and sand content is possibly more predominant than the clay. For 84% of the catchment, the soil overlies gravel and sand.

A significant content of silt, clay and humic material in the soil of the Greater Walbrook Valley would preclude a classification of Type A, a soil having a very low content of these materials. Therefore, for the purposes of the HydroCAD software, soil found in much of the catchment has been classified as of the Type B group, i.e. with moderate rates of infiltration and transmission for those parts of the catchment area where the superficial deposits are predominantly gravel. However, for those areas where the geological record has shown there to be a significant proportion of superficial deposits of London Clay as well as gravel, Type C soil group will be used. In calculating estimates of storm run-off rates, as reported in Section 5.9.2, Type B soil has been used for sub-catchments B and C and Type C soil for Sub-catchments A and D, sub-catchments having been defined in Section 5.9.1 and Figure 5-11.

5.7.4 Antecedent moisture condition (AMC)

The antecedent moisture condition (AMC), also known as the antecedent rainfall condition, can have a significant effect on the rate at which rainfall runs off any particular surface. The HydroCAD software recognises four AMC states numbered 1 to 4 – dry (AMC 1), normal (AMC 2), wet (AMC 3) and saturated/frozen (AMC 4) (Hydrocad, 2011). The dry state, AMC 1, is applicable to desert and arid climates and assumes that the soil will absorb as much rain as its natural permeability will permit. Whereas under saturated or frozen conditions, AMC 4, all but 2% of the rain is considered to drain to the watercourses. Neither of these extremes would represent conditions found in the temperate climate of Roman southeast England.

An appropriate AMC state for conditions immediately preceding a storm in the Greater Walbrook Valley is therefore a choice between AMC states 2 or 3. Runoff Curve Numbers used in the HydroCAD software have been developed for AMC 2. For the wetter soil condition, AMC 3, a factor is applied by the software to the AMC2 Curve Number values to enhance the amount and rate of runoff to the river (HydroCAD, 2011: 154), given that the soil would be wetter and less able to absorb the rain compared with AMC 2. It is quite common for prolonged, low intensity rainfall to precede storm events in autumn, winter and spring in the London region. Storms of high intensity can occur in the autumn, winter and spring, but less frequently than in the summer months. From Table 5-2, the months when higher intensity storms should occur with a greater frequency than the annual average are shown to be June to October. Summer storms are more likely to occur when the ground is dry and more able to absorb rainfall rather than generating runoff. However, for southeast England, wet summer periods do occur and a wet antecedent soil condition, although rarer than in winter can occur in the summer months.

A mix of AMC 2 and AMC 3 would therefore best represent the Greater Walbrook Valley situation. The following approach to AMC for the estimation of storm runoff to the Roman Walbrook has therefore been adopted:

- AMC3 has been adopted to calculate runoff for storms having a return period of 50 years or less (to reflect autumn, winter and spring conditions)
- AMC2 has been adopted for the more intense storms having a return period of 100 years or more (to reflect the summer condition)
- as illustrated in Section 5.9.2, Figures 5-14 to 5-17, a graphical best-fit curve has been used to derive the storm flow values between the 10-year and 500-year storms, the more intense, long return-periods representing the summer months of June to August and the intermediate return periods representing the transition months of April/May and September/October.

However, the effect of storms of summer intensity falling on wet ground in winter, i.e. an AMC state of 3 throughout the year, has also been modelled for those areas considered to be at greatest risk of flooding to assess the extent of this enhanced level of risk.

5.7.5 Landscape – vegetation and settlement and HydroCAD Curve Numbers

Rain falling on a catchment drains across the landscape to the nearest ditch or watercourse. The nature of the landscape through which the run-off drains exerts a very significant influence on the magnitude of the storm-generated flows in the watercourse. As an example, a dense tree canopy will delay rain falling on it from reaching the ground and any delay in runoff reaching the watercourse will reduce the rate of storm flow in the river. A lightly-wooded area will retard the flow to a lesser extent. The nature and density of vegetation will also affect the rate of flow of rainfall runoff as will the type of crops grown in the catchment, e.g. brush has a greater retarding effect than pasture. Rain falling on impermeable surfaces of a development will drain quickly and the rate of run-off can be further accelerated by the installation of an effective system of drainage.

It is therefore important to define the constituent elements of the landscape of the Greater Walbrook Valley immediately prior to and during the Roman period. The nature of a catchment's landscape is converted to values which can be used in the HydroCAD software by combining the type of landscape cover and soil permeability into a factor called the Curve Number (CN) (Hydrocad, 2011), as defined in Section 5.5.

Unfortunately, there is no contemporaneous written record of what constituted the landscape of the Greater Walbrook Valley in the immediate pre-Roman period, either for the rural or for the urban areas. The problem of determining the landscape is further complicated by the modern catchment being completely covered by dense urban development, whereas the natural catchment landscape would have been rural in character possibly with scattered, small settlements. The nature of the landscape of the Greater Walbrook Valley immediately prior to the Roman invasion and during occupation has therefore been developed from two main sources:

- environmental archaeological evidence; and
- literature sources relating to the upper Thames catchment.

The constituents of the landscape thus derived, vegetation and settlement have been used to derive the composite CN for each of the sub-catchments of the Greater Walbrook Valley. The development of these values appropriate to this research is reported in Section 5.9.1.

Environmental archaeological evidence has been discussed in Section 4.8. However, to date, the published evidence, principally relating to pollen analysis within Roman London, is very limited. The six sites discussed all lie within the urban Roman London area, a small portion of the whole catchment. The conclusions drawn from a review of this evidence provides an insight into the types of vegetation current before and during the Roman period within the catchment – but not the extent of each.

The Greater Walbrook Valley, in common with other parts of Greater London north of the Thames, is commonly described as having been covered by dense woodland. This impression is reinforced by the area being called the Forest of Middlesex in the Domesday Book. However, at the time, "forest" was used to describe all unenclosed land, whether wooded or not. Wildwood first colonised Britain towards the end of the last period of glaciation, about 11,000 BP. By about 6,000 BP, pioneer species, birch, aspen and willow, had given way to alder, oak, lime, elm, ash, maple and hornbeam (Rackham, 1986, 71-72). Increased rainfall in the periglacial period, compared with the preceding Devensian glacial period would probably not have generated an increase in runoff due to a dense woodland canopy (Lockwood, 1979, 297-310). In a classification of wildwoods, the London area is designated part of the "Lime Province of Lowland England" (Huntley and Birks, 1983).

Trees grow best where they can get a good purchase in the soil and this condition is better satisfied on clay than gravel (Muir, 2005, 11-31; 197-227). Whilst it is quite possible that the general area of Greater London, founded on London Clay, was covered by wildwood, i.e. woodland that had never been managed, this is unlikely to have been the case for areas such as the Greater Walbrook Valley, where gravel and sand were the predominant superficial deposits. Environmental evidence (see Section 4.8.1) supports the presence in the catchment of oak, beech, birch, hazel, elm, lime, willow and alder. Clay is found at the western and northern boundary areas of the Greater Walbrook Valley catchment and ancient woodland could have developed there. Willow and alder Carr would have lined the riverbanks and the floodplain of the Walbrook. Figure 5.8 provides examples of ancient woodland and of alder Carr lining the banks of a stream, the latter having an appearance similar to that which could have been found in the middle and lower reaches of the ancient Walbrook.

There being no contemporary description of the landscape of urban Roman London, literature sources have been accessed which deal with a soil and climate situation similar to those of the Greater Walbrook Valley, i.e. small catchments which have remained almost undeveloped.

Mesolithic settlers imported crops, animals and weeds into Britain about 6,000 BP. Rackham (ibid) in his book on the history of the British countryside , estimates that by the early Iron Age, half of England had been cleared of wildwood and converted to farmland, rating clearance of millions of hectares as one of the greatest achievements of the period. However, with removal of the extensive woodland canopy, surface runoff rates would have significantly increased (Lockwood, 1979, 297-310). Recent archaeological investigations carried out at 1 Poultry (ONE94) on the flora and fauna of the middle

Figure 5-8 Examples of ancient woodland (3 upper photos; Hengistbury Head, Dorset) and of alder Carr lining the banks of a stream (photos by author)

URWV (Scaife, 2011, 533-538) has provided more substantial evidence of the natural pre-Roman environment and may be taken to indicate the general nature of the vegetation that would have characterised the Greater Walbrook Valley of that period. This source states that the main tree elements were typically oak, hazel and alder with a small but significant presence of holly and beech. Alder would have grown in the lower, wetter areas of the valley with other tree taxa growing locally on the drier valley sides. Tall grasses would have been dominant in an open landscape of rough pasture with bracken colonisation and only scattered trees. There would have been small patches of cereal cultivation where the scrubland had been removed.

Evidence therefore points to the Greater Walbrook Valley having been predominantly open, long grass pasture but with the fringes and small areas of clay soil being lightly wooded with oak, lime and hazel trees.

Sources other than archaeological, including Natural England and English Nature, provide general descriptions of the conditions found on the gravel terraces of the London region. The easy soils of the gravel terraces are typified by a gentle topography and open landscapes with sinuous lines of trees along the river valleys and at wetland scrapes (Baxter, 2011, 69). Widely-scattered small copses on London Clay are described as examples of what had been lost elsewhere in the London region, every settlement having had its own small wood (English Nature, 1997, 21). One source describes the London Clays as having been thinly inhabited with some isolated clearings, particularly by streams and that agricultural settlements were found at the margins of the wood growing on damp clay (Finberg, 1972, 67). This latter description could be applied to the situation at the Angel, Islington at the northwest extremity of the catchment where the gravels give way to London Clay.

The last three cited sources stress that the gravel soils were easily worked and therefore well-suited as a base to agriculture. They also indicate that woodland was mostly confined to the London Clay and that settlements were unusual on the clay. These and other attributes of the gravel terraces with respect to settlement and agriculture on the gravel terraces are under-scored by archaeological sources.

With respect to the Greater London area, D G Bird writes (Bird, 1996, 220) that that the loamy soils of the London gravels are some of the best soils in England and that Iron Age people and Romano-British were reluctant to establish settlements on clay. Occupation sites were frequently sited on the junctions of geological types, more specifically, with settlements on gravel with woodland on clay close by to facilitate pig breeding, the pigs left to roam the woodland foraging for nuts. Reporting on the archaeological excavations at Ashford Prison, the investigation team confirmed this conclusion and emphasised the attractiveness of the gravel to settlement and how areas of clay were avoided (Carew et al., 2006, 4-5).

The gravel terraces of the Upper and Middle Thames are a good surrogate for the gravel terraces of the Walbrook Valley being similar in their superficial deposits and subject to virtually the same climate pattern. Most importantly, they have been subject to considerable archaeological investigation both at the macro-level involving the mapping of cropmarks enhanced by modern computer-aided photogrammetric identification and plotting as well as investigation (Whimster, 1992, 1-9) at the site-specific micro-level.

The following have been abstracted from various publications describing landscape situations found in the course of archaeological investigations on the Upper and Middle Thames gravels and their consequent influence on vegetation, settlement and agriculture.

Archaeological work reported by Allen et al in the Maidenhead, Windsor and Eton areas of the Middle Thames Valley (Allen et al., 2013, 11) pointed out that as the loamy soil became more permeable and workable, due to a higher content of sand, it also became more suitable for agricultural working, particularly for cereals and grasses.

In a survey of the gravels of the Upper Thames Valley, Oxfordshire Archaeological Unit reported (Benson and Miles, 1974: 18) that more archaeological sites are found on the gravel terraces than in any other area within the region. The density of sites developed on gravel is attributed to the attraction of the terraces for early and subsequent settlers; the relatively light woodland was easily cleared, the well-drained soils were conducive to primitive agriculture.

Fulford has commented upon the range of crops cultivated in the first millenium BCE, the period of transition from the late Iron Age to the Roman period, on the gravel areas of the southern half of England. These included barley, spelt and bread wheat, rye, oats and the celtic bean (Fulford, 1988, 26; 37-38). The Roman settlement pattern on the gravels was established in the period between the mid-first century BCE and the mid-first century CE and settlements that originated in that period continued until at least the fourth or fifth century.

Lambrick also commented upon the period of transition from the Iron Age through to the Roman period for gravel sites (Lambrick, 1991, 223-224) citing archaeological evidence for livestock farming in conjunction with cultivation of arable crops. Lambrick has also noted (Lambrick, 1988, 78-105) how the effectiveness of animal husbandry was improved by the Roman introduction of the technique of hay-making to Britain.

Willis speculated (Willis, 2007), quite reasonably, that the transition from urban to rural within Roman towns when progressing from their centres to their suburbs would have been a gradual one and that the proximity of a ready market would have stimulated the growth of farms in their peripheral areas to satisfy the demands of the urban population.

The existence of a marsh at Moorfields is documented from at least the 11th century and marshy conditions were almost certainly either created or made worse by construction of the town wall completed about 220 CE. (see Section 7.4). Palaeo-stratigraphic analysis of the URWV carried out as part of the current research has demonstrated that there was a very shallow “bowl” effect in the land surface between Lothbury in the south and Finsbury Pavement to the north. This would probably have resulted in marsh or fen-like conditions within this area, the amount of land involved probably varying with the seasons and amount of rainfall.

Summarising the foregoing:

- clearing of woodland for settlements and farming on a grand scale began about 6,000 calendar years BP;
- it has been estimated that more than 50% of ancient woodland had been cleared for settlement and agriculture by about 2,500 calendar years BP, with woodland on clay more likely to have been left intact;

- farmers from at least the Iron Age forward preferred to settle where there was a more readily workable loamy soil on a gravel base rather than on clay that was difficult to work, where such a choice was available;
- farmers were attracted to the gravels by easily-worked, fertile soils with good drainage characteristics and the added attraction that woodland was less dense, if present at all, and readily cleared; in contrast, clay soils were heavy to work, poorly-drained and densely wooded and houses would have felt cold and damp on the clay;
- loamy soil on gravel permitted the cultivation of a range of crops – emmer and bread wheat, rye, oats and the Celtic bean – in the drier areas away from the floodplain of the river and the wetter meadows near the river provided pasture for livestock and an opportunity to make hay; and
- to have sited a settlement on the boundary between an area of gravel and clay-lands, typified by the situation of the Angel, Islington would have enabled a farming community to reap the benefits from both soil situations.

The last point must be considered speculative. A settlement at the Angel, Islington, pre-dating the Roman invasion, would have had all of the farming advantages of loam on gravel, copious spring sources of water, pasture for cattle and cultivation of arable and horticultural crops on the gravels and a source of wood and the conditions for rearing pigs in the nearby clay woodland.

Early Britons may have considered a small settlement close to the Thames on or near Ludgate Hill or Cornhill too vulnerable to attack by sea-going marauders arriving from the Thames' estuary. However, a south-facing settlement on the "heights" of the Angel, Islington would have had an unimpeded view down to the Thames from Greenwich through to Vauxhall but being some 4 km from its banks, there would have been some notice of an attack from the river giving time to prepare for its defence. Modern buildings obscure the view that would have prevailed prior to their construction. However, a sketch made from the viewpoint of the reservoir above New River Head at the Angel, Islington by Thomas Bowles, c.1752, Figure 5-9 (Ward, 2003, 14-15), clearly depicts how open the view was looking southwards to the Thames, in a sweep from east of the Tower through to Westminster in the west, prior to urbanisation of the intervening land.

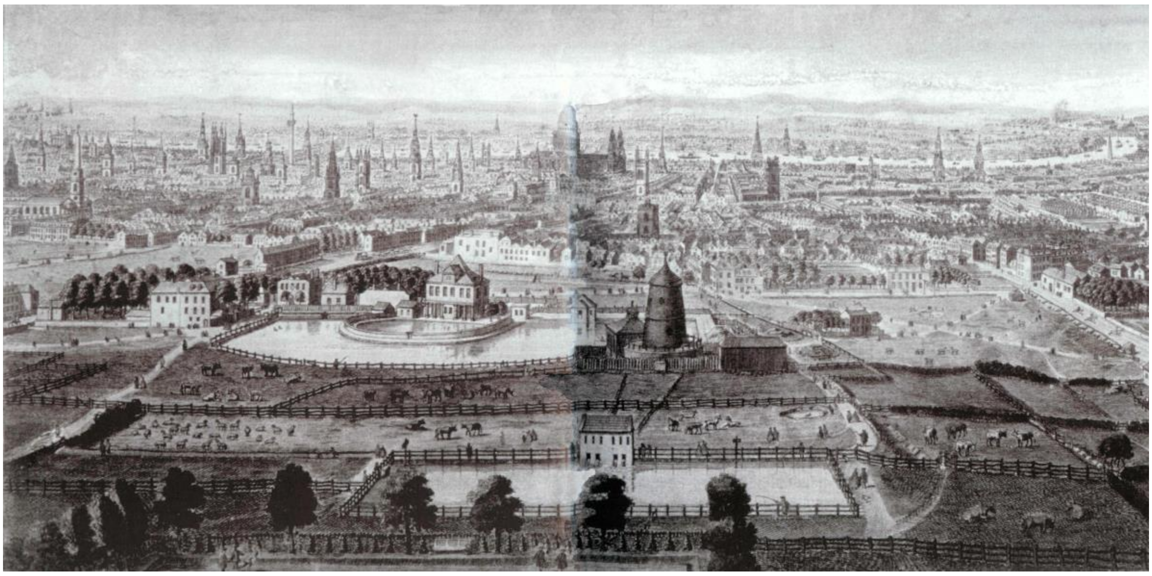


Figure 5-9 London from the New River Head Reservoir, Thomas Bowles, 1752 (Ward, 2003, 14-15)

Webb has suggested (Webb, 2011, 72) that the Greater Walbrook Valley, with the Trinovantes tribe to the east, the Catuvellani to the west and the Regni south of the Thames, may have been a border trading area and a location at which to settle disputes. The remains of prehistoric trackways and settlements have been found both to the east and the west of the Greater Walbrook Valley (Lewis et al., 2010, 175-186) but none in the valley itself. To the east, Neolithic trackways have been found at Fort Street, Silvertown and Bramcote Grove, Bermondsey and Bronze and Iron Age settlements at Warwick Reservoir, Tottenham Hale; Low Maynard Reservoir, Forest Road; Banbury Reservoir, Lea Valley Park; Wick Lane, Parnell Road; and Lefevre Walk, Old Ford and to the west at Heathrow, Stanwell Circus in the Middle Thames Basin. None of the foregoing areas has the topographic, hence defensive, advantages as good as the Angel, Islington promontory. It is possible that trackways existed However, other than a few prehistoric tools and flints, no archaeological evidence has been found in the Greater Walbrook Valley of settlements or farming activity pre-dating the arrival of the Romans. However, taking into consideration the foregoing and respecting the maxim "absence of evidence is not evidence of absence", the hydrological work will assume that there was a small-pre-Roman settlement in the upper Greater Walbrook Valley at Islington and that small-scale farming was carried out in upper and middle parts of the valley.

5.7.6 HydroCAD Landscape Curve Numbers

Landscape types are represented in the HydroCAD software by Runoff Curve Numbers (CN). Individual CN values are attributed to a range of different types of cover constituting landscape (Hydrocad, 2011), a value of 100 representing no retardation, all rainfall falling on the catchment rapidly reaching the watercourse. Most landscape elements have values within the range 50 to 90. The CN value for any specific type of landscape cover varies according to the soil type and condition on which it is founded – values being lowest for Type A soil, highly permeable soil, and highest for Type D soil, impermeable clay. In addition, some cover types are attributed different values according to the condition of the cover – denoted respectively "poor", "fair" and "good".

For the purposes of this research, CN numbers appropriate to the type of vegetation or settlement, as discussed in Section 5.7.5, have been selected for Soil Types B and C.

As the Roman period progressed, three factors would have led to increasing and more rapid runoff to the Walbrook compared with the natural state of the catchment:

- a demand for timber for building would have led to a great reduction in woodland;
- a large portion of the non-marshy catchment outside of the walled area will almost certainly have been converted to intensive agricultural, horticultural and animal husbandry activities with its attendant improved land drainage; and
- a limited amount of similar agricultural and horticultural activity within the walls and a progressive reduction in the permeability of the ground surface in the urbanised area, due to the construction of roads furnished with drainage and of thatched and tiled roofs of dwellings and public buildings.

Agricultural irrigation and drainage channels will have sped rainfall runoff more rapidly on its way to the river over most of the catchment and, within the urbanised area, surface water drainage pipelines and open channels would have had the same effect. This would have resulted in a more rapid rise and fall in the flow rates in the downstream, "urban" stretch of the river and its urban tributaries in times of storm.

As indicated by the stratigraphic analysis reported in Chapter 4, Section 4.6.2.1, it is probable that a marsh in the area of flat land, later called Moorfields, existed prior to the Roman development of Londinium. A marsh through which a river passes can exert an influence on flow patterns, particularly at times of storm, when the marsh can serve as a reservoir, reducing flow peaks downstream. However, the construction of the town wall, sometime between 190 and 220 CE, almost certainly further contributed to the marshy nature of the area. The effect of the wall on the hydrology of the area is reported in Chapter 7, Section 7.4. The current research has demonstrated how the wall would almost certainly have acted as a dam across the Walbrook impeding the flow of surface water runoff from the catchment entering the urban area, excess storm runoff being stored in the Moorfields marsh, which would have acted as an informal reservoir.

The HydroCAD manual does not provide a CN for marshland as such. For the purposes of runoff calculations, rain falling on an area of marsh will almost all flow to the river unimpeded with a small proportion being delayed as runoff by islands in the marsh. Such a situation would be represented by a relatively high Curve Number. For the purposes of compiling a composite Curve Number for any part of the Greater Walbrook Valley considered to be marsh, a Curve Number of 90 has been attributed to that area. CN values appropriate to the various types of cover and condition attributed to the Greater Walbrook Valley immediately prior to and during the Roman period for the adopted soil Types B and C are shown in Table 5-5.

The development of composite Curve Numbers representing the Greater Walbrook Valley catchment immediately prior to and during the Roman period is reported in Section 5.9.1.

Table 5-5 Runoff Curve Numbers appropriate to the types of cover attributed to the Greater Walbrook Valley immediately prior to and during the Roman Period

(SourceHYDROCAD. 2011: 150-153). HydroCAD Stormwater Modelling System Version 10 Owner's Manual. Appendix A2. Tables 2.2a to 2.2c. HydroCAD Software Solutions LLC. Chocorua, NH)

Cover Description	**Condition**	**Curve Number - CN (Hydrologic Soil Group)**	
		Type B	**Type C**
Settlements	poor (Grand Quartier Generale 1er Et 3e Quartier, 1915, 160-161)	86	91
Rural land use			
Crops	average (2)	72	84
Horticulture	average (2)	72	81
Pasture - grazing	good (Grand Quartier Generale 1er Et 3e Quartier, 1915, 160-161)	61	74
Uncultivated grassland	-	69	79
Brush	poor (4)	67	77
Woods	good (5)	60	73
Marsh (ponded portion)	-	90	90

Table notes: poor - primitive settlement similar to pasture, grass cover <50%; (2) average - composite value for all plantings in category; good - > 75% ground cover and lightly or only occasionally grazed; (4) poor - <50% ground cover; (5) good - no grazing and litter and brush adequately cover the soil

5.7.7 Tide Levels in the Thames at the Walbrook

The questions relevant to this research relating to Thames tide levels in the Roman period are:

a. Was the Thames tidal as far as the Walbrook and, if so, what were the tidal levels that could be anticipated?
b. If the Thames was tidal at its confluence with the Walbrook, was the Walbrook tidal and, if so, for what distance upstream?
c. Would tide levels in the Thames or the Walbrook have influenced groundwater levels beneath Roman London?
d. Would tide levels in the Thames or Walbrook have caused or affected flooding of the estuarine zone?

The first three of these questions are addressed in this section and the fourth in Sections 6.4 and 6.4.4.

The Thames in the Roman period at the point of its confluence with the Walbrook was quite different to the river of today. Whereas today, the river is constrained to a width of approximately 200m between the embankments constructed in the middle of the 19th C, in the 1st C, the Thames had no such artificial constraints. Its formal channel was at least three times its modern width and much of the area between Southwark and Lambeth on its south bank was low-lying mudflats. At high tides most of this area would have been submerged increasing its width to more than 1km (Milne, 1985, 84). The north bank was better and more permanently defined by the slopes of Ludgate Hill and Cornhil that rose away from the river.

It is often claimed that the site for London was chosen for two main reasons, that it was the first point upstream where the river could be bridged (Grimes, 1968, 3) (Merrifield, 1965, 33-34) and shipping could make use of tides to facilitate their passage to and from the sea (Rowsome, 2008, 25).

It is claimed that by the Late Bronze Age, 3,000 BP, the Thames was consistently tidal upstream at least as fa as Westminster but it then underwent a period of regression that had reversed before the Romans arrived (Sidell, 2000, 110). There are indications that at some undefined time, possibly early in the Holocene, the Thames was not tidal as far as the Walbrook. In the course of the LYD88 investigation, a 1m thick dense deposit of peat was found at the confluence of the Walbrook with the

Thames. It was significant that the peat, an unusual phenomenon on the north bank of the Thames and considered to have been washed down the Walbrook, was found only in the Thames on the downstream side of the mouth of the Walbrook. Had the Thames been tidal, the peat would almost certainly have been washed upstream and downstream of the Walbrook's estuary.

Analysis of mollusca on the Roman foreshore at Westminster has indicated that the river was not saline in the Roman period (Milne, 1985).

However, at least for the early Roman period, based on archaeological and palaeoecological data, there is little doubt that the Thames was tidal at least as far as the site of the Roman bridge (Merrifield, 1965)(Milne, 1985, 81-86) and probably to a point between the Walbrook estuary and Westminster. Nevertheless, the location of its tidal limit in the Roman period has never been defined with any certainty nor has the strength of the tide at the Walbrook been ascertained.

The seminal work on historic tides at Tilbury in the Inner Thames Estuary, some 30km downstream of London Bridge, from 3,500 BP to the present (Devoy, 1979, 355-407) proposed that:

- Mean High Water Spring (MHWS) tides were approximately 0.5m OD
- That there was period of tidal regression from the early 2nd C lasting about 150 years and that tide levels only reached their 1st C levels by thre departure of the Romans at the beginning of the 5th C

Today, there is a 0.7m difference in tide levels between Tilbury and London Bridge (Port of London Authority, 2014, 33). However, it is possible that the tidal difference between Tilbury and London Bridge on the Thames may have been less than those of today. An MHWS of between 1.0 and 1.2m OD may therefore be implied for the London Bridge area in the Roman period.

Archaeological investigations that have exposed Roman revetments on the Thames between London Bridge and the Walbrook indicate that their top surfaces were constructed to levels between 1.3m and 2.15m OD. Work on the Suffolk House site (SUF94) discovered a series of revetments, with the quay set at 2.15m OD and on the DGH86 site a riverside clay embankment was discovered with its crest at 1.5m OD. The New Fresh Wharf investigation uncovered pile tops at 1.3m OD, with the roadway estimated to be 0.5 to 0.7m higher at 1.8 to 2.0m OD (Miller and Schofield, 1986).

Investigations at Miles Lane, Regis House and Pudding Lane showed quaysides set at a top level of about 2.0m OD. (Milne and Milne, 1979, 198-204, Port of London Authority, 2014, 33).

A report on the work at Pudding Lane (Milne and Milne, 1979, 198-204), just downstream of London Bridge, suggested that Highest and Lowest Astronomical Tides (HAT and LAT) in the early Roman period, 60 to 65 CE, were respectively 1.5m OD and –0.5m OD. The highest tides, HAT, occur only every 18 years and in the modern era, HAT is approximately 0.5m higher than MHWS at London Bridge (Port of London Authority, 2014, 33). Again, however, the difference in the two tidal levels may have been less in the Roman era as tidal range was less than half that of today.

It would appear from archaeological data that the highest tide was not expected to exceed approximately 2.0m OD, which coincides with an estimated HAT and which would therefore correspond to an MHWS of between 1.5 and 1.7m OD. The tidal range would appear to be about 2m and MLWS would therefore lie between 0.0 and -0.5m OD. Based upon archaeological evidence from the Roman and Medieval periods, a graph of MHWS and MLWS levels was produced for the Thames in the vicinity of London Bridge for the last 2,000 years (Milne, 1985). This graph was further refined in 1990 by later archaeological evidence (Brigham, 1990, 99-183) and Devoy's earlier graphs added. This graph, modified to show only data relevant to this research is included as Figure 5-10. This graph has been further validated by more recent investigations e.g. Thames Exchange, Regis House, Cannon Street Station and Bull Wharf.

The graph demonstrates that there was a period of tidal regression commencing in the second half of the 1st C, shortly after the Roman invasion, with renewed transgression not commencing until almost the point of their departure. The rapidity of this change in tidal levels would indicate that it was not due to glacial isostatic adjustment. However, in this respect, it is interesting to compare the regression and transgression of the tides in this period with the historic temperature for the same period shown in Figure 5-4. This graph, produced in 2008 and based on tree-ring growth, shows a dip in temperatures over the same period that the tide levels in the Thames fell. It is, therefore, probable that sea level change – and hence tidal levels in the Thames – was the result of changes in the mass of glaciers in the Northern Hemisphere.

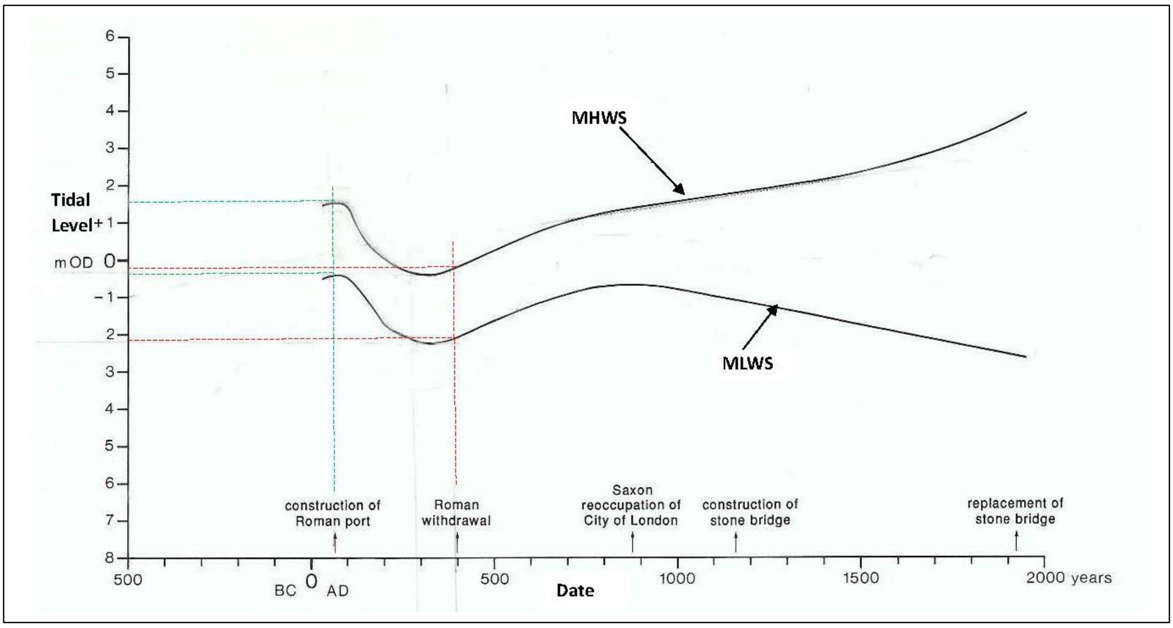


Figure 5-10 Graph of river levels in the Thames at London Bridge over the last 2,000 years (Brigham, 1990, 99-183)

The graphs of MHWS and MLWS shown in Figure 5-8 are compatible with tide levels implied as a result of archaeological investigation. Table therefore shows approximate tide levels for the Roman period drawn from the graphs.

Table 5-6 Estimates of MHWS and MLWS in the Roman period (after Brigham, 1990, 99-183)

Tidal state	Year CE) and Tide level (m OD)				
	43	100	200	300	400
MHWS	1.3	1.5	0.0	-0.4	-0.2
MLWS	-0.5	-0.4	-1.7	-2.2	-2.0

The Walbrook estuary being only a few hundred metres upstream of the London Bridge, tidal levels will be virtually the same as those shown in Table 5-6. Whether the Walbrook itself was tidal can be understood by comparing its bed levels at key points along its length, Table 5-7, with MHWS levels.

Table 5-7 Bed levels at points along Walbrook from Thames

Point along Walbrook	Distance from confluence with Thames (m)	Walbrook bed level (m OD)
At Thames	0	-1.0
Cannon Street	130	0.3
Bucklersbury	250	1.8
Poultry	320	3.0

On arrival of the Romans, tide levels were nearing their maximum for the Roman period and the Walbrook would have been tidal as far as the northern half of the Bloomberg site, approximately 210m upstream of the Thames, at spring tides. However, as MHWS occur only twice a month and are a normal maximum level, the Walbrook would have been tidal only between the southern half of the Bloomberg site and its northern half at this early period.

Tidal regression began about 100 CE and by 150 CE, MHWS was 0.8m OD, and tidal movement in the Walbrook would have reached just north of Cannon Street receding to Cloak Lane, just 90m from the Thames by 200 CE, by which time MHWS had fallen to 0.0m OD. From about 250 CE until the departure of the Romans, the Walbrook would only have been tidal for a short distance not exceeding 50m from the Thames, just north of College Street.

Investigations just east of Cannon Street Station (SUF94) showed how, initially, the bank of the Thames, was located parallel to and about 15m north of Upper Thames Street. However, the first quayside was constructed along the line of Upper Thames Street and subsequent re-building took place a number of times, progressively further south into the Thames. This appears to reinforce the view that the Thames underwent a period of tidal regression. In the earliest period of the Roman occupation, the Walbrook may have been navigable by shallow draft, flat-bottomed vessels that could be safely beached as tides rose and fell. However, it is unlikely that any such vessels would have been able to reach any further than the first bridge over the Walbrook, at Cannon Street. Tidal access for vessels would have become progressively more difficult and would probably have ceased by the middle of the 2nd C.

Tides in the Walbrook may initially have led to raised groundwater levels as far as Bucklersbury for the first 50 years of the occupation. As a consequence, the land on the Bloomberg site (BZY10) site may have been rendered wet and structurally weak. It may be that this was the motivation behind the raising of ground level in this area as investigations have found evidence of workshops and other commercial activity. However, groundwater levels would have fallen with falling tides and it is most unlikely that the groundwater levels affected land surface conditions in any part of Roman London after the middle of the 2nd C and never more than 200m from the Thames prior to this.

5.8 Urban Roman Walbrook – Mean Base Flow Rate

5.8.1 Flow estimation methods

The superficial deposits of the Greater Walbrook Valley are predominantly permeable gravels and silts overlaying a base of impermeable London Clay at shallow depth. Under the climatic conditions of Southeast England, unless over-exploited or subject to rare periods of drought, this geological situation results in an aquifer always replenished by rainwater. Springs occur where the aquifer and gravel/clay interface coincide with the surface of the land. This would have occurred throughout the Roman Walbrook catchment, particularly on and below the Canonbury ridge and close to the Old Street/City Road intersection. Under these conditions, base flow in the Roman Walbrook would not have had much variation, other than when affected by surface runoff. For the purposes of this research, the base flow rate of the river is taken to be the term “mean flow rate” used in flow records.

As flow in the Roman Walbrook cannot be the subject of a metering campaign, consideration was given to estimating the mean base flow rate of the Roman river using two methods:

- an empirical method based upon modern climate data; and
- a surrogate river analysis, in which modern flow gauging records for catchments having climate and hydrological characteristics similar to those of the Walbrook are used to derive a base flow (Section 5.8.2).

The empirical method would be dependent upon an assessment of how much rain falling on the groundwater catchment would permeate to the aquifer, having taken into consideration the amount lost through evapo-transpiration. It was decided that there were too many unknowns and uncertainties involved in an empirical method and that, as a consequence, any estimate of base flow in the Roman Walbrook based on the method would be unreliable.

It was considered that the surrogate river analysis method would be more robust as it would be based upon modern river flow gauging records.

5.8.2 Surrogate river analysis

The background to the surrogate river analysis and the source of data has been described in Section 5.6.1. From the 147 modern flow gauging stations in the Thames Region, five with individual recording durations of between 10 and 35 years were selected, as having catchments upstream of them most comparable with the Greater Walbrook catchment. The five gauging stations and their key statistics are listed in Table 5-8 and their locations are shown in Figure 5-11.

Table 5-8 Five modern Thames Region gauging stations selected for use in the surrogate river analysis (Marsh, 2008; 99-112)

Station location, river and UK Hydrometric Register reference (pages 103-112)	UK Hydrometric Register data (pages 99-102)					
	Catchment size (km²)	Base flow index (BFI)	River flow rates at gauging station (m³/sec)			
			Mean	Q^{95}	Q^{70}	Q^{50}
Letccombe Bassett Letcombe Brook (39061)	4.0	0.96	0.09	0.01	0.04	0.07
Letcombe Bassett Arabella's Lake (39112)	3.1	0.93	0.03	0.00	0.01	0.02
Letcombe Regis Manor Farm Brook (39113)	1.4	0.78	0.01	>0.00	>0.00	0.01
Sulham Sulham Brook (39116)	3.0	0.63	0.07	>0.00	0.02	0.03
Blewbury Mill Brook (39146)	2.0	0.96	0.10	0.02	0.06	0.09

Detailed hydrological statistics for the five gauging stations are reported in Appendix 5C, Tables 5C-2 to 5C-6. Data in Table 5-9 has been abstracted from the average statistics for the five gauging stations in Appendix 5C.

Table 5-9 Hydrological statistics for the 5 chosen Thames Region gauging stations

Parameter	Units	Average	Range	
			Max.	**Min.**
Catchment size	m^3	2.7	na	na
Duration of records	years	18	na	na
Average base flow index (BFI)		0.86	0.96	0.63
Base flow rate	**$m^3/sec/km^2$**	**0.023**	0.050	0.001
Q^{95} (flow exceeded 95% of the time)	$m^3/sec/km^2$	0.003	0.010	0.000 – 0.005
Q^{70} (flow exceeded 70% of the time)	$m^3/sec/km^2$	0.012	0.030	0.03
Q^{50} (flow exceeded 50% of the time)	$m^3/sec/km^2$	0.017	0.045	0.006

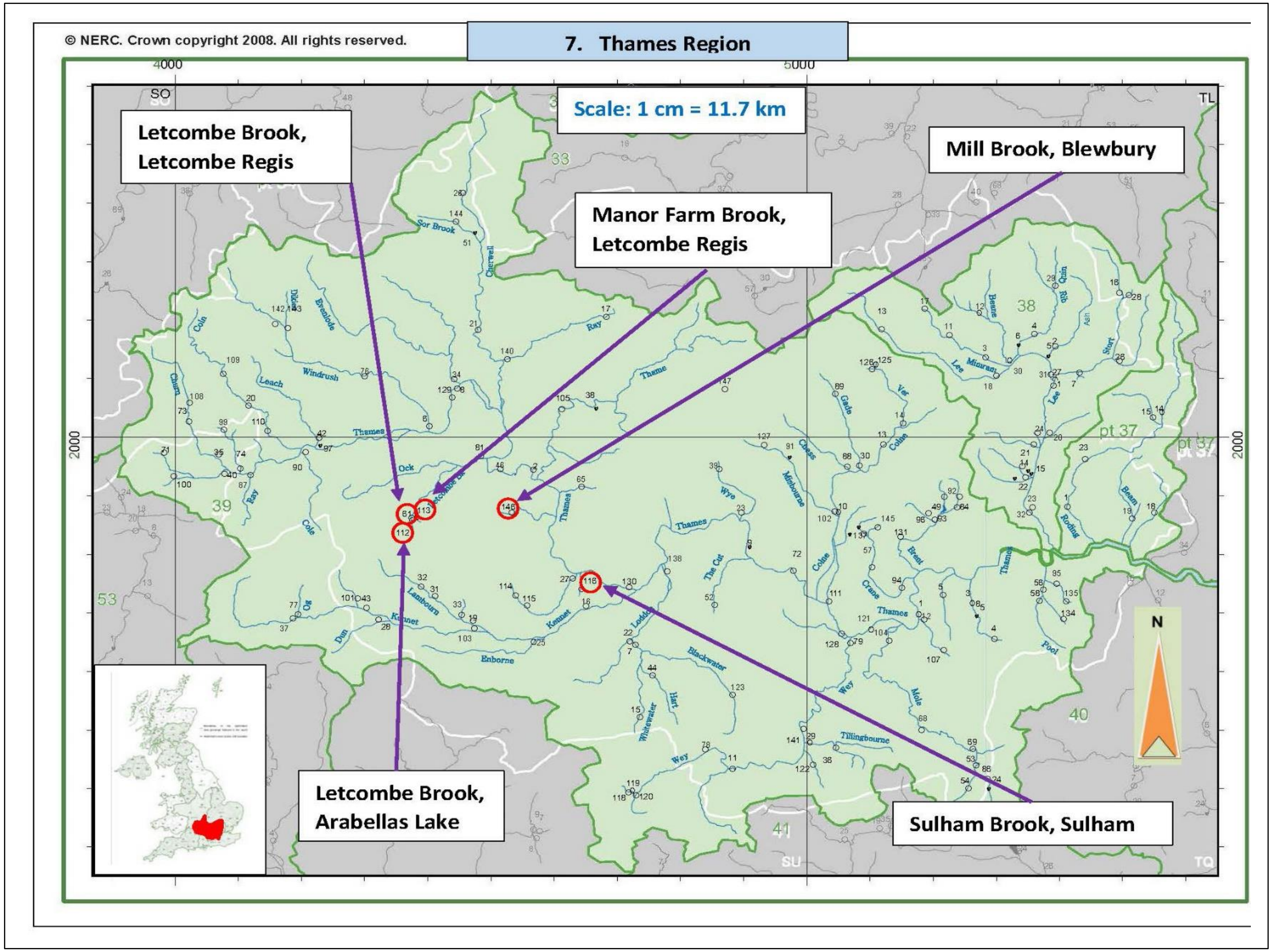


Figure 5-11 **Five modern river flow gauging stations in the Thames Region**

Figures 5-12 and 5-13 show the streams at or near to their gauging station after a dry period followed by a few light showers. Marked onto the photos are the width of the stream, its total width, including the sloping banks and the width of water flow at the time, the water depth and estimates of the velocity and its volumetric flow rate. The banks vary in height above the riverbeds between 0.5 metres and 1.5 metres, with an average height of 1.0 metre. The slope to the banks can vary between 30° to the horizontal and vertical, but most commonly slope at approximately 45°.

Both the Sulham Brook and the Mill Brook at Blewbury are rivers on a broad, flat floodplain, the Manor Farm Brook flows off a sloping landscape with the gauging station a short distance downstream of the foot of the slope and the gauges for the two streams at Letcombe Bassett are on upland slopes of the Thames Valley. The principal sources of water for all of the streams are springs – as for the Walbrook. Their catchments are wholly rural in nature and a photo of the Thames Valley, Figure 5-14, taken in the upper Thames Valley shows this. Although the fields in the photo are being farmed, the area is otherwise a reasonable surrogate for the original, undeveloped topography and landscape both prior to and during the Roman period at the downstream end of City Road from the sloping hillside of the Angel, Islington to the flat land from Moorfields southwards.

A photo is also included of the Lambourn at Great Shefford. The source for this stream is located on the other side of the same watershed as for the selected streams. Although this stream has too large

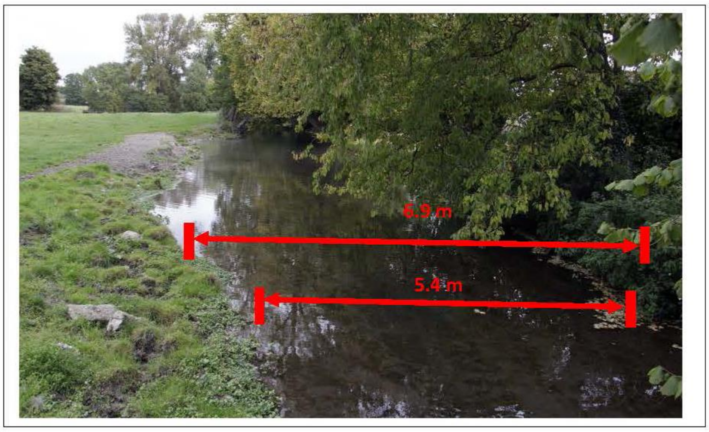
a catchment to be used in the surrogate river analysis, the stream is another example of how the bed of the stream is broad and flat where the bed slope is shallow, as is the case with the Sulham Brook and the Mill Brook at Blewbury. The beds of the other three streams are flat but the width tends to be narrower due to their smaller catchments.

Sulham Brook at Sulham

Water depth 0.10 m

Velocity (est) 0.6 m/s

Flow rate (est) 0.24 m^3/sec

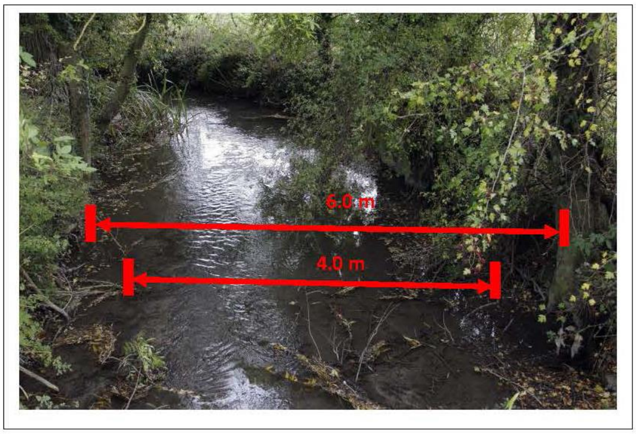


Mill Brook at Blewbury

Water depth 0.20 m

Velocity (est) 0.1 m/s

Flow rate (est) 0.086 m^3/sec



Manor Farm Brook at Letcombe Regis

Water depth 0.10 m

Velocity (est) 0.3 m/s

Flow rate (est) 0.096 m^3/sec

Figure 5-12 Sulham Brook, Mill Brook and Manor Farm Brook at or near to the flow gauging stations included in the surrogate river analysis

Letcombe Brook at
Letcombe Bassett

Water depth 0.20 m

Velocity (est) 0.3 m/s

Flow rate (est) 0.168 m³/sec

Arabella's Lake at
Letcombe Bassett

Water depth 0.10 m

Velocity (est) 0.1 m/s

Flow rate (est) 0.024 m³/sec

Lambourn at
Great Shefford

Water depth 0.20 m

Velocity (est) 0.6 m/s

Flow rate (est) 0.528 m³/sec

Figure 5-13 Letcombe Brook and Arabella's Lake at or near to the flow gauging stations included in the surrogate river analysis; the Lambourn at Great Shefford

Figure 5-14 The upper Thames Valley typical of a wholly rural river catchment as was the Greater Walbrook Valley in the immediate pre-Roman period

Table 5-10 reports flow rates calculated for the Roman Walbrook by multiplying the mean volumetric flow rate for the five surrogate rivers listed in Table 5-9 by the area of the Greater Walbrook Valley catchment. This has been done for both the topographic catchment alone and for the maximum catchment area, i.e. the sum of the topographic and groundwater catchment areas. A further adjustment to the flow rates resulting from Table 5-9 has been applied to take account of the different annual rainfall in the upper Thames Valley and the Greater Walbrook Valley. Average annual rainfall for the Greater Walbrook Valley, based on rain gauges at Greenwich, is 584 mm (Section 5.6.3), whereas average annual rainfall for the selected 5 catchments in the upper Thames Valley is 726 mm according to the UK Hydrometric Register. To better reflect this difference in rainfall, flow rates derived in Table 5-9 have been adjusted by a factor of 0.8, i.e. the proportion of 584 mm to 726 mm.

Table 5-10 Flow rates calculated for the Roman River Walbrook (surrogate river analysis)

River Flow Parameter	**Flow rate (m³/sec)**			
	Topographic catchment only		**Topgraphic and groundwater catchments**	
	Average statistics from Table 7-6	**Table 5-9 statistics adjusted for rainfall**	**Average statistics from Table 7-6**	**Table 5-9 statistics adjusted for rainfall**
Mean flow rate	0.108	0.087	0.163	0.131
Q^{95} (flow exceeded 95% of the time)	0.014	0.011	0.021	0.017
Q^{70} (flow exceeded 70% of the time)	0.056	0.045	0.085	0.068
Q^{50} (flow exceeded 50% of the time)	0.080	0.064	0.121	0.097

5.8.3 Conclusions

The base flow would have been sourced by springs at the gravel/clay interface from its two main sources at Barnsbury (western stream) and Canonbury (eastern stream) and at many points along the streams; as such, the base flow would have been perennial and reliable.

An empirical method of estimating base flow was rejected as being insufficiently robust in favour of a surrogate river analysis based upon actual long-term, flow gauging records for rivers having similar physical characteristics, catchment descriptors and climate to those of the Roman Walbrook.

Flow rates estimated using the groundwater catchment area alone can be considered conservative values, whilst those based upon the combined topographic and groundwater catchments generates maximum values for flow rates. On this basis, estimates of the mean base flow rate range from 87 to 131 litres/second, respectively relating to the exclusion and inclusion of the groundwater catchment,

Conservatively, for the purposes of this research, the extended groundwater catchment will not be counted as its extent is open to interpretation. A mean base flow rate of 87 litres/second, relating to the topographic catchment alone, will be adopted for the urban stretch of the Roman Walbrook, downstream of the confluence of the eastern and western streams. Applying the other average volumetric flow statistics listed in Table 5-6, on the same conservative basis, the base flow in the river would have exceeded 64 litres/sec for 50% of the time, 45 litres/sec for 70% of the time and 11 litres/sec for 95% of the time.

Base flow rate is of importance when considering the uses to which water from the Walbrook may have been put – as a prospective supply for both domestic and industrial purposes and for the generation of power to a mill. It would be reasonable to adopt the mean base flow rate of 87 litres/second if the supply is stored in a pond or reservoir upstream of the points of use, as the main purpose of storing water is to reduce the effects of fluctuations in flow. However, were little or no storage to be provided, it would be prudent to adopt a lower rate of flow to the point of use to cater for periods of prolonged dry weather. Fortunately, although periods of drought do occur in the London region, they are not common and to adopt the Q^{50} value of 64 litres/second for a reliable base flow rate, where there is no storage, would be reasonable.

Milling may be used to illustrate the importance of base flow to usage. In Section 4.6.4, it has been suggested that a suitable point of offtake from the Walbrook of water to power a mill would be between Princes Street and Lothbury. The potential for water-powered milling is summarised in Section 8.7 and reported in more detail in Appendix 8B.

5.9 Urban Roman Walbrook – Storm Flows at Critical Locations

The HydroCAD software, described in Section 5.4, has been used to develop the storm run-off, hence storm flow rates, in the Roman Walbrook at key points along its watercourse. The data used in applying the software have, for the most part, been reported and developed in Sections 5.6 and 5.7. The fundamental importance of the HydroCAD parameter, Curve Number (CN) to the calculation of storm run-off has been stressed in Section 5.7.6, where background to this parameter was presented. In this section, composite CN values are developed to reflect the landscape and soil combinations at the time of the Roman invasion and at a point when their occupation was well established. These and other parameter values, as reported in Sections 5.6 and 5.7, have been used to calculate estimates of the storm run-off to be expected for a range of storm intensities and storm return periods.

5.9.1 Development of composite Curve Numbers

The Greater Walbrook Valley catchment is one of the smallest compared with other rivers in the London Region. Only two other north bank rivers have similar size catchments, Counter’s Creek in the west and Black Ditch to the east (Myers and Barton, 2016). Given the small size of the Walbrook catchment, it would not normally be necessary to sub-divide the catchment into yet smaller areas for storm run-off calculations. However, the character of the landscape would have altered through the Roman period and the nature of the alterations would have been different for the urbanised area and the rest of the catchment. In addition, account must be taken of the probability that the catchment was subject to an increase in settlement and cultivation in the Roman period and that each of these factors, with attendant reductions in woodland, grassland and meadow, would have resulted in an altered composite CN for any specific sub-catchment. For the purposes of calculating storm runoff and consequent river flows, the Greater Walbrook Valley was divided into four sub-catchments as illustrated in Figure 5-15. Sub-catchment and total catchment surface areas are listed in Table 5-11.

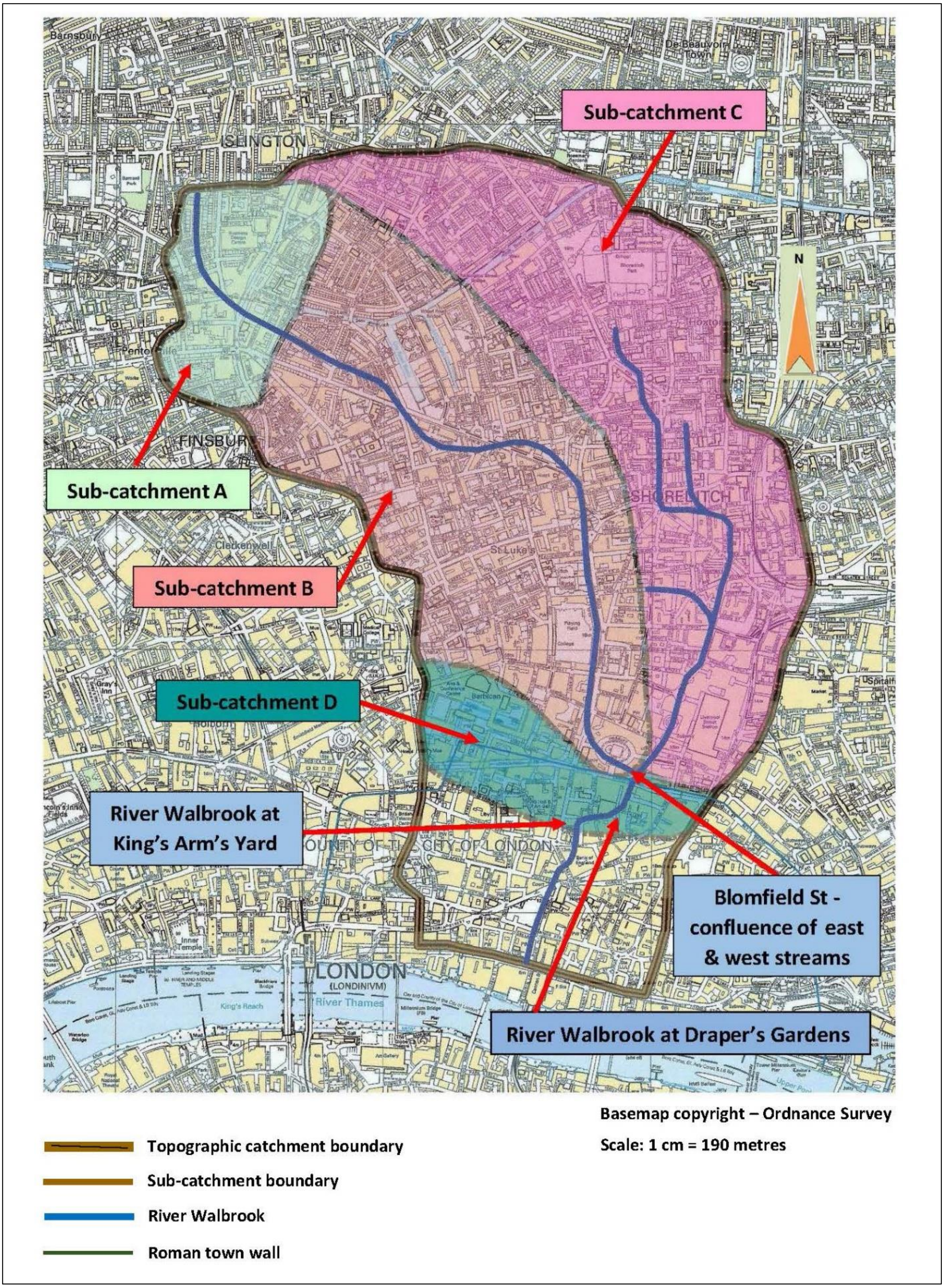


Figure 5-15 Greater Walbrook Valley catchment and sub-catchments

Table 5-11 Sub-catchment and catchment surface areas

Walbrook constituent stream	**Greater Walbrook Valley sub-catchment**	**Sub-catchment surface area (m²)**	**Total catchment surface area (m²)**
Western	A	401,704	
Western	B	1,679,133	
Western total area	***A + B***		***2,080,837***
Eastern	C	1,679,835	
Western & eastern streams – total area	***A + B + C***		***3,760,672***
Walbrook tributaries to general area of Draper’s Gardens	D	352,485	
Total area at Draper’s Gardens/Tokenhouse Yard	***A B + C + D***		***4,113,157***

The four sub-catchments do not include approximately 50 ha of urban Roman London closes to the Thames. Rainfall runoff from 50% of this area drained directly to the Thames and the small balance of the area drained to the Walbrook along tributaries that were confluent with it close to the Thames and were unlikely to significantly affect flood risk to the estuarine areas of the catchment.

Composite CN values have been developed for each of the four sub-catchments for each of the two periods considered, “Immediate pre-Roman” and “Roman Period” using the CN values for individual types of cover listed in Table 5-4, Section 5.7.6. The composition of cover in each of the sub-catchments and the consequent composite CN value is developed and reported in Table 5-12 for the Immediate Pre-Roman period and in Table 5-13 for the Roman Period.

Given the complete lack of contemporaneous written evidence for the period, the types of land cover attributed to each of the sub-catchments, and the proportions of the catchment landscape that they each cover, as listed in Tables 5-10 and 5-11, can only be best estimates. The types of cover and the values attributed to them have been based upon the discussion in Section 5.7.5 of archaeological evidence relating to landscapes founded on similar gravel terraces in the Thames Region. However, it is of interest to note that:

- for the Immediate Pre-Roman Period
    - the three fully rural areas, B, C and D, although different in the nature of their cover, have the same composite CN value, 65;

Table 5-12 Greater Walbrook Valley – Composite CN Values – Immediate Pre-Roman Period

Ref	Sub-catchment			Soil Type	CN Values		
	Location	Cover Type	Cover Proportion %		Cover CN	Weighted CN	Composite CN
A	*Upper rural western Walbrook stream*	Settlement	2	C	91	1.8	79
		Woodland	10		73	7.3	
		Grassland	68		79	53.7	
		Crops	15		82	12.3	
		pasture	5		74	3.7	
B	*Lower rural western Walbrook stream*	Woodland	25	B	60	15.0	65
		Brush	50		67	33.5	
		Pasture	20		61	12.2	
		Marsh	5		90	4.5	
C	*Upper & Lower rural eastern Walbrook stream*	Woodland	30	B	60	18.0	65
		Brush	55		67	36.9	
		Pasture	10		61	6.1	
		Marsh	5		90	4.5	
D	*Rural combined Walbrook stream*	Woodland	30	C	60	18.0	65
		Brush	55		67	36.9	
		Pasture	10		61	6.1	
		Marsh	5		90	4.5	

Table 5-13 Greater Walbrook Valley – Composite CN Values – Roman Period

Ref	Sub-catchment			Soil Type	CN Values		
	Location	Cover Type	Cover Proportion %		Cover CN	Weighted CN	Composite CN
A	*Upper rural western Walbrook stream*	Settlement	5	C	91	4.6	80
		Woodland	2		73	1.5	
		Grassland	43		79	34.0	
		Crops	40		82	32.8	
		pasture	10		74	7.4	
B	*Lower rural western Walbrook stream*	Settlement	5	B	86	4.3	72
		Crops	20		74	14.8	
		Horticulture	30		72	21.6	
		Pasture	10		61	6.1	
		Woodland	5		60	3.0	
		Brush	10		67	6.7	
		Grassland	10		69	6.9	
		Marsh	10		90	9.0	
C	*Upper & Lower rural eastern Walbrook stream*	Settlement	5	B	86	4.3	71
		Crops	20		74	14.8	
		Horticulture	30		72	21.6	
		Pasture	10		61	6.1	
		Woodland	5		60	3.0	
		Brush	15		67	10.1	
		Grassland	10		69	6.9	
		Marsh	5		90	4.5	
D	*Rural and urban mix:) combined Walbrook stream*	Settlement	35	C	91	31.9	83
		Crops	5		82	4.1	
		Horticulture	15		81	12.2	
		Pasture	10		74	7.4	
		Woodland	5		73	3.7	
		Brush	8		77	6.2	
		Grassland	20		79	15.8	
		Marsh	2		90	1.8	

  - a small amount of settlement and agricultural activity in Sub-catchment A, the upper rural western Walbrook stream, results in an increase in the CN value, to 79; and
  - due to its relatively small area compared with the other three, a composite CN of 66 for the whole catchment, i.e. a small increase on the values estimated for sub-catchments B, C and D, would almost certainly produce a similar runoff and storm flow value both at entrance to what would become the urban area and the downstream end of the upper URWV
- For the Roman Period
  - the difference in CN values for each of the sub-catchments between the Immediate Pre-Roman and Roman Periods is not very significant, varying between a minimum of only 1.2% for Sub-catchment A and about 11% and 9% respectively for Sub-catchments B and C;
  - in effect, a single, composite CN of 73, only slightly different to that of the rural sub-catchments B and C, for the whole of the catchment would almost certainly produce a similar runoff and storm flow value at entrance to the urban area; however,
  - as was expected, the greatest increase in CN values between the two periods is experienced by Sub-catchment D, the northern portion of the Roman urbanised area, from 65 in the Immediate Pre-Roman Period to 83 in the Roman Period, an increase of almost 28%, due to its radical change in character from rural to semi-urban.

5.9.2 Calculation of storm run-off estimates

Storm run-off to the Walbrook was calculated using the HydroCAD software and data acquired, developed and reported in Sections 5.6, 5.7 and 5.9.1, for each of the five hydrological zones, A to E, as defined in Section 4.5.2 and on Figures 4-19 and 4-20.

Storm flows at each of these five locations were also calculated for two periods:

- Immediate pre-Roman, i.e. the Greater Walbrook Valley catchment in its natural state; and
- during the Roman occupation, considered to be the mid to end 2nd C when the upper and middle URWV would have been occupied by industry (Chapter 8, Section 8.4) and dwellings

of those employed there and extra-mural land in the greater catchment would have been partially developed for farming and horticulture (Chapter 8, Section 8.5).

Figure 5-15, Section 5.9.1 showed the Greater Walbrook Valley divided into four sub-catchments, A to D, which drained to the Walbrook. The routing diagrams relating to the calculation of storm flows are shown in Figures 5-16 and 5-17, respectively for runoff draining to Blomfield Street and Draper's Gardens/Tokenhouse Yard. The routing diagrams, based on these sub-catchments, refer to the 1-year storm but are relevant to all storm return periods. The references within the various nodes of the diagram have been generated automatically by the software and have no relevance to the research.

The catchment descriptors, i.e. the composite Curve Number (CN) values, developed in Section 5.9.1, for each of the four sub-catchments in Figure 5-14 and other key parameters fixed by the HydroCAD software were as follows:

- CN values
    - Sub-catchment A - soil Type C; CN = pre-Roman, 79; Roman, 80
    - Sub-catchment B - soil Type B; CN = pre-Roman, 65; Roman, 72
    - Sub-catchment C - soil Type B; CN = pre-Roman, 65; Roman, 71
    - Sub-catchment D - soil Type C; CN = pre-Roman, 65; Roman, 83
- Antecedent Moisture Content – combination of 2 and 3 (Section 5.7.4)
- P2 – total rainfall in 24 hours with a 2-year return period - 36mm
  (developed from extension of data in Table 5-2, Section 5.6.3)
- Storm Type - Type II - 6 hour storm
  This represents the "shape" of the storm, i.e. the timeline over which rainfall intensity increases with time, reaches a maximum and then falls away; the Greater Walbrook Valley catchment being small in hydrological terms with times of concentration (T_c) of 6 hours or less, this storm type is the most appropriate.

The HydroCAD storm run-off model was run for rainfall having storm intensities relating to the 6-hour storm for return periods of 1, 2, 5, 10, 20, 50, 100, 200, 500-year return periods drawn from the rainfall intensity/duration/return periods listed in Table 5-1, Section 5.6.3, also shown graphically in Figure 5-4, Section 5.6.3.

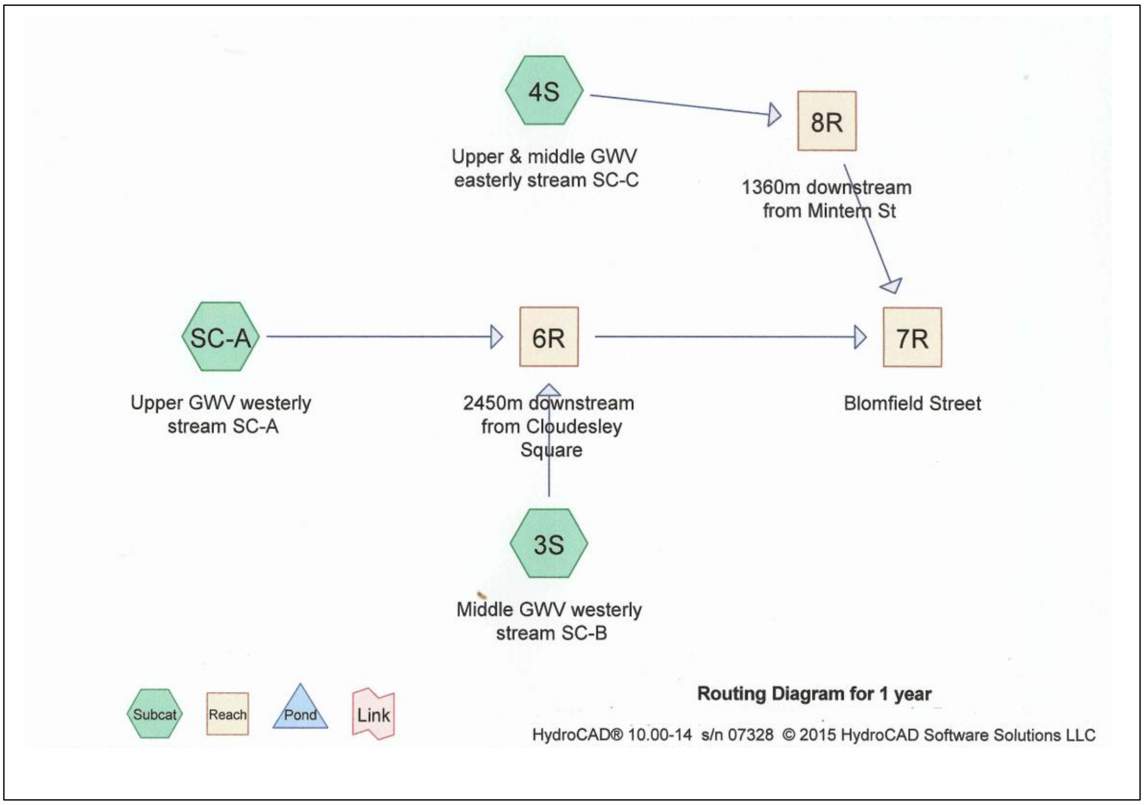


Figure 5-16 Routing diagram for sub-catchments draining to Blomfield Street

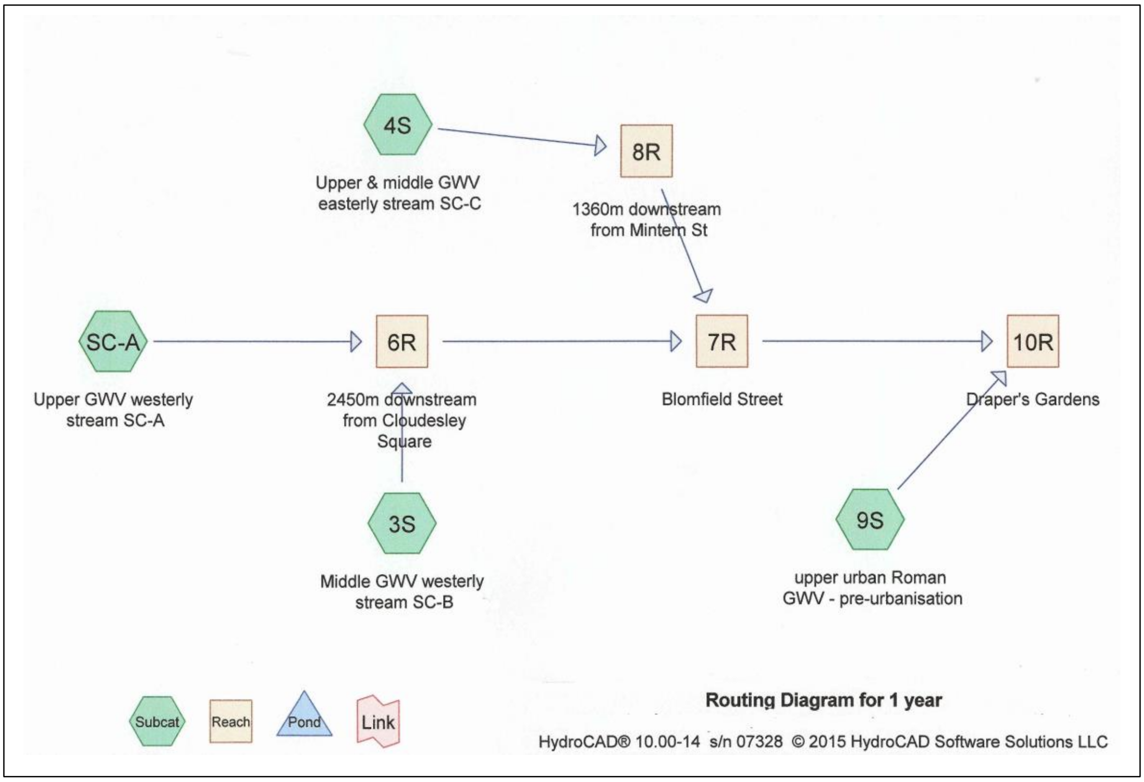


Figure 5-17 Routing diagram for sub-catchments draining to Draper's Gardens/Tokenhouse Yard

Volumetric storm flow rates in the river, including a base flow rate of 0.08 m³/second, as generated by each scenario are listed in Table 5-14 for an AMC of 3 and Table 5-15 for an AMC of 2. All 72 of the model runs are reported in Appendix 5D on the DVD attached to the inside back cover of the thesis. A full technical report on each of these runs can be generated from the related model run file.

Table 5-14 Storms flows at Blomfield Street and Drapers' Gardens Antecedent Moisture Content (AMC) 3

Soil Type B - SC-B & SC-C; Soil Type C - SC-A & SC-D
Antecedent Moisture Condition (AMC) 3

Storm Return	Storm Flows (inc 0.08 m³/s base flow)			
	at Blomfield St		at Draper's Gardens/ Kings Arms Yard	
Period (years)	pre-Roman (m³/s)	Roman (m³/s)	pre-Roman (m³/s)	Roman (m³/s)
1	0.56	1.03	0.67	1.26
2	1.19	2.01	1.41	2.38
5	2.96	4.41	3.39	5.04
10	5.05	7.00	5.69	7.89
20	7.81	10.28	8.72	11.46
50	13.12	16.30	14.49	17.97
100	18.62	22.30	20.43	24.45
200	26.16	30.35	28.57	33.11
500	38.55	43.28	41.89	46.98

Table 5-15 Storms flows at Blomfield Street and Drapers' Gardens Antecedent Moisture Content (AMC) 2

Soil Type B - SC-B & SC-C; Soil Type C - SC-A & SC-D
Antecedent Moisture Content (AMC) 2

Storm Return	Storm Flows (inc 0.08 m³/s base flow)			
	at Blomfield St		at Draper's Gardens/ Kings Arms Yard	
Period (years)	pre-Roman (m³/s)	Roman (m³/s)	pre-Roman (m³/s)	Roman (m³/s)
1	0.09	0.10	0.10	0.13
2	0.12	0.18	0.14	0.24
5	0.29	0.68	0.36	0.88
10	0.74	1.55	0.89	1.93
20	1.56	3.00	1.87	3.59
50	3.75	6.28	4.38	7.28
100	6.60	10.12	7.56	11.51
200	11.15	15.84	12.58	17.78
500	19.69	26.01	21.92	28.84

The values in Tables 5-12 and 5-13 have been used to construct the storm flow graphs for the following situations that draw upon the appropriate values generated by the two conditions AMC 2 and 3 in accordance with the criteria defined in Section 5.7.4. The storm flow values reported in Tables 5-12 and 5-13 have been merged as described in Section 5.7.4, Antecedent Moisture Condition, to reflect appropriate seasonal conditions. The outcome is reported in Table 5-14 and depicted in Figures 5-18 to 5-21 as follows:

- Figure 5-17 Storm flows at Blomfield Street – immediate pre-Roman period
- Figure 5-18 Storm flows at Blomfield Street – Roman period
- Figure 5-19 Storm flows at Draper's Gardens/Kings Arms Yard – pre-Roman period
- Figure 5-20 Storm flows at Draper's Gardens/Kings Arms Yard – immediate Roman period

The storm flows as shown in Figures 5-18 to 5-21 have been summarised in Table 5-16. have been applied in Chapter 6 for assessing the general risk of flooding.

Table 5-16 Storms flows at Blomfield Street and Drapers' Gardens

Combination of Antecedent Moisture Conditions 2 and 3

Soil Type B - SC-B & SC-C; Soil Type C - SC-A & SC-D
Antecedent Moisture Content - combined AMC 2 & 3

Storm Return	Storm Flows (inc 0.08 m³/s base flow)			
	at Blomfield St		at Draper's Gardens/ Kings Arms Yard	
Period (years)	pre-Roman (m^3/s)	Roman (m^3/s)	pre-Roman (m^3/s)	Roman (m^3/s)
1	0.56	1.03	0.67	1.26
2	1.19	2.01	1.41	2.38
5	2.96	4.41	3.39	5.04
10	5.05	7.00	5.69	7.89
20	6.30	8.60	7.90	9.80
50	8.10	10.20	10.80	11.48
100	10.68	12.00	13.54	13.70
200	14.50	17.10	17.50	20.70
500	19.69	26.01	21.92	28.84

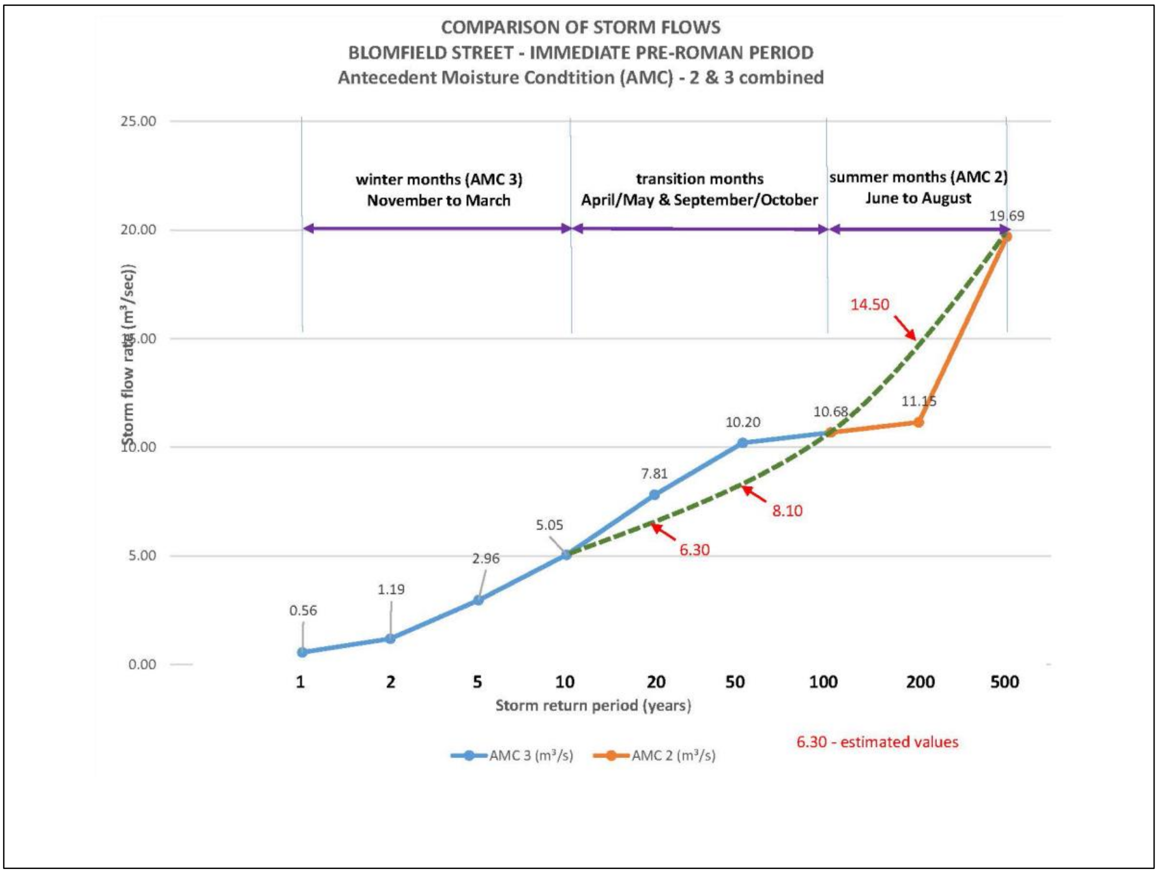


Figure 5-18 Storm flows at Blomfield Street – immediate pre-Roman period – AMC 2 and 3

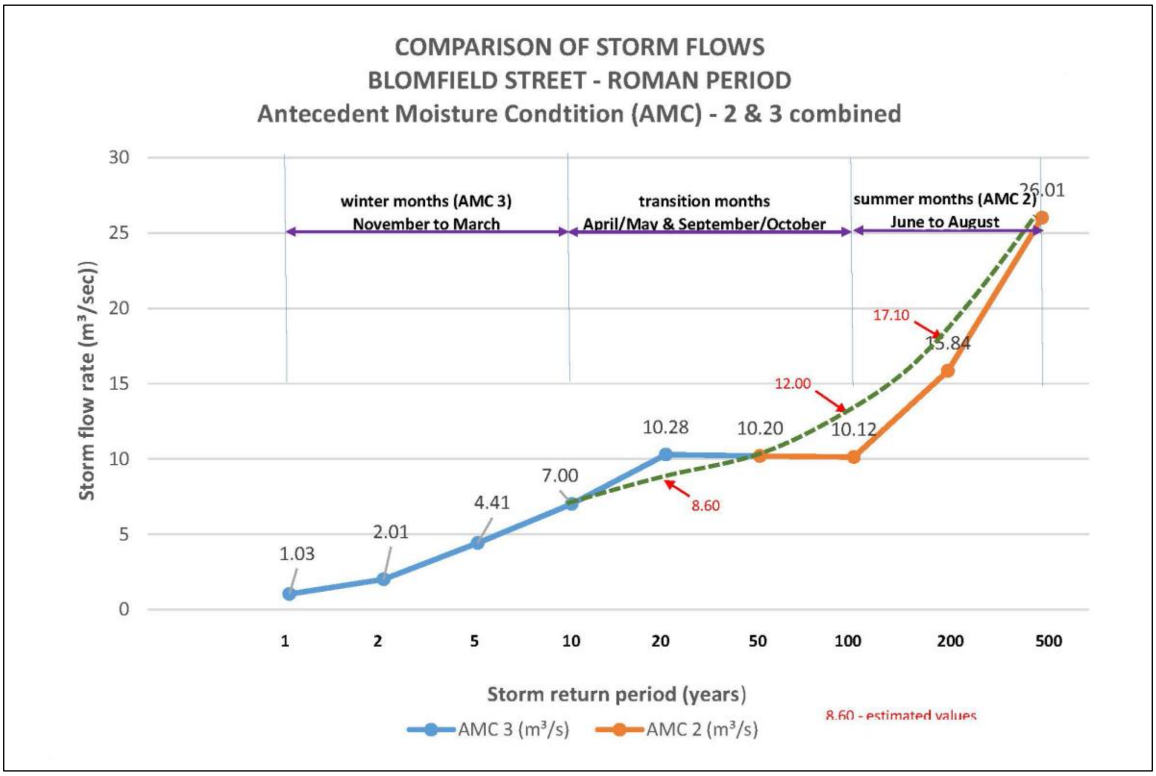


Figure 5-19 Storm flows at Blomfield Street – Roman period – AMC 2 and 3

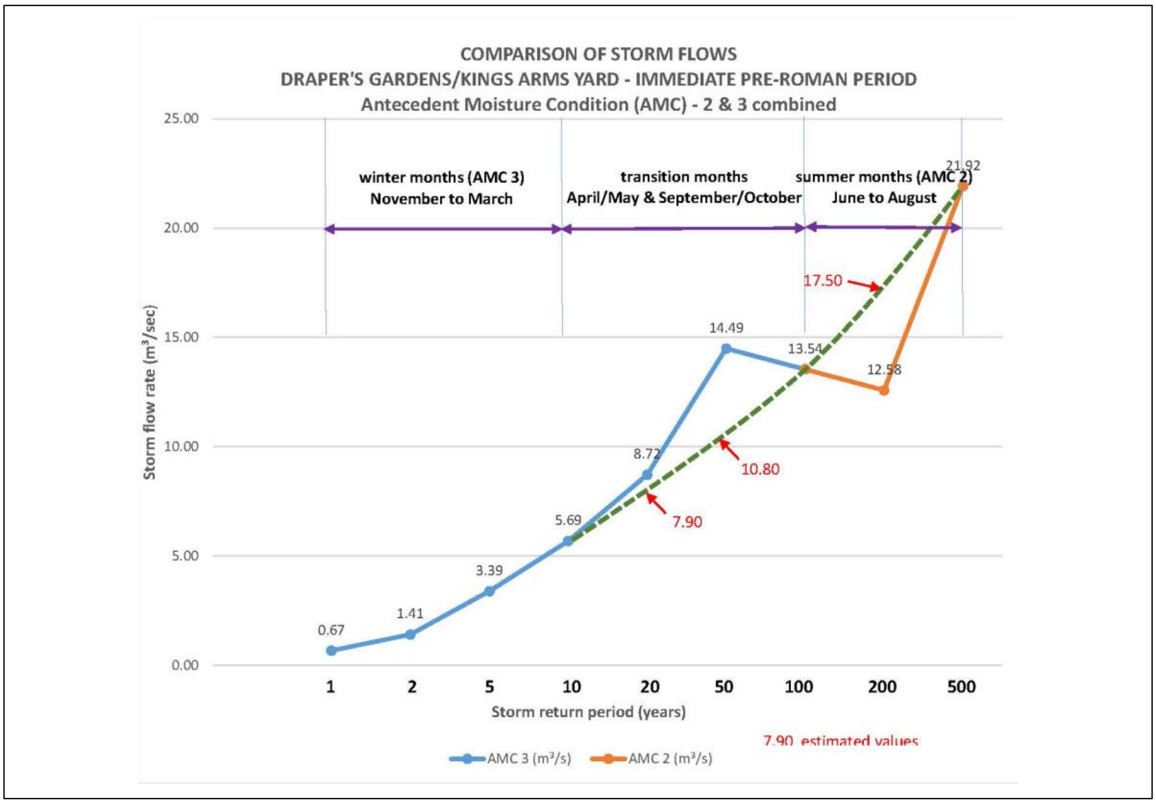


Figure 5-20 Storm flows at Draper's Gardens/Kings Arms Yard – immediate pre-Roman period – AMC 2 and 3

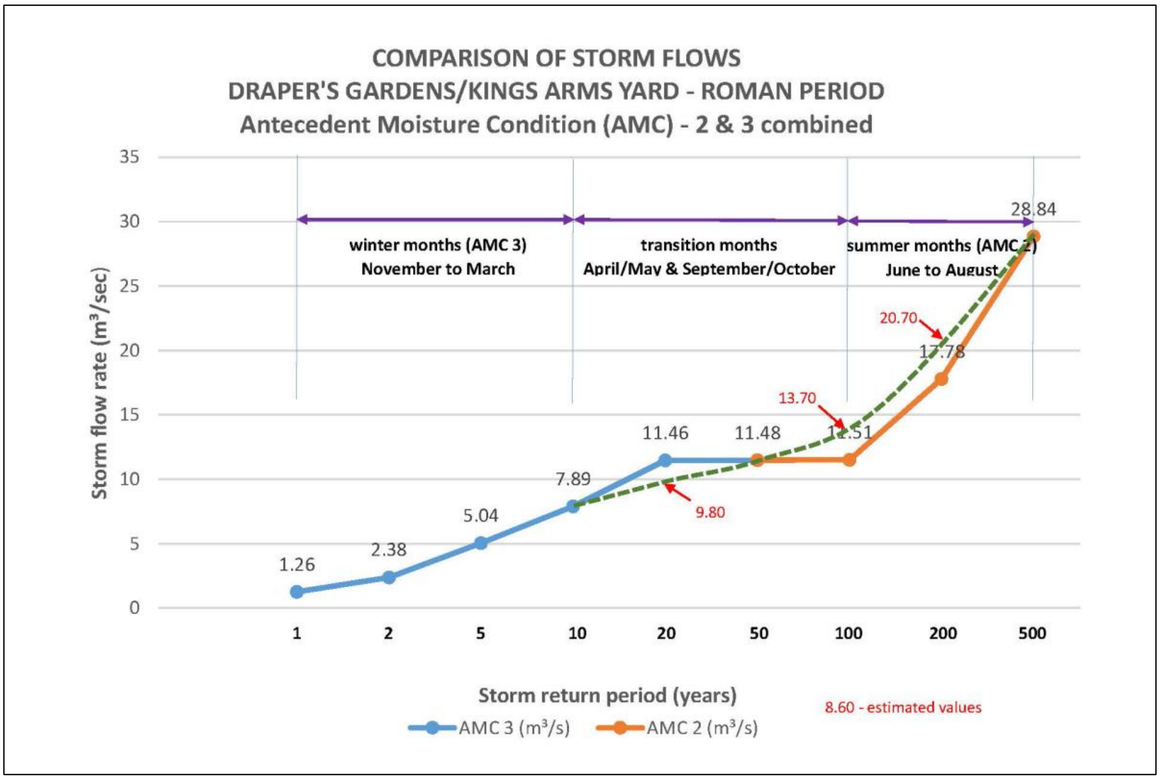


Figure 5-21 Storm flows at Draper's Gardens/Kings Arms Yard – Roman period – AMC 2 and 3

The following observations are based upon the data in Tables 5-12 to 5-14:

- Storms that occur after a period of dry weather (AMC 2) produce significantly less runoff to the river than those that occur as an adjunct to a period of wet weather (AMC3).
- Storm events producing river flow rates of 0.56 m^3/sec and 0.67 m^3/sec could have been expected at Blomfield Street at least once a year when the catchment was in its natural, pre-Roman state. These rates rose respectively to 1.03 m^3/sec and 1.26 m^3/sec as a result of the Roman occupation, development and usage of the urban and extra-mural catchment. Storm flow rates therefore almost doubled in the Roman period, for storms with annual return periods; this could offer an explanation for their raising of the land surface in stages, Chapter 7, Section 7.3.2, as their own development activities progressively increased the risk of flooding.
- Many meteorological factors of local and global significance interact to create climate at a specific time and these include rainfall patterns. In practice, a storm of any particular return period can occur at any time. As an example, a 20-year storm may occur a number of times in a 20-year period. However, storms of return periods of 100 years or more, whilst they can occur with greater regularity than the statistics would suggest, do tend to be rare occurrences. In assessing the risk of flooding to Roman London by the Walbrook, it would therefore be prudent to assume that storms could have occurred with a greater frequency than the statistics suggest and that storms with a statistical 1-year return period may have occurred several times a year.
- As periods of unseasonal warm weather can occur in the winter, it would be prudent to check the effect on flood frequency for a worst-case scenario of an intense storm at any time of the year under an Antecedent Moisture Condition of 3 for those areas at greatest risk of flooding.

5.10 Storm Flows – Eastern Stream Only

Prior to the current research, the Walbrook system had been understood to consist of a single main stream, the eastern stream, fed by a number of tributaries , principally from the Barbican and from both banks of the urban Roman Walbrook. If this had been the case, then storm flows in the Walbrook from a far smaller catchment would have been substantially less than those in a river system as defined by the current research.

To demonstrate this, storm flow rates have been calculated for the eastern stream alone. Storm flow rates in the river, have been calculated on a worst-case basis, i.e. an AMC state 3, the results of which are in Table 5-15. The same base flow rate of 0.08 m^3/sec has been added to the storm run-off as the full spring flow from the whole catchment may still have eventually reached the eastern stream even had the western stream not existed. Storm flow rates for the complete river system, abstracted from Table 5-12, have been reported in the table for the purposes of comparison.

The storm flows reported in Table 5-15 for the complete river system and the eastern stream are shown graphically for Blomfield Street and Drapers' Gardens/Tokenhouse Yard in Figures 5-22 and 5-23 respectively.

The storm flow rates for a Walbrook system had it consisted only of the eastern catchment and stream could only have resulted in a considerably reduced flood frequency. The reduction in this risk that would have occurred is further examined and reported in Chapter 6, Section 6.6.

Table 5-17 Storms flows at Blomfield Street and Drapers' Gardens – Eastern stream only

Soil Type B - SC-B & SC-C; Soil Type C - SC-A & SC-D
Antecedent Moisture Condition (AMC) 3

Storm Return Period	Storm Flows (inc 0.08 m/s base flow)			
	at Blomfield St		at Draper's Gardens	
(years)	actual catchment (m^3/s)	eastern stream only (m^3/s)	actual catchment (m^3/s)	eastern stream only (m^3/s)
1	0.56	0.08	0.67	0.21
2	1.19	0.23	1.41	0.47
5	2.96	0.68	3.39	1.13
10	5.05	1.21	5.69	1.90
20	7.81	1.92	8.72	2.89
50	13.12	3.31	14.49	4.76
100	18.62	4.75	20.43	6.68
200	26.16	6.74	28.57	9.30
500	38.55	10.01	41.89	13.57

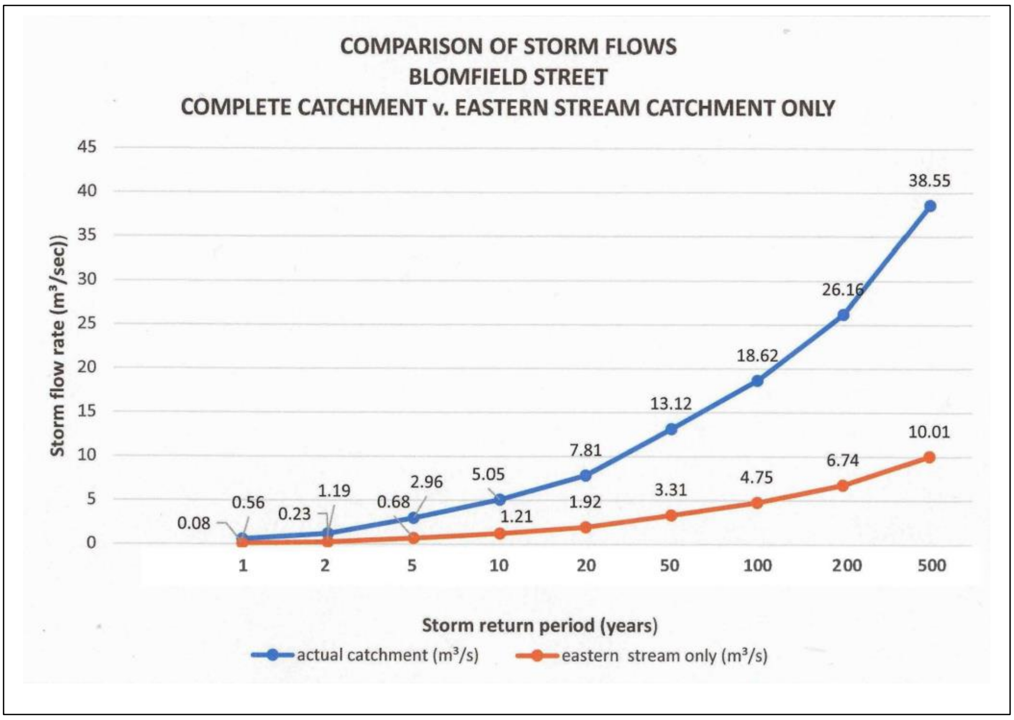


Figure 5-22 Comparison of storm flows and their return periods for the complete Walbrook river system and the eastern stream only at Blomfield Street

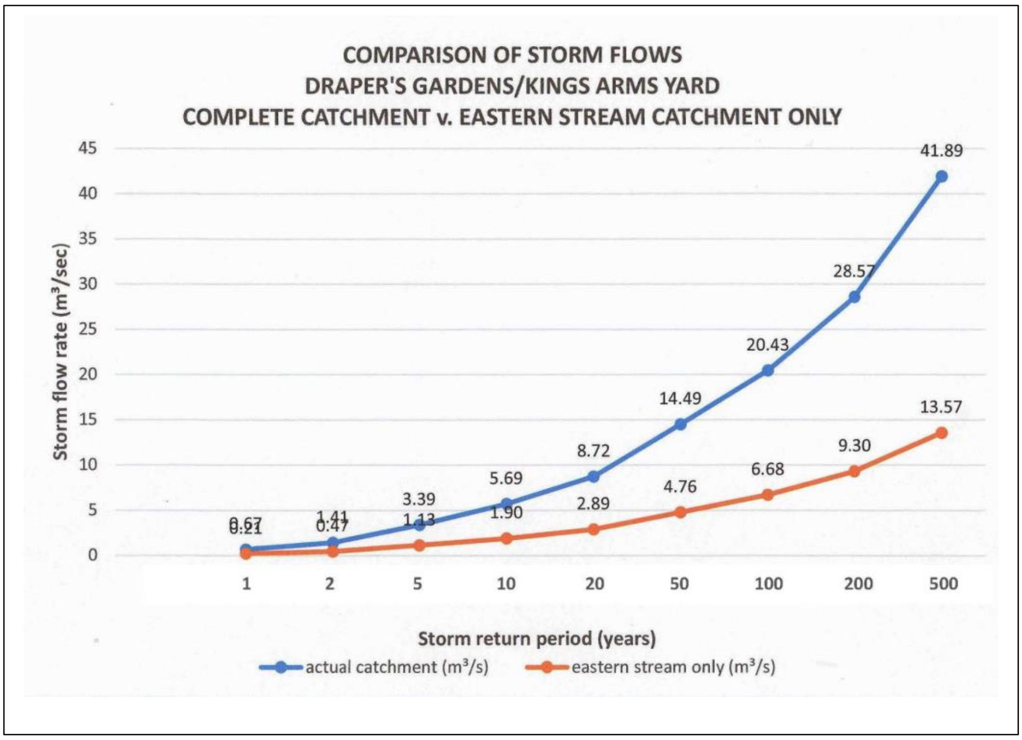


Figure 5-23 Comparison of storm flows and their return periods for the complete Walbrook river system and the eastern stream only at Draper's Gardens/Tokenhouse Yard

Chapter 6

Flood Frequency Analysis - Urban Roman Walbrook

6.1 Objectives

Outputs from the research from the palaeo-stratigraphy and palaeo-hydrology components, reported in Chapters 4 and 5 respectively, combine to provide the basic data for a flood analysis of the Urban Roman Walbrook Valley (URWV).

The objective of the flood-risk analysis of the Walbrook is to establish, for a range of local channel dimensions and riverbed gradients, the likely frequency of flooding within the flatter areas of urban Roman London through which the river passed.

6.2 Methodology

A river floods when the volumetric rate of flow at any point in its course exceeds the capacity of the channel to convey that flow such that the water level rises above its banks flooding neighbouring land. For the purposes of the research, this critical rate of flow is termed the "flow-full capacity" of the Walbrook at a specific point along its course, synonymous with the term "bank-full" situation also used in hydrological literature. In a rural environment, periodic flooding can be considered beneficial, so-called water meadow being prized for its grazing and productivity. In an urban situation, flooding carries with it no such benefit and may cause substantial damage to properties and infrastructure.

One of the principal questions to which this research seeks to respond is whether the Walbrook was capable of flooding urban Roman London and, if so, with what frequency and what, if any, measures were taken to avoid or reduce that flooding?

The methodology used to assess flood-risk was as follows:

a. the "flow-full capacities" of the River Walbrook channel, i.e. the rate of flow in the river above which the river would over-top its banks and flood, were calculated for a range of channel cross-sections and riverbed slopes at those points along the urban stretch of the Walbrook identified as being at greatest risk from flooding in the palaeo-stratigraphy component (Section 4.6.3); and

b. storm flow runoff rates generated in the hydrological analysis (Tables 5-14 to 5-17, Section 5.9.2) were contrasted with the flow-full capacity of the river at those critical points in its course within urban Roman London to determine, under storm flow conditions, whether the "flow-full" capacities would be exceeded and, if so, the probable frequency of occurrence of flooding.

6.3 Flow-Full Capacity Estimation

The key to determining whether the Walbrook flooded urban Roman London is the estimation of the river's flow-full capacity. The Manning formula for open-channel flow has been adopted for this purpose. The formula is reported in Appendix 6A together with background to its development.

Values for R, hydraulic radius, for the Roman Walbrook have been derived from channel cross-sections found in archaeological excavations, supplemented by data on the dimensions of modern river channels having similar catchments used in the surrogate river analysis, Section 5.8.2. For urban stretches of the river, a range of values for Manning's roughness coefficient, n, has been derived from standard tables (Nelson, 1983, 21.51-21.52) (Hydrocad, 2011). The values chosen were dependent upon the conjectured nature of the river's course and bed, in particular relating to the type and amount of aquatic vegetation and other obstructions to flow, such as accumulations of solid detritus disposed of to the river.

6.4 Flood Frequency Assessment – Urban Roman Walbrook – Combined Western and Eastern Streams

It is apparent from the palaeo-stratigraphy that the area at greatest risk of flooding would have been the upper and middle urban stretches of the Walbrook between the point of confluence of the western and eastern streams, at Blomfield Street, through to Lothbury. However, the flood risk to other parts of riparian urban Roman London has also been assessed. As it exerts such a major influence over the carrying capacity of a river, bed slope has been used to divide the river into four urban lengths for the purposes of assessing flood frequency, as detailed in Section 4.5.2, Figure 4-20, viz:

- Zones D and E - Blomfield Street to Lothbury - two points have been assessed, Blomfield Street, at entry to the urban area, and Draper's Gardens/Tokenhouse Yard area, as representative of the depressed, bowl-shaped area;
- Zone C - Lothbury to Bucklersbury, a steeper sloping stretch, bridged by the main Roman London east-west road;
- Zone B - Bloomberg Development, a shallow amphitheatre of land surrounded on three sides by higher ground and a slope towards the estuary ten times that of Blomfield Street to Lothbury; and
- Zone A - Cannon Street to the Thames, a stretch through to the estuary with a slightly flatter gradient compared with that of ZoneB.

The flow-full capacity of the Walbrook was assessed for all four of these stretches using three bed conditions represented by a range of values for the Manning constant, n (Nelson, 1983, 21.51-21.52) (HydroCAD, 2011):

- 0.04 – a winding earth channel, free of reeds and large stones;
- 0.07 – a winding earth channel, its bed and banks lightly reeded and/or lightly obstructed; and
- 0.12 – a winding earth channel, its bed and banks heavily reeded and/or heavily obstructed.

A value of 0.04 would model the river as having its greatest flow-full capacity and therefore least likely to flood, whereas a value of 0.12 represents the situation when the channel has not been maintained and would be most likely to cause flooding. The value of 0.07, between the two extremes models the situation that would represent the state of the river channel for the majority of the time.

Other variables relate to the physical dimensions of the channel and at each point of assessment, three bed widths and four depths of channel have been modelled. The channel dimensions have been varied to correspond with those most probable along each of the four stretches. A standard slope to the bank of 45° has been used, as this is a common channel configuration for the surrogate rivers However, given the width of the channel compared with the depth, bank slope exerts the least effect on flow-full capacity. It would little effect the outcome of the flood frequency analysis were the banks have been considered to have been vertical. Combining these options, thirty-six, flow-full capacity situations have been estimated at five points along the urban stretch of the Roman Walbrook.

The resulting flow-full capacities have then be compared with the storm flow conditions reported in Section 5.9.2, Table 5-14, for storms with return periods of 1 to 500 years for the composite CN values for each of the immediate pre-Roman and Roman periods derived in Section 5.9.1.

Flow-full capacities under 36 channel conditions and the storm flows for 9 return periods for each point of assessment both pre-Roman and Roman have been reported on the same figure for each key location on Figures 6-2 to 6-10. Each flow full capacity is compared to the storm flow for a particular return period. The lighter blue infill indicates flooding at a frequency greater than that indicated and the darker blue a flood frequency greater than once a year.

When interpreting the flood-risk as detailed for each of Zones A to D in the following sections, it is important to note the following:

a. Zones D and E were contiguous had a similar topographic character and, before the construction of the wall, would have had the same character. Their division into two separate zones for the purposes of this research is artificial, related primarily to the exclusion effect of the eventual town wall.
b. Zone D contained the shallow, bowl-shaped depression through which the Walbrook passed. Under the condition of a prolonged period of dry weather, followed by a storm, the depression in the ground would have been relatively dry when storm flows entered the zone and would have needed to be filled before Zones C to A downstream would have received storm flows. Flooding of Zone D would therefore have acted as a flood attenuation reservoir and the depression in the ground and the floodplain would have had to be filled before the full magnitude of a storm flow was experienced downstream.
c. However, Zone D would almost certainly have been marsh for much of the year and the depressed area may well have been a lake full of water. Under these conditions, the degree to which storm flows would have been attenuated would have been reduced.
d. Each of the zones, C to A, has therefore been assessed as if it received the full brunt of storm flows entering the urban Roman portion of the Walbrook catchment. The resulting flood frequency should therefore be considered a conservative assessment for these zones. A reminder to this effect is included at the end of the assessment for each of the three zones.

e. Given the results of the assessment of tide levels, reported in Section 5.7.7, it is unlikely that tides combined with high tides would have caused or exacerbated flooding other than in in Zone A and possibly the southern portion of Zone B. By the middle of the 2nd C, tidal influence on flooding would have been minimal for all areas other than the immediate estuarine area of Zone A.

6.4.1 Flood frequency assessment – Zone D (north) - Blomfield Street to Lothbury

The landscape through which this stretch of the river passes has been described in Section 5.7.5 as flat with an extensive heart-shaped, shallow depression covering much of the area, boggy in nature with the river winding and braided, its channel poorly-defined in places. Where the banks of the stream were well-defined, they would have been from 0.5 to 1.5 metres high, however, a situation where they were poorly-defined has also been modelled by reducing the bank height to just 0.25 metres. The width of the riverbed, i.e. the width that accommodated the base flow, has been taken to lie in the range 5.0 to 7.0 metres, a width between 5.0 and 6.0m being typical of the modern surrogate rivers, Section 5.8.2, Figures 5-8 and 5-9, and those found in the course of archaeological investigations, Figure 6-1. Other modest, modern London rivers, such as the Pinn and the Brent do reach 7 metres in width in their middle stretches (Myers, 2011) and so this width has been modelled as an upper limit. Flow-full capacities for the Walbrook have been estimated at both Blomfield Street and Draper's Gardens/Tokenhouse Yard. These have been compared with storm flows for the pre-Roman and Roman periods in Figures 6.2 and 6.3 respectively and flood frequency at each of the locations derived for the two periods. Figure 6.4 compares flood frequency at both locations.

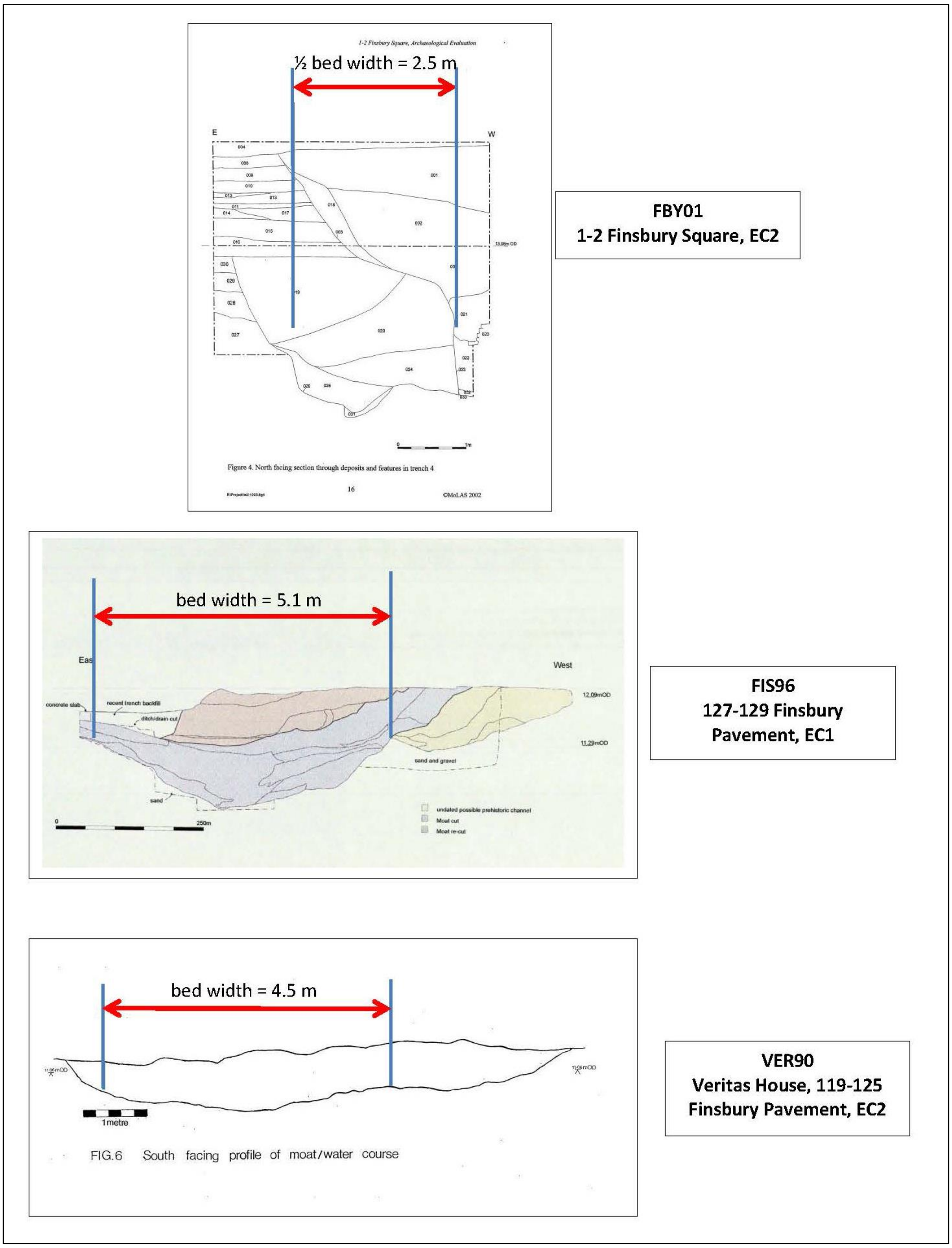


Figure 6-1 Bed width of ancient Walbrook - archaeological investigations where the complete width of riverbed has been found

(for locations of these sites, see Section 3.4.9, Figure 3-12, "7 metre-wide stream channel uncovered on 3 archaeological sites")

Figure 6-2 Blomfield Street to Draper's Gardens/Tokenhouse Yard (Zone D north) – Walbrook flow-full capacities, storm return periods and consequent flood frequency

Greater Walbrook Valley
Checks on "flow full" capacity of Walbrook channel - and consequent flood frequency
Composite AMC 2 & 3 flows
Walbrook location: ***Zone E - Blomfield Street to Draper's Gardens/Tokenhouse Yard - average river bed slope = 10.5 m/10,000 m***

Flooding at a frequency greater than that indicated
Flooding at a frequency greater than once a year
1.19 Storm flow at the above frequency, e.g. 1.19 m³/sec at frequency of once in 2 years

Manning formula — Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) — "Flow full" capacity, Q = A.v

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.12 — Slope of river channel - 0.00105 (10.5m/10,000m) — River bed width - max 7.0 m; min 5.0 m — Depth of river when full - max 1.5 m; min 0.25 m

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m²)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m³/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding										
0.04	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.88	**11.24**
0.04	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.71	**5.65**
0.04	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.47	**1.77**
0.04	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.31	**0.56**
0.04	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.86	**9.70**
0.04	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.69	**4.85**
0.04	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.47	**1.52**
0.04	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.31	**0.48**
0.04	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.84	**8.19**
0.04	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.68	**4.07**
0.04	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.46	**1.26**
0.04	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.30	**0.40**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding										
0.07	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.50	**6.42**
0.07	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.40	**3.23**
0.07	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.27	**1.01**
0.07	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.18	**0.32**
0.07	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.49	**5.55**
0.07	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.40	**2.77**
0.07	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.27	**0.87**
0.07	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.17	**0.27**
0.07	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.48	**4.68**
0.07	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.39	**2.32**
0.07	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.26	**0.72**
0.07	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.17	**0.23**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding										
0.12	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.29	**3.75**
0.12	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.24	**1.88**
0.12	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.16	**0.59**
0.12	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.10	**0.19**
0.12	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.29	**3.23**
0.12	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.23	**1.62**
0.12	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.16	**0.51**
0.12	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.10	**0.16**
0.12	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.28	**2.73**
0.12	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.23	**1.36**
0.12	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.15	**0.42**
0.12	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.10	**0.13**

Flooding frequency (i.e. river bank over-topped) - once in ? Years

	Immediate pre-Roman									Roman								
Years	1	2	5	10	20	50	100	200	500	1	2	5	10	20	50	100	200	500
Storm flow (m³/s)	0.56	1.19	2.96	5.05	6.30	8.10	10.68	14.50	19.69	1.03	2.01	4.41	7.00	8.60	10.20	12.00	17.10	26.01

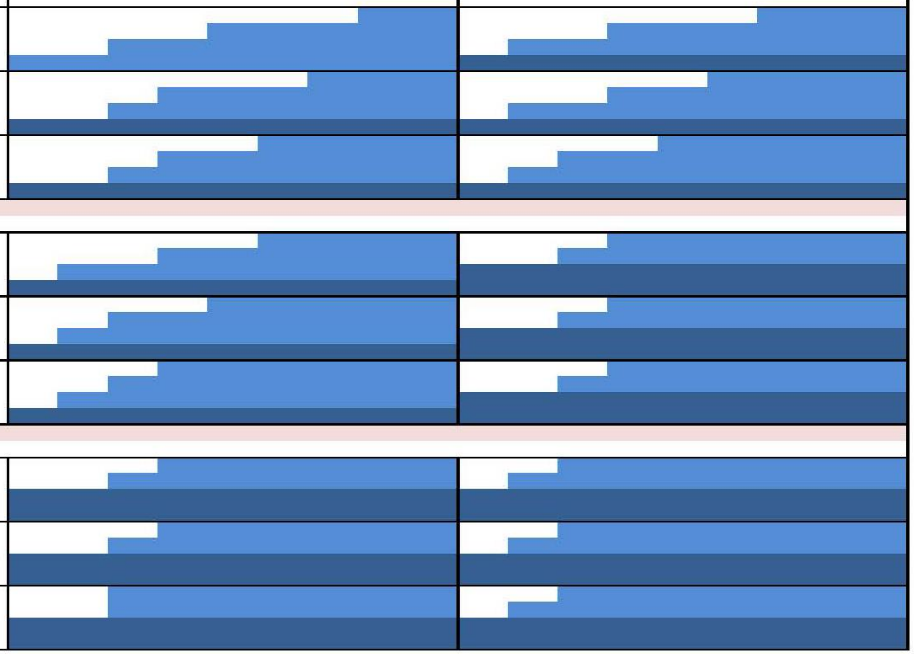


Figure 6-3 Draper's Gardens/Tokenhouse Yard to Lothbury (Zone D south) – Walbrook flow-full capacities, storm return periods and consequent flood frequency

Greater Walbrook Valley

Checks on "flow full" capacity of Walbrook channel - and consequent flood frequency

Composite AMC2 & 3 flows

Walbrook location: ***Zone D - Draper's Gardens/Tokenhouse Yard to Lothbury - average river bed slope = 10.5 m/10,000 m***

Flooding at a frequency greater than that indicated

Flooding at a frequency greater than once a year

1.41 Storm flow at the above frequency, e.g. 1.41 m^3/sec at frequency of once in 2 years

Manning formula — Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) — "Flow full" capacity, $Q = A.v$

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.12 — Slope of river channel - 0.00105 (10.5m/10,000m) — River bed width - max 7.0 m; min 5.0 m — Depth of river when full - max 1.5 m; min 0.25 m

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m^2)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m^3/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding										
0.04	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.88	**11.24**
0.04	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.71	**5.65**
0.04	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.47	**1.77**
0.04	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.31	**0.56**
0.04	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.86	**9.70**
0.04	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.69	**4.85**
0.04	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.47	**1.52**
0.04	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.31	**0.48**
0.04	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.84	**8.19**
0.04	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.68	**4.07**
0.04	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.46	**1.26**
0.04	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.30	**0.40**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding										
0.07	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.50	**6.42**
0.07	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.40	**3.23**
0.07	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.27	**1.01**
0.07	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.18	**0.32**
0.07	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.49	**5.55**
0.07	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.40	**2.77**
0.07	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.27	**0.87**
0.07	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.17	**0.27**
0.07	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.48	**4.68**
0.07	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.39	**2.32**
0.07	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.26	**0.72**
0.07	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.17	**0.23**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding										
0.12	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.29	**3.75**
0.12	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.24	**1.88**
0.12	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.16	**0.59**
0.12	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.10	**0.19**
0.12	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.29	**3.23**
0.12	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.23	**1.62**
0.12	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.16	**0.51**
0.12	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.10	**0.16**
0.12	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.28	**2.73**
0.12	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.23	**1.36**
0.12	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.15	**0.42**
0.12	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.10	**0.13**

Flooding frequency (i.e. river bank over-topped) - once in ? Years

	Immediate pre-Roman									Roman								
Years	1	2	5	10	20	50	100	200	500	1	2	5	10	20	50	100	200	500
Storm flow (m^3/s)	0.67	1.41	3.39	5.69	7.90	10.80	13.54	17.50	21.92	1.26	2.38	5.04	7.89	9.80	11.48	13.70	20.70	28.84

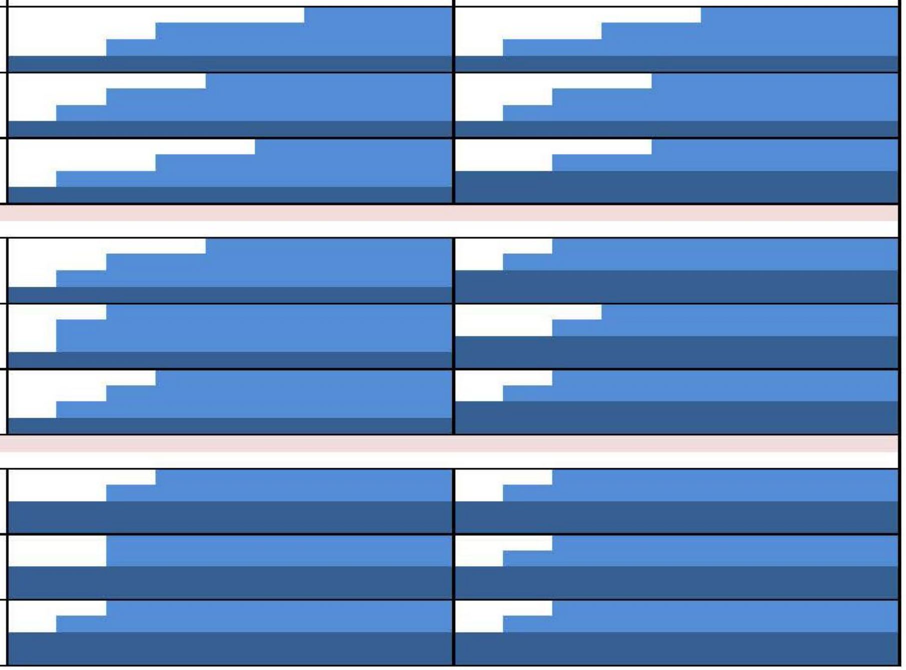
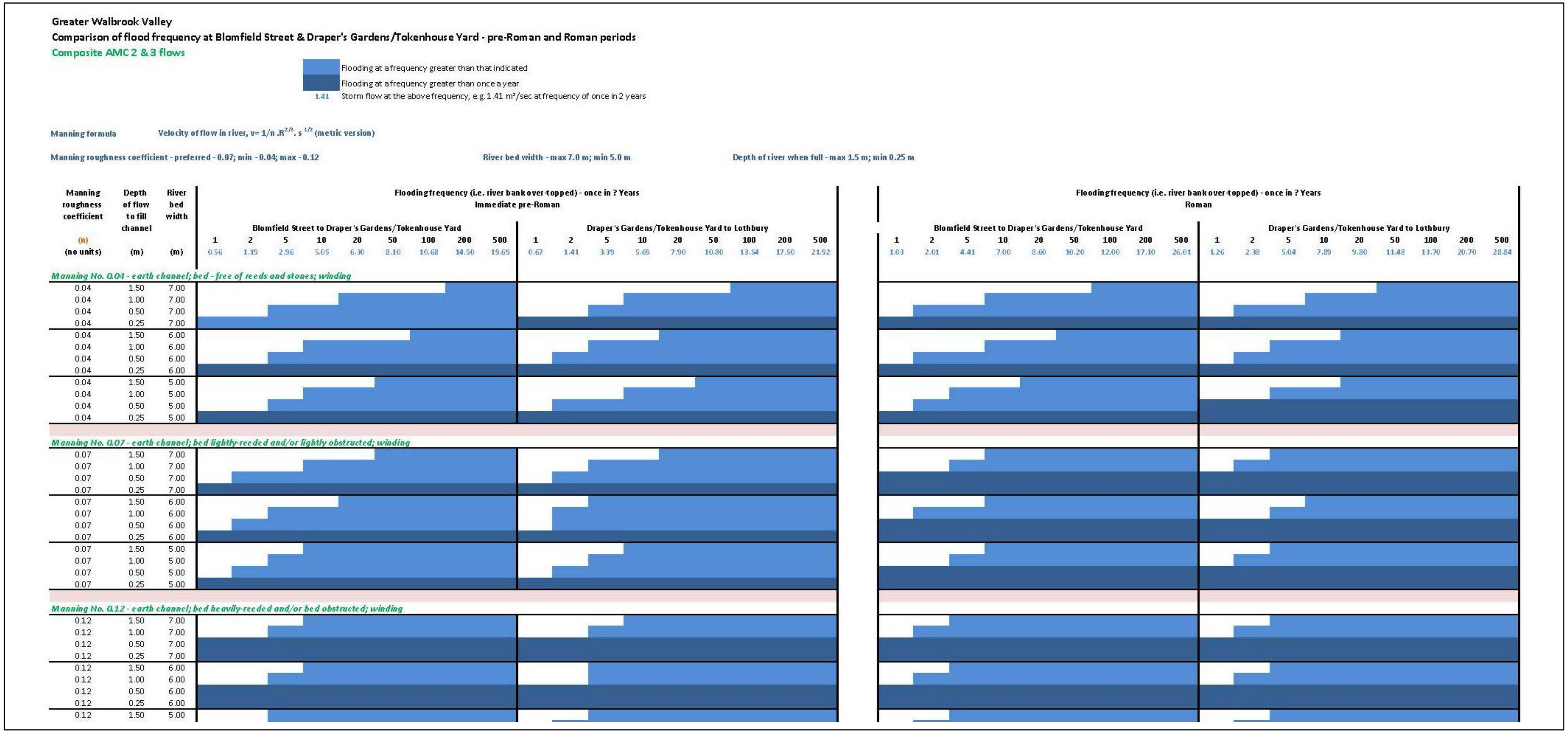


Figure 6-4 Comparison of flood frequency at Blomfield Street to Draper's Gardens/Tokenhouse Yard and Draper's Gardens/Tokenhouse Yard to Lothbury



The following observations arise from examination of Figures 6-2 to 6-4:

Figures 6-2 and 6-3

- The flat gradient to the river through this stretch, 10.5 m/10,000 m, combined with the magnitude of the storm flows generated, would have rendered both locations highly susceptible to flooding. For all but a few of the scenarios, floods could have been expected with a frequency of between 2 and 5 years.
- The only exception to the foregoing situation, could have been those scenarios where the Manning coefficient, n, was 0.04 combined with depths of channel between 1.0m and 1.5 m, an improbable combination in the area, when flood frequency could have been expected to be between 10 and 20 years and 20 and 50 years respectively. Only for the Roman period in both locations would the flood frequency have fallen to between 5 and 10 years for these unlikely configurations.
- For those parts of the area where the banks were very low providing for water depths in the channel of 0.25m or less, the river would have flooded the land either side of the river several times a year under almost all channel and storm combinations.
- Under these circumstances, in those areas where the land was lowest and no land raising activity had taken place, a large part of the area would have become marshy, dotted with frequent, linked pools of water under most storm situations as well as during prolonged periods of sub-storm rainfall intensities.
- The situation was little better for depths of flow up to 0.5 m, flooding could have been expected for most scenarios at least annually and, for many of those situations with an even greater frequency.
- Where the land was 1 metre or more above riverbed level, flooding could have been expected with a frequency between 2 and 5 years, with the exception of the pre-Roman period at Blomfield Street where flooding would have been less frequent, occurring with a frequency of between 5 and 10 years.
- For the river condition, where the channel would have been well-defined, i.e. width 6.0 m, depth 1.0m and a Manning coefficient of 0.07, the frequency of return of flooding would have been between 2 and 5 years at both locations and both periods. However, this would only

have occurred where "islands" of higher land were to be found and for both locations, the flooding frequency would have been closer to every 2 years during the Roman period.

- Risk of flooding at both locations is consistently greater during the Roman occupation than when the catchment was in its undeveloped state prior to their arrival.
- Whenever the channel deteriorated and become obstructed, in effect increasing "n" to a value of 0.12, flooding could have been expected during most storms under all but a very few situations and for 50% of the scenarios, flooding could then have been expected more than once a year. This emphasises the importance of regular channel maintenance to clear natural obstructions, material deliberately dumped in the channel or excessive growth of reeds.
- Increasing flood frequency as use of the catchment for agriculture and horticulture became progressively more intense could explain the raising of the level of the land by the Romans in Zone D in stages (Section 7.3.2). A surface elevation early in the occupation that may have coped with floods might soon have proved too low as run-off rates increased with urbanisation and woodland clearance and farming in the upper catchment. Raising the land to counter the tendency to flood at any point in time may well have proved unable to cope as storm flows increased, necessitating further land raising.

Figure 6-4 Comparison of flood frequency between the two locations, Blomfield Street and Draper's Gardens/Tokenhouse Yard

- For any given scenario, the risk of flooding at Draper's Gardens/Tokenhouse Yard is consistently either equal to, or greater than, at Blomfield Street, although there are no radical differences between the two locations.
- For a given value of "n" combined with riverbed width, the depth of the channel has relatively little effect on the frequency of flooding.
- By the Roman period, flood frequency at Blomfield Street and Draper's Gardens/Tokenhouse Yard are the same for all but the more extreme scenarios, i.e. n equal to 0.04 combined with the widest and deepest channels.

The HydroCAD project calculation reports, Appendix 5D, indicate that flooding may have occurred upstream in the GWV, reducing storm flow rates through the urban area. However, for the pre-Roman period, storms would need to have had a return period greater than 50 years at Blomfield Street and

20 years at Draper's Garden before such up-catchment flooding occurred. For the Roman period, the equivalent storm return periods would have been 20years and 10 years. Therefore, all but a few of the observations drawn from the tables would remain unaffected had such flooding occurred.

6.4.2 Flood frequency assessment – Zone C - Lothbury to Bucklersbury

The southern edge of the shallow bowl within Zone D is formed by a very low ridge of land at Lothbury, running east to west parallel with the modern Lothbury. The river cuts a path through the low rise of land after which its gradient increases sharply from 10.5 m/10,000m to 164 m/10,000 m, falling from a bed elevation of 5.74m OD at Lothbury to 1.80m OD at Bucklersbury over a distance along the stream of 240m. The river passes through a more pronounced valley over this stretch, with land to the east remaining at between 6.0 and 6.50m OD. On the west side of the stream at Bucklersbury, ground level a short distance from the stream is similar to that on the east bank, however the ground slopes sharply upwards and westwards and at POU05, about 75m from the Walbrook, Roman ground level was already at 9.10m OD. The upward slope continues westwards forming the eastern slope of Ludgate Hill. The valley through which the river passes appears to narrow from its passage across Princes Street through to Poultry after which it opens out again to Bucklersbury over a distance of just 50m. At the valley's narrowest point at Poultry, a bridge was constructed to span the river to carry the main east-west road of Roman London.

Flow-full capacities for the Walbrook have been estimated for this stretch of the Walbrook. These have been compared with storm flows for the pre-Roman and Roman periods in Figure 6.5. In order to place the flood frequency over this stretch in context, Figure 6-6 shows the flood frequency diagram for the stretch of the river between Lothbury and Bucklersbury and that for the section Draper's Gardens to Lothbury, both diagrams being for the Roman period. Examination of Figures 6-5 and 6-6 lead to the following observations:

- In only one of the scenarios examined out of 36 for the pre-Roman period would the river have flooded with a frequency of between 10 and 20 years but in the Roman period flood frequency increased to between 10 and 20 years in 3 out of 36 cases examined.
- Flood frequency of between 20 and 50 years occurred in 5 out of the 36 scenarios for the pre-Roman period, only rising to 6 out of 36 cases in the Roman Period.

Figure 6-5 Lothbury to Bucklersbury (Zone C) – Walbrook flow-full capacities, storm return periods and consequent flood frequency

Greater Walbrook Valley
Checks on "flow full" capacity of Walbrook channel - and consequent flood frequency

Walbrook location: **Zone C - Lothbury to Bucklersbury - average river bed slope = 164 m/10,000 m**

Flooding at a frequency greater than that indicated
Flooding at a frequency greater than once a year
1.41 Storm flow at the above frequency, e.g. 1.41 m^3/sec at frequency of once in 2 years

Manning formula — Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) — "Flow full" capacity, Q = A.v

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.12 — Slope of river channel - 0.0164 (164 m/10,000 m) — River bed width - max 7.0 m; min 5.0 m — Depth of river when full - max 2.0 m; min 1.0 m

Flooding frequency (i.e. river bank over-topped) - once in ? Years

	1	2	5	10	20	50	100	200	500
Immediate pre-Roman	0.67	1.41	3.39	5.69	7.90	10.80	13.54	17.50	21.92
Roman	1.26	2.38	5.04	7.89	9.80	11.48	13.70	20.70	28.94

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m^2)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m^3/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding										
0.04	2.00	7.00	45	2.83	18.00	12.66	1.42	0.01640	4.05	**72.96**
0.04	1.75	7.00	45	2.47	15.31	11.95	1.28	0.01640	3.78	**57.88**
0.04	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01640	3.48	**44.41**
0.04	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01640	2.79	**22.31**
0.04	2.00	6.00	45	2.83	16.00	11.66	1.37	0.01640	3.96	**63.33**
0.04	1.75	6.00	45	2.47	13.56	10.95	1.24	0.01640	3.70	**50.12**
0.04	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01640	3.41	**38.35**
0.04	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01640	2.74	**19.18**
0.04	2.00	5.00	45	2.83	14.00	10.66	1.31	0.01640	3.84	**53.81**
0.04	1.75	5.00	45	2.47	11.81	9.95	1.19	0.01640	3.59	**42.43**
0.04	1.50	5.00	45	2.12	9.75	9.24	1.05	0.01640	3.32	**32.35**
0.04	1.00	5.00	45	1.41	6.00	7.83	0.77	0.01640	2.68	**16.07**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding										
0.07	2.00	7.00	45	2.83	18.00	12.66	1.42	0.01640	2.32	**41.69**
0.07	1.75	7.00	45	2.47	15.31	11.95	1.28	0.01640	2.16	**33.08**
0.07	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01640	1.99	**25.38**
0.07	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01640	1.59	**12.75**
0.07	2.00	6.00	45	2.83	16.00	11.66	1.37	0.01640	2.26	**36.19**
0.07	1.75	6.00	45	2.47	13.56	10.95	1.24	0.01640	2.11	**28.64**
0.07	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01640	1.95	**21.92**
0.07	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01640	1.57	**10.96**
0.07	2.00	5.00	45	2.83	14.00	10.66	1.31	0.01640	2.20	**30.75**
0.07	1.75	5.00	45	2.47	11.81	9.95	1.19	0.01640	2.05	**24.24**
0.07	1.50	5.00	45	2.12	9.75	9.24	1.05	0.01640	1.90	**18.49**
0.07	1.00	5.00	45	1.41	6.00	7.83	0.77	0.01640	1.53	**9.18**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding										
0.12	2.00	7.00	45	2.83	18.00	12.66	1.42	0.01640	1.35	**24.32**
0.12	1.75	7.00	45	2.47	15.31	11.95	1.28	0.01640	1.26	**19.29**
0.12	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01640	1.16	**14.80**
0.12	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01640	0.93	**7.44**
0.12	2.00	6.00	45	2.83	16.00	11.66	1.37	0.01640	1.32	**21.11**
0.12	1.75	6.00	45	2.47	13.56	10.95	1.23	0.01640	1.23	**16.71**
0.12	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01640	1.14	**12.78**
0.12	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01640	0.91	**6.39**
0.12	2.00	5.00	45	2.83	14.00	10.66	1.31	0.01640	1.28	**17.94**
0.12	1.75	5.00	45	2.47	11.81	9.95	1.19	0.01640	1.20	**14.14**
0.12	1.50	5.00	45	2.12	9.75	9.24	1.05	0.01640	1.11	**10.78**
0.12	1.00	5.00	45	1.41	6.00	7.83	0.77	0.01640	0.89	**5.36**

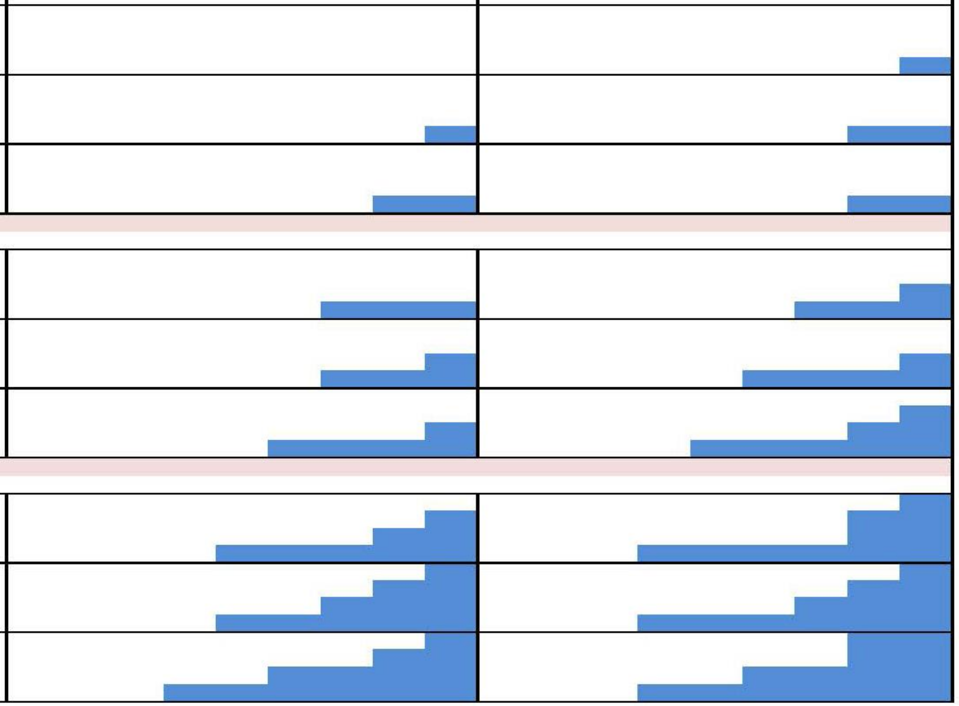
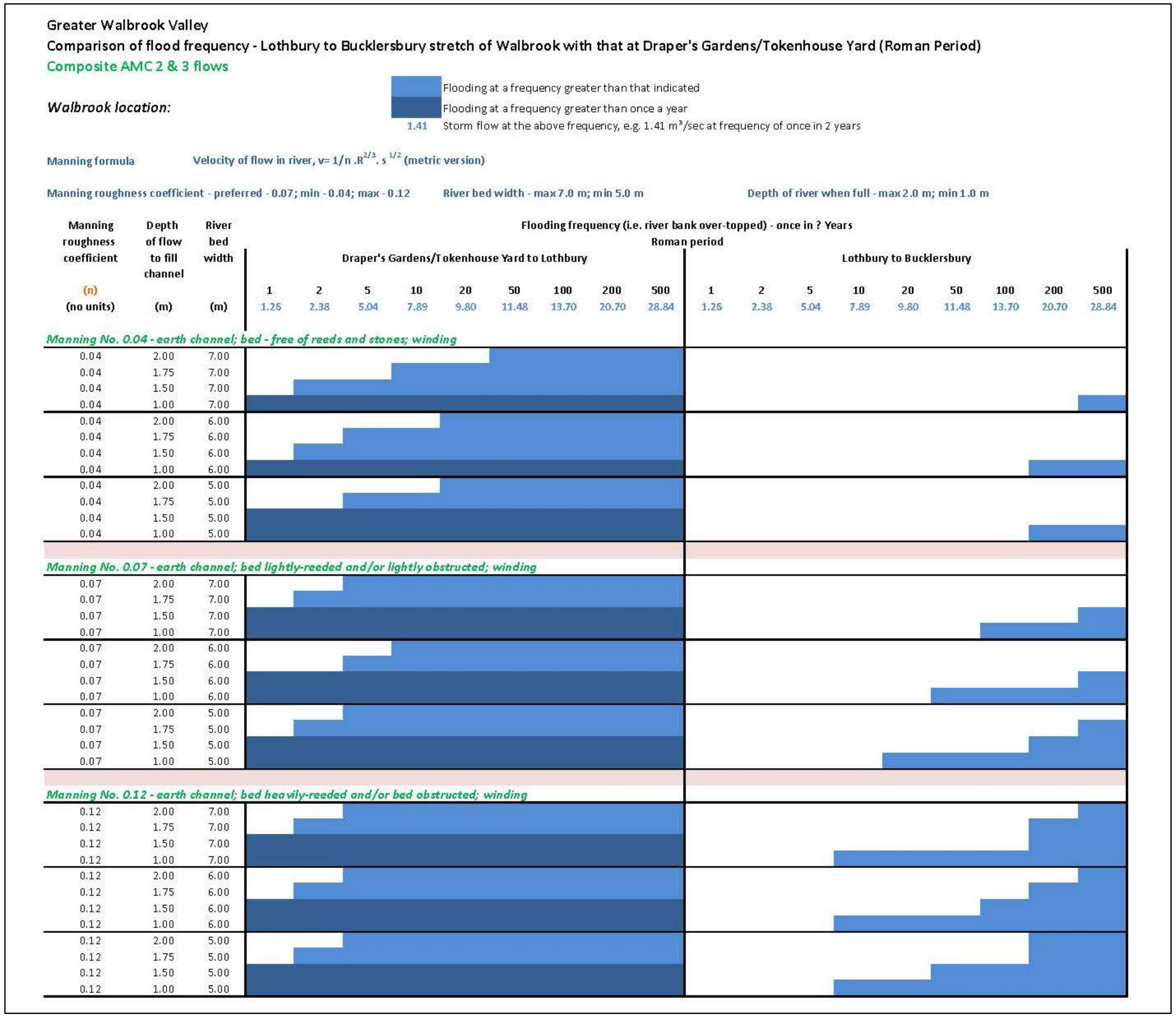


Figure 6-6 Flood frequency along Lothbury to Bucklersbury stretch of Walbrook compared with Draper's Gardens to Lothbury (Roman period)



- For the majority of cases, flooding would have occurred with a frequency greater than 100 years in both the pre-Roman and Roman periods.
- The far lower propensity for the Walbrook to flood this area, compared with Zones D and E, is well illustrated by comparison with Zone D in Figure 6-5.
- Flooding that did occur would have been of limited extent, due to the greater depth of the channel and restricted width of the floodplain over this stretch.

6.4.3 Flood frequency assessment – Zone B – Bucklersbury to Cannon Street (Bloomberg Development)

The land forming the Bloomberg Development sloped slightly more gently southwards compared to Zone C; it was flanked on its western, northern and eastern sides by land rising rapidly, 3 metres or so, away from its floodplain. From a standpoint on the low bluff to the east of the Walbrook, upon which a high-status building formerly known as the “Governor’s Palace” stood (Merrifield, 1983) (Milne, 1996, 49-56), the Walbrook floodplain would have appeared to be the floor of a low-rise amphitheatre of land sloping away to the Thames. Land away to the south continued, at a slightly flatter gradient, down towards the Thames and this would have further increased the impression of a shallow amphitheatre.

The Walbrook would have passed straight across the area from a little east of north to just west of south, parallel to, and not more than 20 metres from, the later street known as Walbrook. The bed of the stream fell from 1.80m OD to 0.30m OD over a distance of 120 m, i.e. a riverbed slope of 125 m/10,000m. The edge of the low eastern bluff would have followed the orientation of the stream at a distance of only 40m from it, with its upper surface at 6.00 to 6.50m OD (LYD88 & CCP04/CNV08). The slopes on three sides would have limited the extent of the floodplain limiting the distance from east to west across the “floor” of the amphitheatre to a maximum of 100 metres.

Flow-full capacities for the Walbrook have been estimated for this stretch of the Walbrook. These have been compared with storm flows for the pre-Roman and Roman periods in Figure 6.7. In accordance with archaeological observations (WFG44/45 & BZY10), the depth of channel increased over this stretch, having a minimum of 0.75m and a maximum of 2.0m. In order to place the flood frequency over this stretch in context, Figure 6-8 shows the flood frequency diagram for the stretch of the river through the Bloomberg Development and that for the section Draper's Gardens to Lothbury. Both diagrams are for the Roman period. Examination of Figures 6-7 and 6-8 lead to the following observations:

- The frequency of flooding is greater for Zone B than for Zone C immediately upstream but considerably less than that experienced in Zones D and E.
- For the pre-Roman period, in only one scenario did the flooding occur with a frequency of between 2 and 5 years, increasing to six scenarios for a frequency of between 5 and 10 years, the median case being a frequency of between 20 and 50 years.
- For the Roman period, flooding would have occurred under five scenarios with a frequency of between 2 and 5 years, increasing to nine scenarios for a frequency of between 5 and 10 years, the median case being a frequency of between 20 and 50 years.

Figure 6-7 Bucklersbury to Cannon Street (Bloomberg Development - Zone B) – Walbrook flow-full capacities, storm return periods and consequent flood frequency

Greater Walbrook Valley
Checks on "flow full" capacity of Walbrook channel - and consequent flood frequency
Composite AMC 2 & 3 flows
Walbrook location: ***Zone B - Bloomberg Development - average river bed slope = 125 m/10,000 m***

Flooding at a frequency greater than that indicated
Flooding at a frequency greater than once a year
1.41 Storm flow at the above frequency, e.g. 1.41 m^3/sec at frequency of once in 2 years

Manning formula — Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) — "Flow full" capacity, Q = A.v

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.12 — Slope of river channel - 0.01250 (125m/10,000m) — River bed width - max 7.0 m; min 5.0 m — Depth of river when full - max 2.0 m; min 0.75 m

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m^2)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m^3/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding										
0.04	2.00	7.00	45	2.83	18.00	12.66	1.42	0.01250	3.54	**63.70**
0.04	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01250	3.04	**38.77**
0.04	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01250	2.44	**19.48**
0.04	0.75	7.00	45	1.06	5.81	9.12	0.64	0.01250	2.07	**12.01**
0.04	2.00	6.00	45	2.83	16.00	11.66	1.37	0.01250	3.46	**55.29**
0.04	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01250	2.98	**33.48**
0.04	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01250	2.39	**16.75**
0.04	0.75	6.00	45	1.06	5.06	8.12	0.62	0.01250	2.04	**10.31**
0.04	2.00	5.00	45	2.83	14.00	10.66	1.31	0.01250	3.36	**46.98**
0.04	1.50	5.00	45	2.12	9.75	9.24	1.05	0.01250	2.90	**28.25**
0.04	1.00	5.00	45	1.41	6.00	7.83	0.77	0.01250	2.34	**14.03**
0.04	0.75	5.00	45	1.06	4.31	7.12	0.61	0.01250	2.00	**8.61**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding										
0.07	2.00	7.00	45	2.83	18.00	12.66	1.42	0.01250	2.02	**36.40**
0.07	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01250	1.74	**22.16**
0.07	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01250	1.39	**11.13**
0.07	0.75	7.00	45	1.06	5.81	9.12	0.64	0.01250	1.18	**6.86**
0.07	2.00	6.00	45	2.83	16.00	11.66	1.37	0.01250	1.97	**31.60**
0.07	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01250	1.70	**19.13**
0.07	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01250	1.37	**9.57**
0.07	0.75	6.00	45	1.06	5.06	8.12	0.62	0.01250	1.16	**5.89**
0.07	2.00	5.00	45	2.83	14.00	10.66	1.31	0.01250	1.92	**26.85**
0.07	1.50	5.00	45	2.12	9.75	9.24	1.05	0.01250	1.66	**16.14**
0.07	1.00	5.00	45	1.41	6.00	7.83	0.77	0.01250	1.34	**8.02**
0.07	0.75	5.00	45	1.06	4.31	7.12	0.61	0.01250	1.14	**4.92**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding										
0.12	2.00	7.00	45	2.83	18.00	12.66	1.42	0.01250	1.18	**21.23**
0.12	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01250	1.01	**12.92**
0.12	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01250	0.81	**6.49**
0.12	0.75	7.00	45	1.06	5.81	9.12	0.64	0.01250	0.69	**4.00**
0.12	2.00	6.00	45	2.83	16.00	11.66	1.37	0.01250	1.15	**18.43**
0.12	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01250	0.99	**11.16**
0.12	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01250	0.80	**5.58**
0.12	0.75	6.00	45	1.06	5.06	8.12	0.62	0.01250	0.68	**3.44**
0.12	2.00	5.00	45	2.83	14.00	10.66	1.31	0.01250	1.12	**15.66**
0.12	1.50	5.00	45	2.12	9.75	9.24	1.05	0.01250	0.97	**9.42**
0.12	1.00	5.00	45	1.41	6.00	7.83	0.77	0.01250	0.78	**4.68**
0.12	0.75	5.00	45	1.06	4.31	7.12	0.61	0.01250	0.67	**2.87**

Flooding frequency (i.e. river bank over-topped) - once in ? Years

	Immediate pre-Roman									Roman								
Years	1	2	5	10	20	50	100	200	500	1	2	5	10	20	50	100	200	500
Storm flow (m^3/s)	0.67	1.41	3.39	5.89	7.90	10.80	13.54	17.50	21.92	1.26	2.38	5.04	7.89	9.80	11.48	13.70	20.70	28.84

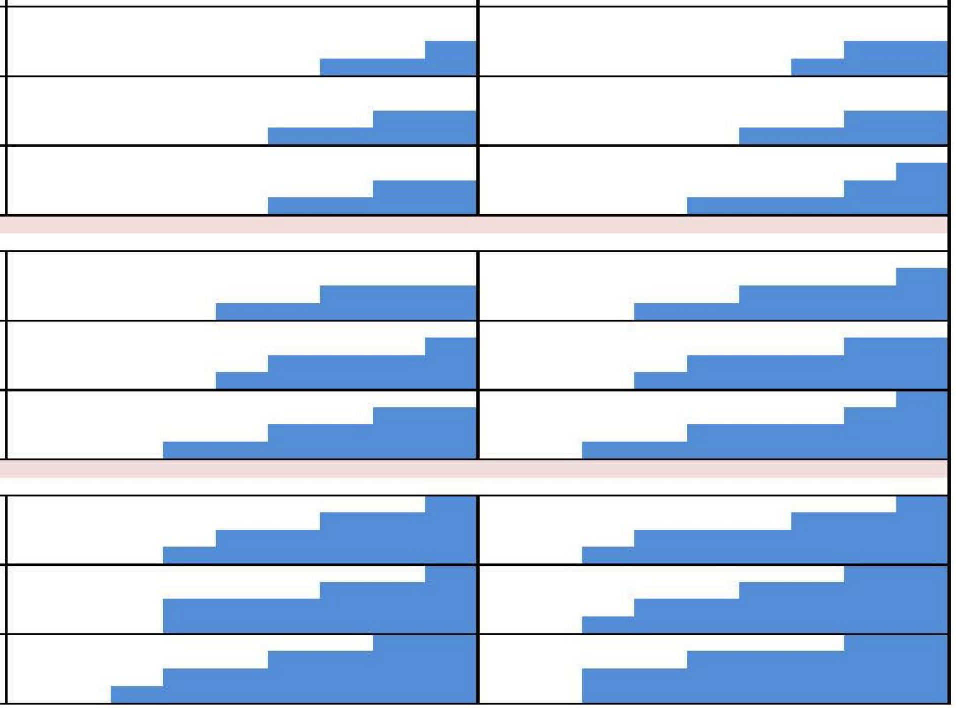
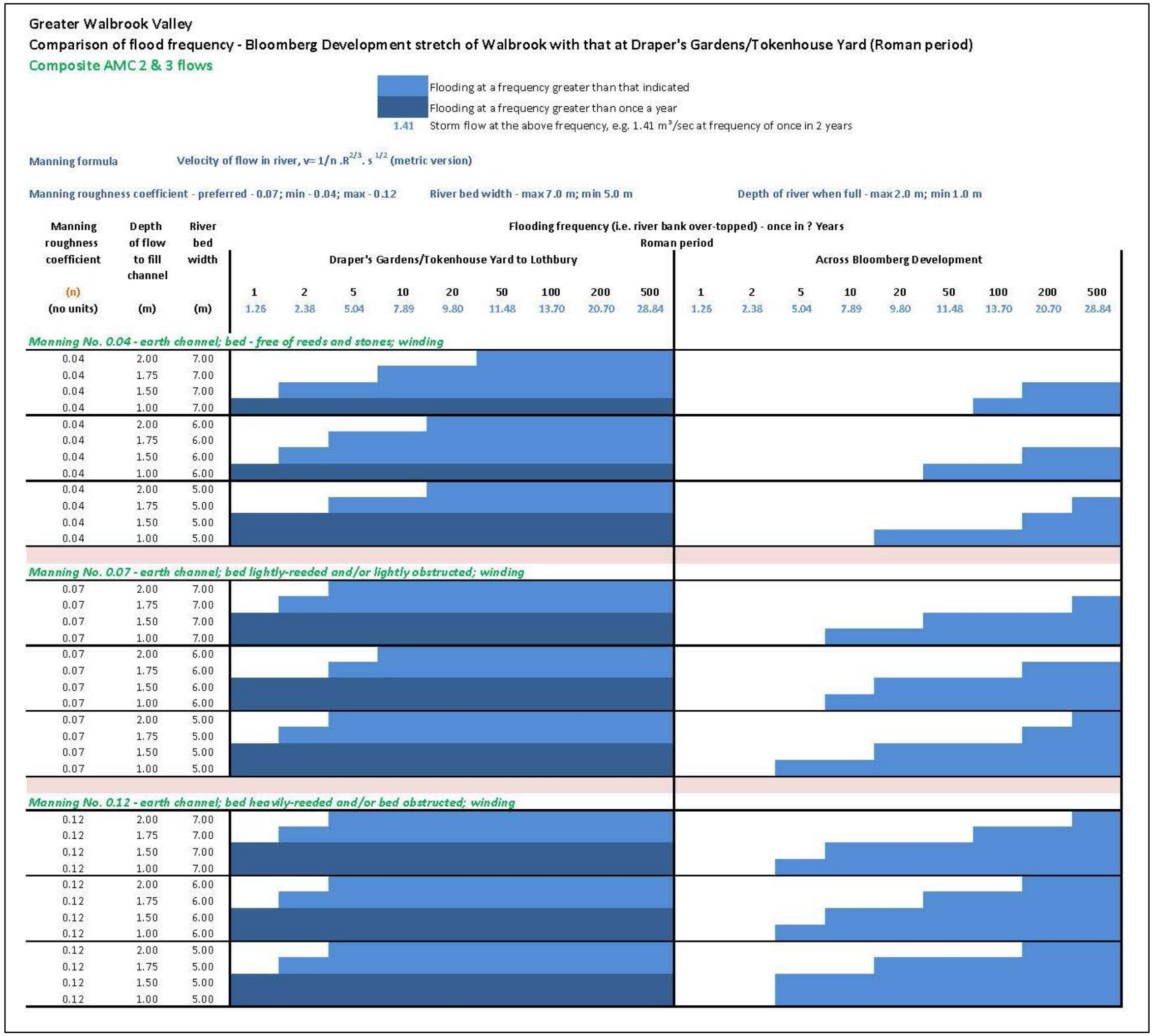


Figure 6-8 Flood frequency across the Bloomberg Development stretch of Walbrook compared with Draper's Gardens to Lothbury (Roman period)



6.4.4 Flood frequency assessment – Zone A - Cannon Street to the Thames

The closer the Walbrook approaches the Thames, the more difficult it becomes to define the topography surrounding the Walbrook estuary in both the pre-Roman and Roman periods. This is because the number of archaeological investigations in the area are few (DGH86 and LYD88) and have been limited in their extent and findings. An east bank of the Walbrook was found during the DGH86 investigation. However, a further east bank was uncovered to the east of the first in the course of the LYD88 investigation. In the case of the latter, revetments were found along the Thames and the Walbrook banks. The two east banks to the Walbrook's estuarine stretches were some 60 metres apart, indicating that the Walbrook split into two channels close to the Thames and, almost certainly, this created a small delta form to the Walbrook mouth. A delta forms where a river broadens out at its confluence with another body of water and silt and clay is deposited in conditions where the velocity of flow falls off significantly. These circumstances require the estuarine land to be flat, a situation found all along the Thames from London seawards.

Tidal levels during the Roman period have been established in Section 5.7.7. There it was indicated that Walbrook would have been tidal to Lothbury until the end of the 1st C, to Cannon Street until about the middle of the 2nd C CE and for the rest of the Roman occupation until their departure a distance of just 50m or less from the Thames. DGH86 discovered an artificial clay bund along the Thames bank, 8 to 10m wide, constructed in the second half of the 1st C and with its crest at 1.50 m OD (Shea, 1987). The bund may have been needed to counter flooding from the Thames and may have been constructed to provide access to a wooden jetty which was found straddling the bund. It was unclear from the investigations to what extent the bund continued along the west bank of the Walbrook and therefore how effective it was at avoiding tidal flooding. However, drains dug into the land behind the bund discharged to the Walbrook and it could therefore be deduced that, under dry weather conditions, tides did not generally cause any flooding of the estuarine zone. However, flooding could have occurred under some storm conditions and may have been worse under exceptional combinations of strong winds affecting the Thames estuary, low atmospheric pressure and high tides.

By the end of the 3rd C, the clay bank had so deteriorated that the estuarine land would have, once again, regularly flooded.

The estuarine character of this stretch of the Walbrook is further reinforced by the investigation at SKN87/CKL88 where what appeared to be a constructed slipway area was found on the west bank of the Walbrook sloping gently down to the river with a building at the top of the slipway that could have been used for maintaining vessels. Falling tides would have rendered this redundant by the mid-2nd C.

Flow-full capacities for the Walbrook have been estimated for this stretch of the Walbrook. These have been compared with storm flows for the pre-Roman and Roman periods in Figure 6-9. The minimum depth of channel examined over this stretch has been reduced to 0.25m to model the "mudflat" situation found nearer to the Thames. The maximum width of channel examined has been increased to 8m as there is a tendency for channel width to increase at an estuary. In order to place the flood frequency over this stretch in context, Figure 6-10 shows the flood frequency diagram for this estuarine stretch and that for the section Blomfield Street to Lothbury, both diagrams being for the Roman period. Examination of Figure 6-9 and 6-10 lead to the following observations:

- Risk of flood events in Zone A whilst not quite as great as for the worst situation along the urban Walbrook, Zones D, is significantly greater in its estuarine section than for Zone B, immediately upstream.
- Under "mudflat" conditions, height of bank 0.25m or less, floods would have occurred regularly, particularly when a storm was combined with high tides; this will have been the situation prior to construction of the river bund shortly after the arrival of the Romans and which would have, re-occurred when the riverbank was breached at the end of the 3rd C.
- For the pre-Roman period, flooding would have occurred once a year or more frequently for three of the 36 scenarios and under fifteen of the scenarios, flooding would have occurred with a frequency of between 2 and 5 years.
- For the Roman period, flooding would have occurred once a year or more frequently for six out of the 36 scenarios, doubling the pre-Roman flood frequency; under seventeen of the 36 scenarios, flooding would have occurred with a frequency of between 2 and 5 years.

In reviewing the records of archaeological investigations, nothing has been found to indicate that the estuary of the Walbrook was used intensively for port activity. This could be due to the propensity of the area to flood, the extensive land reclamation that would have been needed to avoid this and the more advantageous conditions a short way downstream either side of the bridge over the Thames.

Figure 6-9 Cannon Street to the Thames (Zone A) – Walbrook flow-full capacities, storm return periods and consequent flood frequency

Greater Walbrook Valley

Checks on "flow full" capacity of Walbrook channel - and consequent flood frequency

Composite AMC 2 & 3 flows

Walbrook location: ***Zone A - Cannon Street to Thames - average river bed slope = 100 m/10,000 m***

Flooding at a frequency greater than that indicated

Flooding at a frequency greater than once a year

1.41 Storm flow at the above frequency, e.g. 1.41 m^3/sec at frequency of once in 2 years

Manning formula — Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) — "Flow full" capacity, Q = A.v

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.12

Slope of river channel - 0.0100 (100m/10,000m)

River bed width - max 10.0 m; min 6.0 m

Depth of river when full - max 1.5 m; min 0.5 m

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m^2)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m^3/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding										
0.04	1.50	8.00	45	2.12	14.25	12.24	1.16	0.01000	2.77	**39.44**
0.04	1.00	8.00	45	1.41	9.00	10.83	0.83	0.01000	2.21	**19.88**
0.04	0.50	8.00	45	0.71	4.25	9.41	0.45	0.01000	1.47	**6.24**
0.04	0.25	8.00	45	0.35	2.06	8.71	0.24	0.01000	0.95	**1.96**
0.04	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01000	2.72	**34.68**
0.04	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01000	2.18	**17.42**
0.04	0.50	7.00	45	0.71	3.75	8.41	0.45	0.01000	1.45	**5.46**
0.04	0.25	7.00	45	0.35	1.81	7.71	0.24	0.01000	0.95	**1.72**
0.04	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01000	2.66	**29.95**
0.04	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01000	2.14	**14.98**
0.04	0.50	6.00	45	0.71	3.25	7.41	0.44	0.01000	1.44	**4.68**
0.04	0.25	6.00	45	0.35	1.56	6.71	0.23	0.01000	0.94	**1.47**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding										
0.07	1.50	8.00	45	2.12	14.25	12.24	1.16	0.01000	1.58	**22.54**
0.07	1.00	8.00	45	1.41	9.00	10.83	0.83	0.01000	1.26	**11.36**
0.07	0.50	8.00	45	0.71	4.25	9.41	0.45	0.01000	0.84	**3.56**
0.07	0.25	8.00	45	0.35	2.06	8.71	0.24	0.01000	0.54	**1.12**
0.07	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01000	1.55	**19.82**
0.07	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01000	1.24	**9.96**
0.07	0.50	7.00	45	0.71	3.75	8.41	0.45	0.01000	0.83	**3.12**
0.07	0.25	7.00	45	0.35	1.81	7.71	0.24	0.01000	0.54	**0.98**
0.07	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01000	1.52	**17.11**
0.07	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01000	1.22	**8.56**
0.07	0.50	6.00	45	0.71	3.25	7.41	0.44	0.01000	0.82	**2.67**
0.07	0.25	6.00	45	0.35	1.56	6.71	0.23	0.01000	0.54	**0.84**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding										
0.12	1.50	8.00	45	2.12	14.25	12.24	1.16	0.01000	0.92	**13.15**
0.12	1.00	8.00	45	1.41	9.00	10.83	0.83	0.01000	0.74	**6.63**
0.12	0.50	8.00	45	0.71	4.25	9.41	0.45	0.01000	0.49	**2.08**
0.12	0.25	8.00	45	0.35	2.06	8.71	0.24	0.01000	0.32	**0.65**
0.12	1.50	7.00	45	2.12	12.75	11.24	1.13	0.01000	0.91	**11.56**
0.12	1.00	7.00	45	1.41	8.00	9.83	0.81	0.01000	0.73	**5.81**
0.12	0.50	7.00	45	0.71	3.75	8.41	0.45	0.01000	0.48	**1.82**
0.12	0.25	7.00	45	0.35	1.81	7.71	0.24	0.01000	0.32	**0.57**
0.12	1.50	6.00	45	2.12	11.25	10.24	1.10	0.01000	0.89	**9.98**
0.12	1.00	6.00	45	1.41	7.00	8.83	0.79	0.01000	0.71	**4.99**
0.12	0.50	6.00	45	0.71	3.25	7.41	0.44	0.01000	0.48	**1.56**
0.12	0.25	6.00	45	0.35	1.56	6.71	0.23	0.01000	0.31	**0.49**

Flooding frequency (i.e. river bank over-topped) - once in ? Years

	Immediate pre-Roman									Roman								
Years	1	2	5	10	20	50	100	200	500	1	2	5	10	20	50	100	200	500
Storm flow	0.67	1.41	3.39	5.69	7.90	10.80	13.54	17.50	21.92	1.26	2.38	5.04	7.89	9.80	11.48	13.70	20.70	28.84

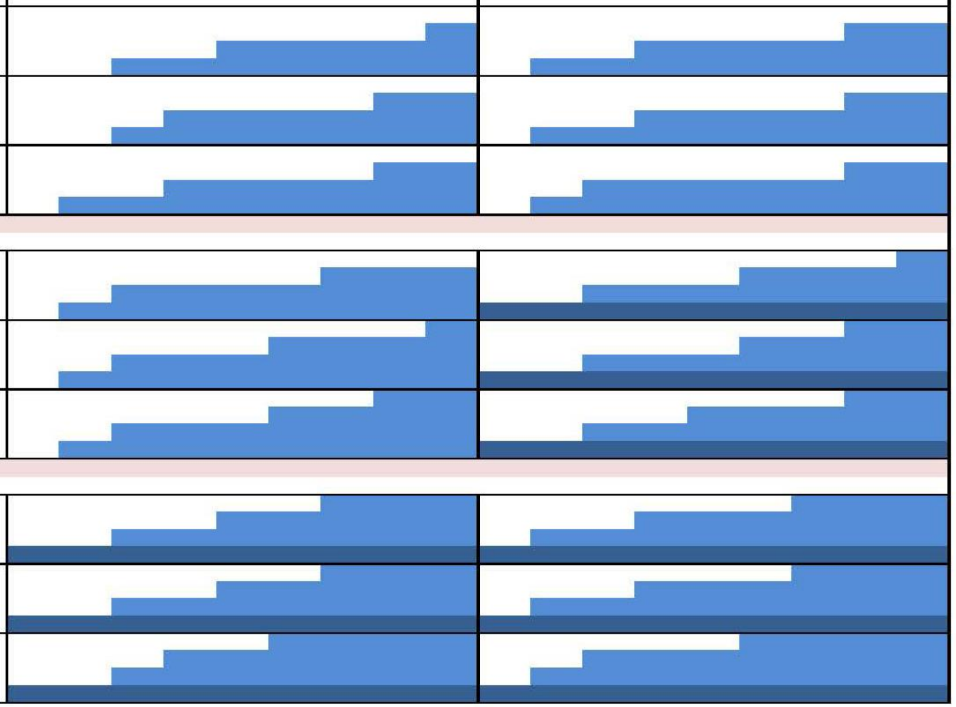
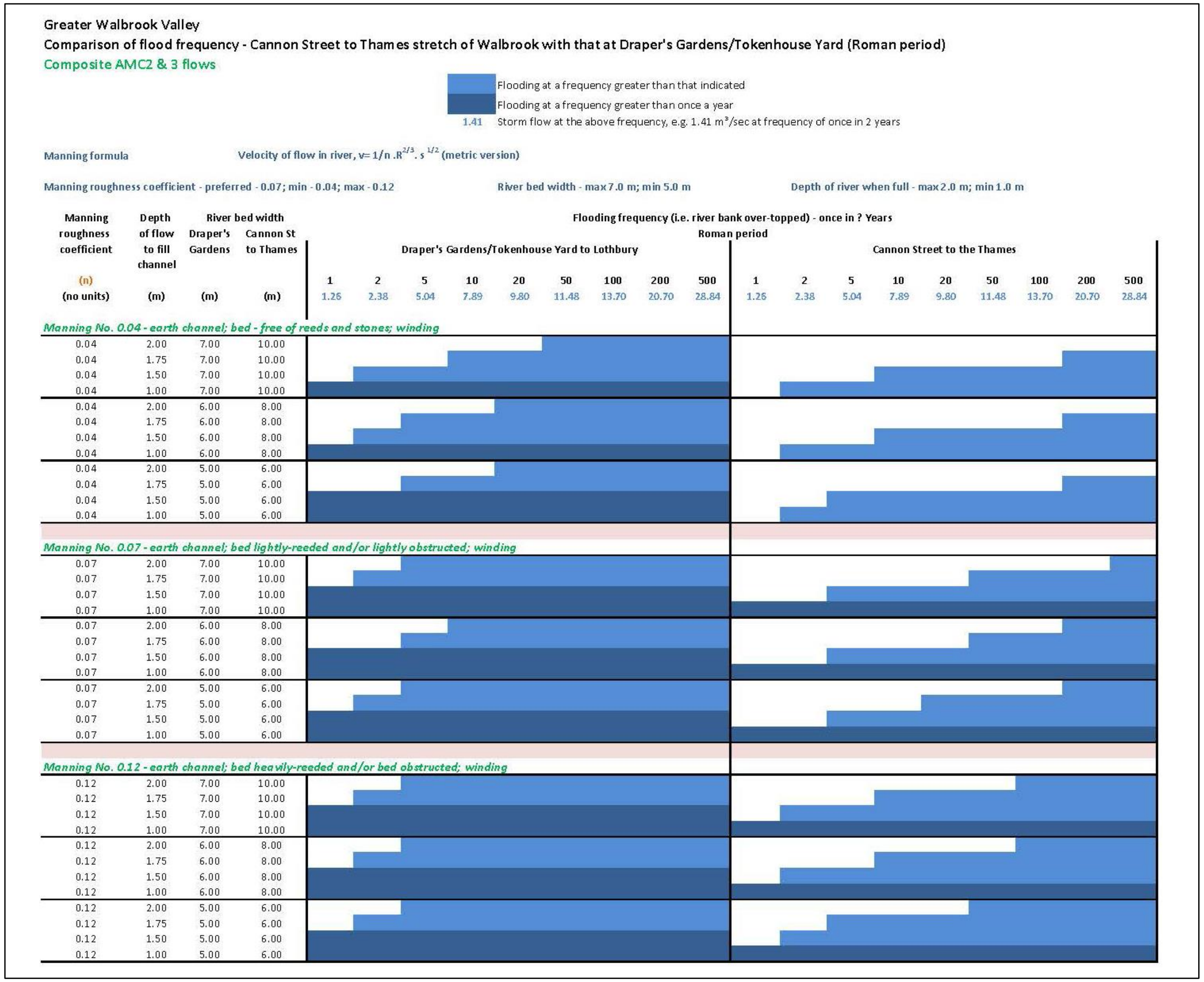


Figure 6-10 Flood frequency along the Cannon Street to the Thames stretch of Walbrook compared with Draper's Gardens to Lothbury (Roman period)



6.5 Influence of Curve Number on Flood Frequency Analysis

The Curve Numbers developed in Section 5.9.1 and Tables 5-10 and 5-11 and used to calculate storm runoff are best estimate values based upon an assessment of probable landscapes both prior to and during the Roman period. It is therefore of interest to understand to what extent the flood-frequency analysis would be affected had the Curve Numbers had values different to those developed. Storm runoff was therefore calculated for two other values of CN for a single situation, Draper's Gardens Tokenhouse Yard in the Roman period under the Antecedent Moisture Condition 3. The two values used were 10% and 15% less than those employed in Section 5.9.2. The storm runoff generated for each of the alternative CN values is reported in Table 6-1, in which the runoff for the preferred CN value, reported in Table 5-12, is also tabulated for comparison purposes. The comparison is also reported as a set of curves in Figure 6-11.

Figure 6-12 shows the effect on flood frequency of reducing the value of CN. It can be seen that had the CN values been 10% less than the preferred value, there would have been a reduction in flood frequency. However, the frequency of occurrence remains such as to little affect the conclusions drawn in Section 6.4. Only were there to have been an over-estimate of the preferred CN value by 15% or more would flood frequency have been reduced such that the conclusions drawn would need to have been revised – although even then flood occurrence would be considered frequent. However, given that the preferred CN values employed in the analysis of flood frequency are composite values, a 15% over-estimate of CN value for any given landscape/vegetation situation is considered unlikely.

Table 6-1 Storm flows generated at Draper's Gardens/Tokenhouse Yard by decreasingCN values to less than the preferred value used in the basic analysis of flood frequency

Storm Flow Comparison - Varying Curve Number

Draper's Gardens/Tokenhouse Yard - Roman Period - AMC3

Storm Return Period (Years)		Storm flows (m^3/s) Preferred CN	Preferred CN - 10%	Preferred CN - 15%
1	1	1.26	0.50	0.26
2	2	2.38	1.16	0.65
5	3	5.04	3.00	2.00
10	4	7.89	5.19	3.71
20	5	11.46	8.10	6.15
50	6	17.97	13.72	11.06
100	7	24.45	19.54	16.33
200	8	33.11	27.55	23.77
500	9	46.98	40.74	36.29

Figure 6-11 Graph of storm flows generated by Varying CN

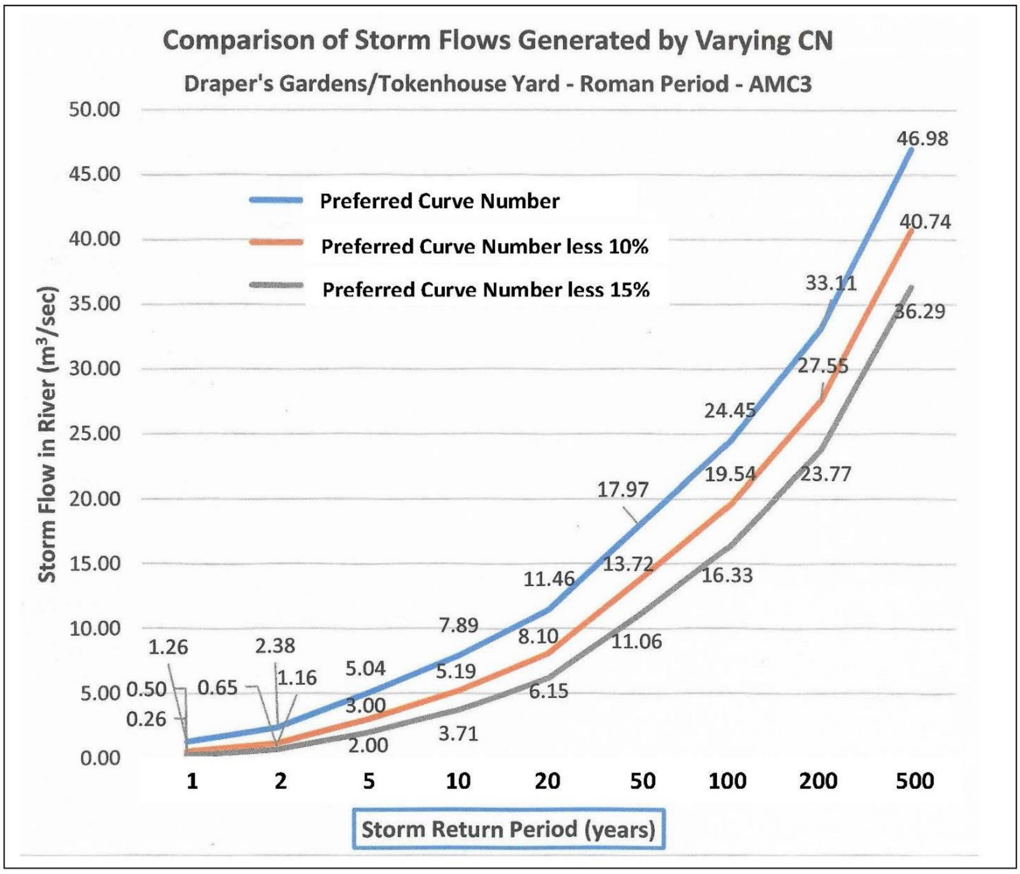


Figure 6-12 Comparison of Flood frequency at Draper's Gardens/Tokenhouse Yard for CN values less than the preferred value

Greater Walbrook Valley
Flood frequency - variation with different values of Curve Number
AMC 3 Roman Period
Walbrook location: Draper's Gardens/Tokenhouse Yard to Lothbury

Flooding at a frequency greater than that indicated
Flooding at a frequency greater than once a year
1.41 Storm flow at the above frequency, e.g. 1.41 m^3/sec at frequency of once in 2 years

Manning formula Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) "Flow full" capacity, $Q = A.v$

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.12 Slope of river channel - 0.00105 (10.5m/10,000m)

River bed width - max 7.0 m; min 5.0 m
Depth of river when full - max 1.5 m; min 0.25 m

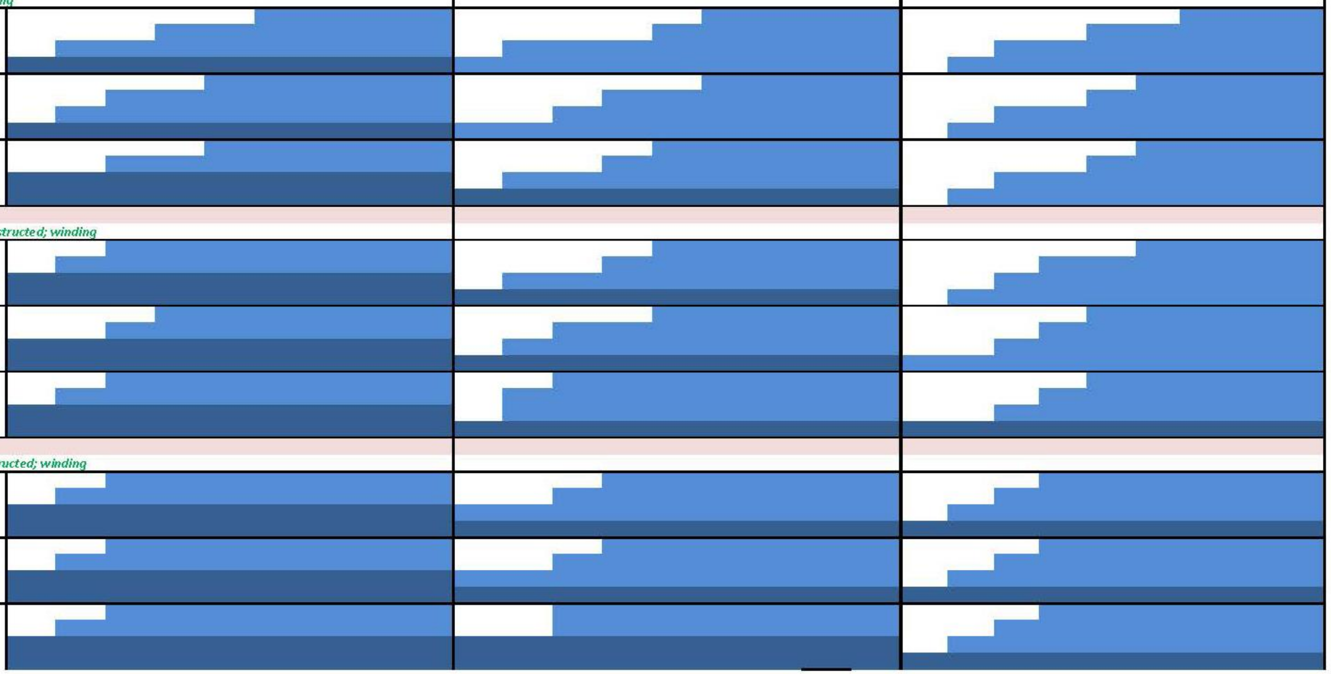
Flooding frequency (i.e. river bank over-topped) - once in ? Years

	Preferred Compsite CN								
Years	1	2	5	10	20	50	100	200	500
Storm flow	1.26	2.38	5.04	7.89	9.80	11.48	13.70	20.70	28.84

	Preferred Compsite CN - values reduced by 10%								
Years	1	2	5	10	20	50	100	200	500
Storm flow	0.50	1.16	3.00	5.19	8.10	13.72	19.54	27.55	40.74

	Preferred Compsite CN - values reduced by 15%								
Years	1	2	5	10	20	50	100	200	500
Storm flow	0.26	0.65	2.00	3.71	6.15	11.06	16.33	23.77	36.29

Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m^3/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding					
1.50	7.00	45	0.00105	0.88	**11.24**
1.00	7.00	45	0.00105	0.71	**5.65**
0.50	7.00	45	0.00105	0.47	**1.77**
0.25	7.00	45	0.00105	0.31	**0.56**
1.50	6.00	45	0.00105	0.86	**9.70**
1.00	6.00	45	0.00105	0.69	**4.85**
0.50	6.00	45	0.00105	0.47	**1.52**
0.25	6.00	45	0.00105	0.31	**0.48**
1.50	5.00	45	0.00105	0.84	**8.19**
1.00	5.00	45	0.00105	0.68	**4.07**
0.50	5.00	45	0.00105	0.46	**1.26**
0.25	5.00	45	0.00105	0.30	**0.40**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding					
1.50	7.00	45	0.00105	0.50	**6.42**
1.00	7.00	45	0.00105	0.40	**3.23**
0.50	7.00	45	0.00105	0.27	**1.01**
0.25	7.00	45	0.00105	0.18	**0.32**
1.50	6.00	45	0.00105	0.49	**5.55**
1.00	6.00	45	0.00105	0.40	**2.77**
0.50	6.00	45	0.00105	0.27	**0.87**
0.25	6.00	45	0.00105	0.17	**0.27**
1.50	5.00	45	0.00105	0.48	**4.68**
1.00	5.00	45	0.00105	0.39	**2.32**
0.50	5.00	45	0.00105	0.26	**0.72**
0.25	5.00	45	0.00105	0.17	**0.23**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding					
1.50	7.00	45	0.00105	0.29	**3.75**
1.00	7.00	45	0.00105	0.24	**1.88**
0.50	7.00	45	0.00105	0.16	**0.59**
0.25	7.00	45	0.00105	0.10	**0.19**
1.50	6.00	45	0.00105	0.29	**3.23**
1.00	6.00	45	0.00105	0.23	**1.62**
0.50	6.00	45	0.00105	0.16	**0.51**
0.25	6.00	45	0.00105	0.10	**0.16**
1.50	5.00	45	0.00105	0.28	**2.73**
1.00	5.00	45	0.00105	0.23	**1.36**
0.50	5.00	45	0.00105	0.15	**0.42**
0.25	5.00	45	0.00105	0.10	**0.13**



6.6 Flood frequency – Eastern Stream Only

Prior to this present research, it was considered that the ancient Walbrook had a single main stream, with its headwaters in the Shoreditch and Hoxton areas. If this had been the case, it would almost certainly have meant that the Walbrook would have been less capable of causing the flooding within urban Roman London that for which evidence was found in 16 archaeological investigations, e.g. LYD88, DGH86 and others (Section 7.2, Table 7-2). An exercise, based on the pre-Roman period and an AMC state of 3, was carried out to determine the flood frequency, at both Blomfield Street and Draper's Gardens/Tokenhouse Yard, posed by the Walbrook had it consisted solely of a single main stream, its eastern stream. The results of this exercise are reported in Figure 6-13. In Figure 6-14, the flood frequencies thus obtained are compared with the flood frequency, at the same locations, obtained when the western and eastern streams contribute storm flows to the combined stream. Table 6-2 has been compiled from Figures 6-13 and 6-14. It compares the number of scenarios out of the total of 36 examined under which flooding is predicted to occur for each of the storm return periods at Blomfield Street and Draper's Gardens/Tokenhouse Yard when considering the eastern Walbrook stream alone and the combined flows from the eastern and western streams.

Figure 6-13 Blomfield Street and Draper's Gardens/Tokenhouse Yard – Walbrook flow-full capacities, storm return periods and consequent flood frequency – eastern stream only

Greater Walbrook Valley

Checks on "flow full" capacity of Walbrook channel - and consequent flood frequency

Eastern stream catchment only

Walbrook location: ***At Blomfield Street - average river bed slope = 10.5 m/10,000 m***

Flooding at a frequency greater than that indicated

Flooding at a frequency greater than once a year

1.19 Storm flow at the above frequency, e.g. 1.19 m^3/sec at frequency of once in 2 years

Manning formula — Velocity of flow in river, $v = 1/n \cdot R^{2/3} \cdot s^{1/2}$ (metric version) — "Flow full" capacity, $Q = A.v$

Manning roughness coefficient - preferred - 0.07; min - 0.04; max - 0.10 — Slope of river channel - 0.00105 (10.5m/10,000m) — River bed width - max 7.0 m; min 5.0 m — Depth of river when full - max 1.5 m; min 0.5 m

Flooding frequency (i.e. river bank over-topped) - once in ? Years — Immediate pre-Roman

	Blomfield Street									Draper's Gardens/Tokenhouse Yard								
Return period (years)	1	2	5	10	20	50	100	200	500	1	2	5	10	20	50	100	200	500
Storm flow (m^3/s)	0.08	0.23	0.68	1.21	1.92	3.31	4.75	6.74	10.01	0.21	0.47	1.13	1.90	2.89	4.76	6.68	9.30	13.57

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m^2)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m^3/s)
Manning No. 0.04 - earth channel; bed - free of reeds and stones; winding										
0.04	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.88	**11.24**
0.04	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.71	**5.65**
0.04	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.47	**1.77**
0.04	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.31	**0.56**
0.04	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.86	**9.70**
0.04	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.69	**4.85**
0.04	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.47	**1.52**
0.04	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.31	**0.48**
0.04	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.84	**8.19**
0.04	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.68	**4.07**
0.04	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.46	**1.26**
0.04	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.30	**0.40**
Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding										
0.07	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.50	**6.42**
0.07	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.40	**3.23**
0.07	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.27	**1.01**
0.07	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.18	**0.32**
0.07	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.49	**5.55**
0.07	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.40	**2.77**
0.07	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.27	**0.87**
0.07	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.17	**0.27**
0.07	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.48	**4.68**
0.07	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.39	**2.32**
0.07	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.26	**0.72**
0.07	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.17	**0.23**
Manning No. 0.12 - earth channel; bed heavily-reeded and/or bed obstructed; winding										
0.12	1.50	7.00	45	2.12	12.75	11.24	1.13	0.00105	0.29	**3.75**
0.12	1.00	7.00	45	1.41	8.00	9.83	0.81	0.00105	0.24	**1.88**
0.12	0.50	7.00	45	0.71	3.75	8.41	0.45	0.00105	0.16	**0.59**
0.12	0.25	7.00	45	0.35	1.81	7.71	0.24	0.00105	0.10	**0.19**
0.12	1.50	6.00	45	2.12	11.25	10.24	1.10	0.00105	0.29	**3.23**
0.12	1.00	6.00	45	1.41	7.00	8.83	0.79	0.00105	0.23	**1.62**
0.12	0.50	6.00	45	0.71	3.25	7.41	0.44	0.00105	0.16	**0.51**
0.12	0.25	6.00	45	0.35	1.56	6.71	0.23	0.00105	0.10	**0.16**
0.12	1.50	5.00	45	2.12	9.75	9.24	1.05	0.00105	0.28	**2.73**
0.12	1.00	5.00	45	1.41	6.00	7.83	0.77	0.00105	0.23	**1.36**
0.12	0.50	5.00	45	0.71	2.75	6.41	0.43	0.00105	0.15	**0.42**
0.12	0.25	5.00	45	0.35	1.31	5.71	0.23	0.00105	0.10	**0.13**

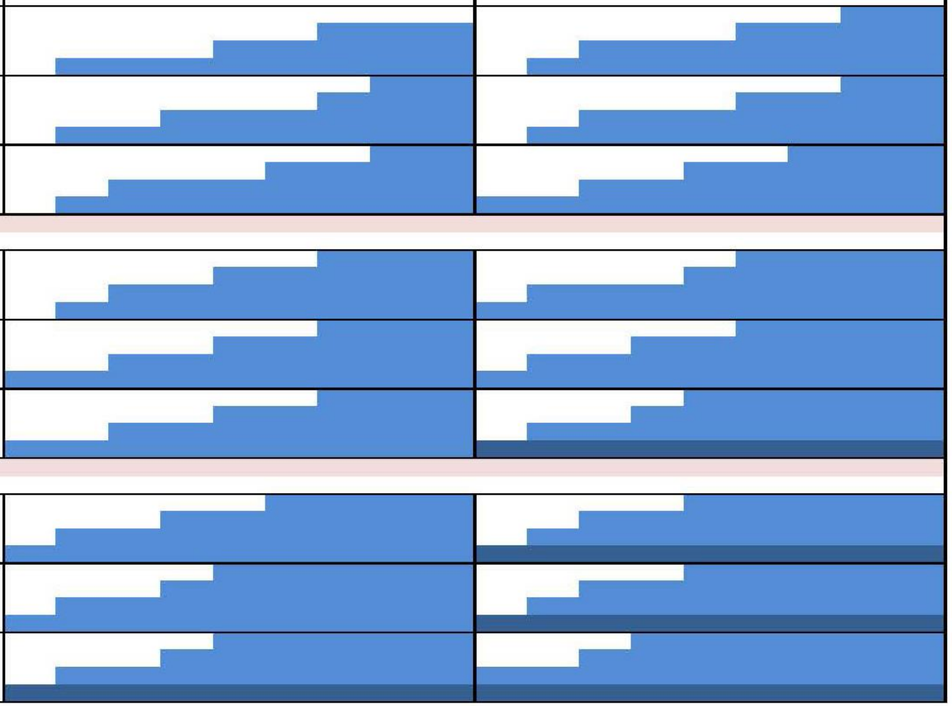


Figure 6-14 Blomfield Street and Draper's Gardens/Tokenhouse Yard - Flood frequency for the combined western & eastern streams compared with those of the eastern stream only

The following conclusions have been drawn:

- As expected, the frequency of occurrence of floods at both locations in the pre-Roman period is far less for a Walbrook consisting of flow from just the eastern stream compared with flows from both streams.
- For any specific return period through to between 100 and 200 years, the frequency of flooding for the eastern stream alone is less than that of the combined streams; whereas at Blomfield Street, flooding occurs more than once a year for 10 scenarios for the case of the combined streams, it only occurs in one scenario for the eastern stream alone; at Draper's Gardens, the corresponding values are 12 and 4.

Although the incidence of flooding would have been significantly less for a Walbrook with just a single source stream, flooding would have occurred and it would have been necessary to carry out land raising activity in the upper and middle urban Roman Walbrook. However, less land raising would have been necessary and it is probable that there would not have been the need to progressively raise the land in stages as has been shown to be the case in a number of excavations.

Table 6-2 Comparison of flood occurrences for the eastern stream alone and the western and the combined eastern streams at Blomfield Street and Draper's Gardens/Tokenhouse Yard

Location and contributing streams	**Frequequency of flooding (years)**									
	>1	**1 to 2**	**2 to 5**	**5 to 10**	**10 to 20**	**20 to 50**	**50 to 100**	**100 to 200**	**200 to 500**	**500**
Blomfield Street										
W & E streams	10	17	23	30	33	***36***	***36***	***36***	***36***	***36***
E stream alone	1	5	12	16	20	26	28	33	***36***	***36***
Draper's Gardens/ Tokenhouse Yard										
W & E streams	12	17	26	31	34	***36***	***36***	***36***	***36***	***36***
E stream alone	4	7	15	21	24	29	33	34	***36***	***36***

6.7 Sediment Transport Potential of the Walbrook

The stratigraphic component of this research focussed on three key horizons, Top Natural, Top Pre-Roman and Top Roman. The material constituting the layer between Top Natural and Top Pre-Roman was, in the main, composed of clay, silt and sand, generally as various mixes of all three in varying proportions but occasionally as single materials. At various locations, the resulting loam was mixed with pebbles and gravel and some organic material of natural origin. It is unlikely that these materials were laid down by erosion and wind action, which would be more typical of dry or desert conditions. It is most likely that these deposited materials were carried there by the Walbrook over a very long period of time as it meandered back and forth across its floodplain.

The type of material that can be transported by a river is dependent upon the range of velocities of flow of the river. The relationship between velocity of flow and the size and nature of particulate material transported by a river was the subject of research by Filip Hjulström in 1935, whose depiction of this relationship is known as the Hjulström Curve. His work was refined by Sundborg in 1956, who produced the Hjulström-Sundborg Diagram which shows not only the velocity/material transported relationship but also the method of transport, Figure 6-15.

The sediment transport potential of the Walbrook in the period from immediate pre-Roman to the departure of the Romans in the early 5th C is dependent upon whether or not it was fed by storm run-off. Under dry weather, base flow conditions of say 80 litres/sec, a stream 5.5m wide would flow at a velocity of 0.10 to 0.15 m/sec dependent upon the depth of flow being between 15 and 10 cm respectively. This is the range of conditions and velocities typically found in the surrogate rivers included in this research, Section 5.8.2.

Figures 6-2 to 6-9 show a wide variation in velocities in the Walbrook channels dependent upon the slope of the riverbed, the degree of impedance to flow (Manning coefficient, n) and the adopted width and depth of the stream.

Table 6-3 lists the maximum and minimum velocities in the Walbrook at times of storm run-off over the four stretches of river analysed including the slope to the riverbed and frequency of return of the storm to which they correspond. These values relate to the average condition analysed, i.e. a Manning coefficient of 0.07, which corresponds to a winding earth channel for which the bed is lightly-reeded or obstructed.

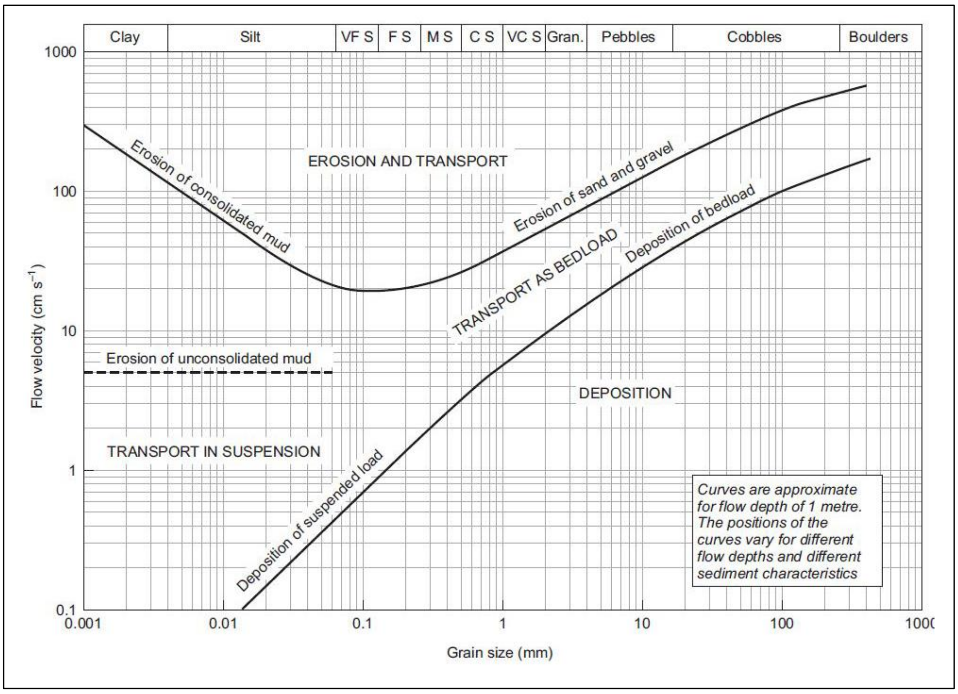


Figure 6-15 The Hjulström-Sundborg Diagram showing the relationship between the size and nature of particulate matter transported according to velocity of flow and the type of transport

Table 6-3 Minimum and maximum velocities in the Walbrook and frequency of storm return for four stretches of the urban Roman Walbrook (Manning coefficient, n = 0.07)

Stretch of the urban Roman Walbrook *(in order of increasing slope to the riverbed)*	**Bed slope (m/10,000m)**	**Velocity at times of storm rainfall (m/sec)**			**Pre-Roman Storm return period (years)**
		Max	**Av**	**Min**	
Blomfield Street to Lothbury	10.5	0.50	0.40	0.17	5-10 2-5 >1
Cannon Street to Thames	100	1.58	0.83	0.54	100-200 2-5 1
Bloomberg Development	125	2.02	1.37	0.90	200-500 20-50 1
Lothbury to Bucklersbury	164	2.32	1.97	1.53	200-500 100-200 1

Figures 6-2 to 6-9 and Table 6-3 demonstrate that it requires storms with a frequency of return greater than 30 years to generate velocities of flow in most stretches of the Walbrook in excess of 1 m/sec. The exception to this is the steepest stretch between Lothbury and Bucklersbury where velocities of 1.5 m/sec would not have been unusual. Velocities of flow through the Blomfield Street to Lothbury stretch would have been in the range 0.17 to 0.4 m/sec for storms of frequency of return up to 5 years.

Figure 6-16 shows the range of base flow velocities and typical storm velocities of 0.4 and 1.0 m/second against the background of the Hjulström-Sundborg diagram. The following conclusions can be drawn from the diagram:

- In periods of dry weather, i.e. with velocities of flow typically between 10 and 15 cm/second, the river was capable of transporting particulate matter of up to 3.5 mm. However, these velocities would have been insufficient to erode either consolidated mud or a sand and gravel bed. In turn, this means that, typically, under dry weather conditions, the Walbrook would not have transported particulate material and would have flowed clear, although unconsolidated clays and silts could be lifted from the riverbed and transported, possibly where new material has been carried into the river or the riverbed physically disturbed.
- It would have taken little run-off to raise the rate of flow to 20 cm/sec at which point muds could have been eroded, unconsolidated clays and silts raised and transported and very fine sand of 0.1 mm diameter could have been lifted and transported. At this velocity, sand of larger grain size would not have been eroded from the riverbed.
- At a velocity of 40 cm/sec, clay, silt and sand up to a coarse sand grain size of 1 mm diameter could have been lifted and transported. At 50 cm/sec, the maximum grains size eroded and transported would have increased to 1.8 mm, considered very coarse sand, rising to 5 mm at 50 cm/sec and at 100 cm /sec, to 7mm, i.e. very small pebbles or pea gravel.
- Velocities would have been higher for the more infrequent storms, typically with a frequency greater than 20 to 30 years; 150 cm/sec would have been capable of eroding and transporting gravel of 10 mm, rising to small cobbles at 22 mm at 200 cm/sec and 45 mm at 250 cm/second.

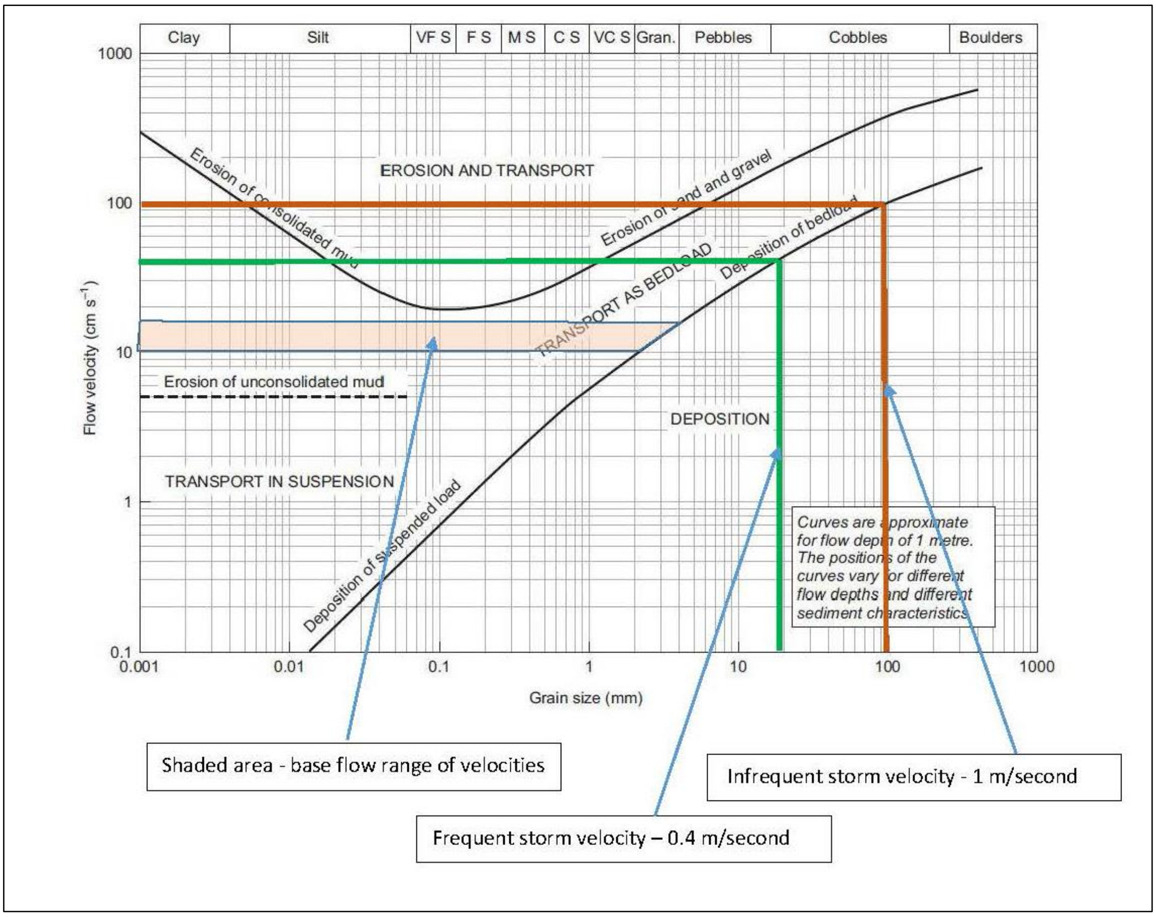


Figure 6-16 Typical velocities in the pre-Roman Walbrook on a background of the Hjulström-Sundborg diagram

The consequences of the foregoing on sediment transport through the four stretches of the urban Roman Walbrook would have been as follows:

Blomfield Street to Lothbury

Under dry weather conditions, disturbed clay or soil, would have settled in this stretch and would not have been carried through to the Lothbury to Bucklersbury stretch. This would also tend to have been the case for coarser sand, gravel and small pebbles carried into the stretch from upstream under the most extreme of storm conditions. Under storm conditions, due to the flat slope and low velocities, the largest particle size likely to be carried through past Lothbury would be about 2 mm, considered very coarse sand.

Lothbury to Bucklersbury

Due to the steeper gradient, velocities of flow would have been routinely high even in dry weather through this stretch of the Walbrook. Any material carried into it from the upstream stretch would have been transported through to the Bloomberg Development. The bed will almost certainly have been made up of cobbles and gravel, as velocities normally in excess of 1.0 m/sec, even in dry weather, would have eroded and transported away all clay, silt and most granular materials. In times of storm, velocities could have risen frequently to 1.5 m/sec and in extreme storms to between 2.0 and 2.3 m/sec. Although the river would then have been capable of lifting and transporting small to large pebbles, 10 to 20 mm, no material of this size could have been carried into the stretch from upstream and the bed would have been made up of pebbles and cobbles larger than this.

Bloomberg Development

The slope to the riverbed eases through the Bloomberg Development and velocities are correspondingly lower than the stretch feeding it. However, the river at this point is capable of maintaining in suspension and transporting all clay, silt and sand entering the upstream stretch from Lothury arriving from Bucklersbury. As velocities in this stretch would have exceeded 0.9 m/sec at least once a year, the bed of the river would have consisted of gravel in excess of 5 to 7 mm and possibly larger gravel and small cobbles carried into it from the upstream stretch at times of more extreme storms.

Cannon Street to the Thames

Sediment transport through this stretch would have been rendered more complex by the diurnal tidal movement within the estuarine stretch, that influence having a progressively greater influence as the confluence of the Walbrook with the Thames was approached. The slope to the riverbed eased further, as do the velocities of flow, although these would have increased and decreased with the ebb and flow of water in the creek. Velocities would still have been high enough to carry clay, silt and sand through this stretch and into the Thames, although larger particles of sand and granular material would have routinely settled out, only to be scoured to the main river at times of storm.

However, the draft report on the geo-archaeology of the BZY10 investigation (Ruddy, 2015) notes that a raised gravel bar or low eyot has been found a short distance offshore from what would have been the line of the Roman bank of the Thames, the bar being parallel to the shore. Although this bar may have been formed in the late glacial Thames braid-plain, it may have become accentuated in a later period. The Walbrook would have been capable of transporting gravel along its bed to this point under extreme storm conditions and this may have contributed to its growth. It has a top level varying between -1.20 and -2.50m OD and would have been partially exposed at late Roman low tides, possibly impeding tidal ingress to the Walbrook.

To summarise, apart from the extensive Blomfield Street to Lothbury stretch, the urban Roman Walbrook would have been capable of maintaining in suspension and transporting clay and silty material under all conditions of flow and smaller granular material for most of the time. However, clay, silt and sand, up to 2mm, would only have been eroded, suspended and transported from upstream of Lothbury – and hence through to the Thames – under storm conditions. Stretches other than from Blomfield Street to Lothbury, would have generated velocities that would have transported granular material, gravel and small cobbles, particularly at times of extreme storm, but would probably have long been swept clear of this type of material by the immediate pre-Roman period.

Chapter 7

Flood Mitigation and River Management

7.1 Research Questions

In Chapter 6, the potential of the Walbrook to flood stretches of the urban Roman Walbrook Valley (URWV) has been assessed based upon estimated rates of storm flow and the capacity of the river to carry flow before its banks would have been over-topped. This flood-risk analysis was made for a range of physical conditions of the river. This chapter is concerned with archaeological evidence of flooding and infrastructure that may have been introduced by the Romans to mitigate the effects of flooding and manage the river. The archaeological record for the URWV provides evidence that the inhabitants of the Roman town, possibly encouraged and assisted by the civil administration, used and developed the area, including its floodplain. This chapter addresses research questions arising out of flooding of the valley by the Walbrook and related river management activity on the part of the town's administration and population, viz.

Q 7.1 What archaeological evidence is there for flooding and of infrastructure to mitigate the effects of flooding such as land-raising, revetments to protect riverbanks and constructed drainage as evidenced by the findings of archaeological investigations? (Section 7.2)

Q 7.2 What measures were taken to protect land from flooding by the Walbrook and to actively manage the river and were they effective? (Section 7.3)

Q 7.3 Could the town wall have been used to limit the Walbrook's rate of flow into and through the urban area and, if so, how would this have impacted upon development within the urban floodplain? (Section 7.4)

Q 7.4 Given that the middle URWV was at risk from frequent flooding why, counter-intuitively, was it used so intensively by industry and craft workshops? (Section 7.5)

7.2 Data – Flood frequency Mitigation and River Management

This section responds to Research Question Q 7.1:

> *What archaeological evidence is there for flooding and of infrastructure to mitigate the effects of flooding such as land-raising, revetments to protect riverbanks and constructed drainage as evidenced by the findings of archaeological investigations?*

The content of this section draws upon the archaeological records of 49 key sites within the URWV, Figure 7-1. These sites are listed in Table 7-1 which groups them according to their location within the URWV (URWV) – Zone A, estuarine lower URWV; Zone B, non-estuarine lower URWV, Zone C, middle south URWV; Zone D, middle north URWV; Zone E, upper URWV. Data within this table has been abstracted from the table that forms Appendix 2E, URWV – Archaeological Site Investigations – Listing of Significant Finds**.** Table 7-1 contains notes for each of the sites under the following headings:

- MoLAS or GLHER site investigation reference; address
- Walbrook – river and tributaries
    - principal channels of the River Walbrook
    - Walbrook tributaries
    - revetments
    - constructed drainage and evidence of flooding
- Land cover
    - reclamation & restructuring
    - depth of fill over the Roman period

Table 7-1 may be difficult to read in hard copy and can also be consulted in the Appendix 7B file on the DVD. Table 7-2 shows the incidence of flooding, reclamation and river management activity found at archaeological sites in the URWV, again allocated to each of the Zones A to E. The data populating Table 7-2 is drawn from Table 7-1 and summarises the incidence of seven categories of findings at the 49 sites analysed, viz. Walbrook main channels; tributaries of the Walbrook; palaeo-channels of the main river and its tributaries flooding; reclamation; revetments; constructed drainage. The figures in red font indicate the incidence of a particular item in a zone as a percentage of the total number of sites.

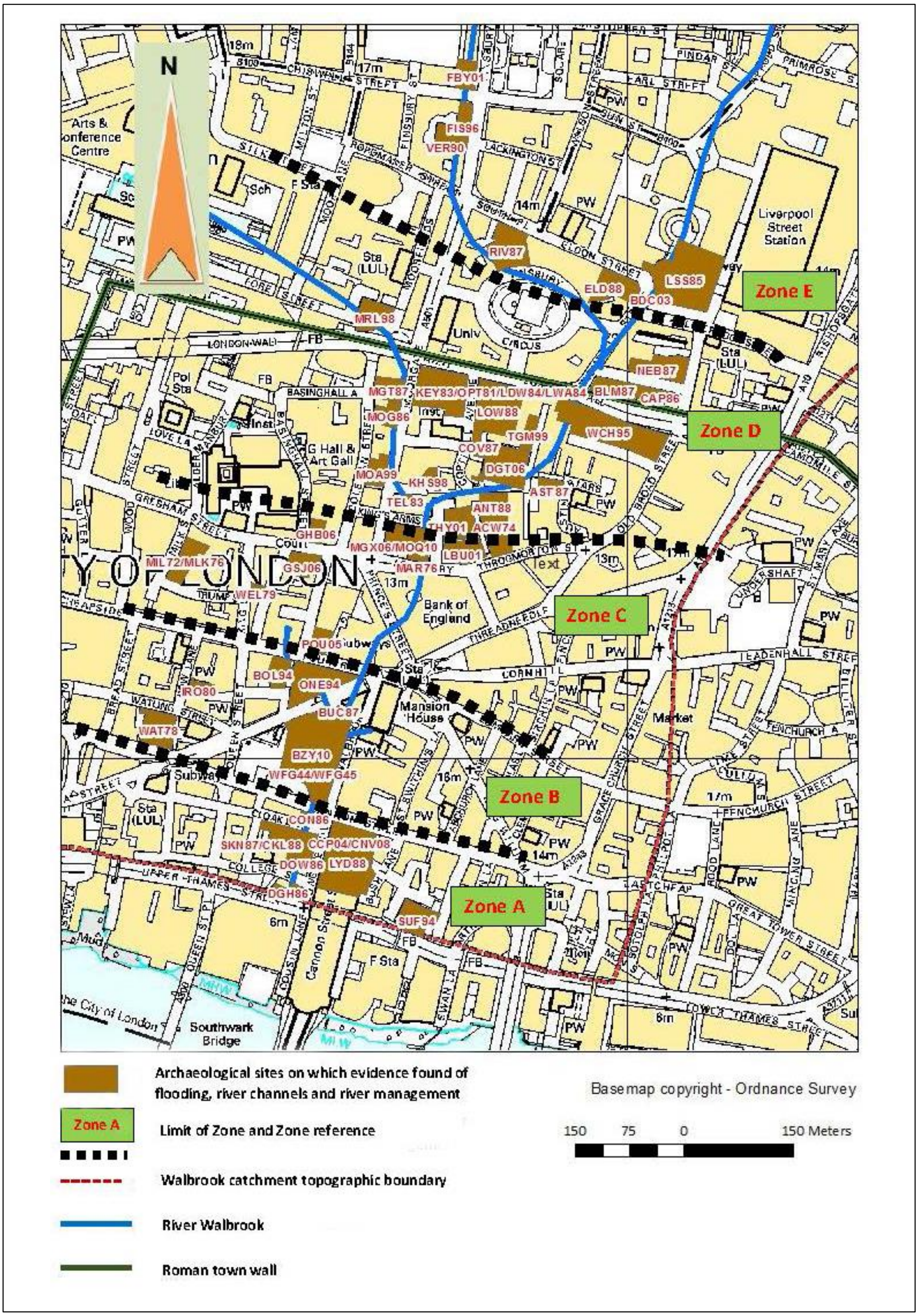


Figure 7-1 Archaeological sites on which evidence has been found of flooding, river channels and river management activity

Urban Roman Walbrook Valley - Flooding, River Management & Land Reclamation & Re-structuring

Table 7-1 Archaeological sites in the Walbrook Valley with incidence of flooding and river management Page 1 of 4

Lower urban Roman Walbrook valley - estuarial	Zone A
Lower urban Roman Walbrook valley - non-estuarial	Zone B
Middle urban Roman Walbrook valley - South	Zone C
Middle urban Roman Walbrook valley - North	Zone D
Upper urban Roman Walbrook valley	Zone E

Zone	Site Investigation Reference	Address	Walbrook - river & tributaries: Walbrook river	Walbrook tributaries	Revetments	Drainage	Flooding	Land cover reclamation & re-structuring	Depth of fill in Roman Period (m)
Zone A	DGH86	Dowgate Hill House, Dowgate Hill, London, EC4	E bank of Walbrook at estuary		early 4th C timber revetment to re-align E bank Walbrook from NW/SE to N/S	early 55 to 80 CE timber drain, NE to SW towards Walbrook; bank & ditches extended northwards to end 3rd C	widespread flooding end 3rd/early 4th C	early 55 to 80 CE to end 3rd C - dumping behind a built W-E clay bank 6 to 10 m wide crossing whole site by Thames; bank eroded away, more reclamation early 4th C to counter widespead flooding, part of fill from in-situ building debris, built up to 1.5m to 1.7m OD & then to 2.80 to 3.35m OD followed by building activity	1.78 to 2.40
Zone A	SUF94	Suffolk House, 5 Laurence Pountney Hill & 154-156 Upper Thames St, EC4 (Source: BRIGHAM, TREVOR & WOODGER, AIDAN. 2001. *Roman and medieval townhouses on the London water front. Excavations at Governor's House, City of London.* MoLAS Monograph 9. MoLAS. London))				N-S timber box drain in SE of site		prehistoric marsh covered S side of site; Thames riverside area terraced for development; revetments constructed to form quays & enable land reclamation for building substantial masonry structures; backfilling behind early 2nd C revetment organic; dumping between 85CE & southernmost revetment initially organic, then rubble with brickearth wharf surface; land over box drain raised to 1.55 m OD; area covered with "dark earth" late 3rd/early 4th C when on-site buildings in state of collapse	
Zone A	CCP04/CNV08	Cannon Place, London, EC4	site at confluence of paleo-Walbrook & Thames on raised plateau to E of paleo-Walbrook	paleochannel drained area from NW to SE across site away from Walbrook towards Thames	Walbrook revetments found in LYD88 not found on this site which is to N of LYD88	timber drains in N of site at "Governor's Palace" drained NNE to SSW			0.29 to 0.85
Zone A	LYD88	Cannon Street Station N, Upper Thames Street (Dowgate Hill), EC4	E bank of paleo-Walbrook at estuary (broad, pre-Roman)		E-W aligned double box revetment along Thames & E bank Walbrook; 2nd C second revetment parallel to & 25m from first (180-190 CE) - double-box construction	substantial drain parallel to Walbrook drained to Thames culverts & drains in retaining walls carried surface water away;		area behind revetment raised to 3.00m OD; an E-W masonry & tile retaining wall behind which land raised to 5.00m OD (2nd half 1st C); late 2nd/early 3rd C, 2nd revetment 25m to W of first (building rubble infill)	1.93 to 2.13
Zone A	SKN87/CKL88	Skinner's Hall Kitchen, 8-9 Cloak Lane, London, EC4	W bank of combined stream (although site is claimed to span river)		stone & timber revetments (only slight evidence)	early timber drains later covered by sloping yard		marshy land, reclaimed using river bank revetments & stone rubble dumps	3.91
Zone A	DOW86	3, 5-7 Dowgate Hill, EC4	stream bank not mentioned - but E bank of Walbrook should be nearby western edge of site						
Zone A	CON86	76 Cannon Street, London, EC4	E bank Walbrook which ran with a slight bias to west of a N-S line		vertical oak piles & horizontal oak planking	NNE to SSW cut towards Walbrook			2.74
Zone B	WFG44 & WGF45	Bucklersbury House (Temple of Mithras), London, EC4	main Walbrook stream passed N-S on E side of site direct towards the Thames; river deposits beneath wall confirmed by headings tunnelled from site; late 2nd/early 3rd C Walbrook channel silted up to 1.7m OD	several tributaries draining from the west	2 sets timber revetments, 2nd 5m back from 1st with timber quayside decking - approx 1.2m level difference between 1st & 2nd quay levels - indicates tidal transgression? 2nd C revetments better & larger with associated buildings & platforms			3 stages dumping from early Roman occupation - clayey silty sand (loam) brickearth & silty clay - ground levels raised to 1.80m, then 3.35m and finally 5.50m OD	1.13 to 2.05
Zone B	BZY10	Blomberg Place, London, EC4	combined stream	enters main stream from west					
Zone B	WAT78	Watling Court, 39-53 Cannon St & 11-14 Bow Lane, London, EC2						pre- 70-80 CE - brickearth & silt dumping to prepare for building	
Zone B	BUC87	DLR Shaft, Bucklersbury, (near Queen Victoria St), EC4	immediately W of commbined stream		revetted open area				

Table 7-1 Archaeological sites in the Walbrook Valley with incidence of flooding and river management (page 2 of 4)

Urban Roman Walbrook Valley - Flooding, River Management & Land Reclamation & Re-structuring

Lower urban Roman Walbrook valley - estuarial	Zone A
Lower urban Roman Walbrook valley - non-estuarial	Zone B
Middle urban Roman Walbrook valley - South	Zone C
Middle urban Roman Walbrook valley - North	Zone D
Upper urban Roman Walbrook valley	Zone E

Zone	Site Investigation Reference	Address	Walbrook - river & tributaries: Walbrook river	Walbrook tributaries	Revetments	Drainage	Flooding	Land cover reclamation & re-structuring	Depth of fill in Roman Period (m)
Zone B continued	ONE94	1 Poultry, London, EC2	Walbrook stream bridged at the site; speculation that the stream was tidal up to bridge & that a market lined its banks downstream of 1 Poultry	tributary 1 passed through SW corner of site to meet Walbrook on Bucklersbury House site, just upstream of Mithras Temple		timber-lined drains to road network (assisted dating) - early box drains replaced by timber plank-lined ditches held by driven vertical timbers; successive rebuilding of drain systems; finally brick-arched culvert built to serve large house on main E-W road (mid-4th C); all drains found surface drains leading to Walbrook		area used as early refuse dump for main town to E of Walbrook; ground levels in the area rose approx 0.6m between 60/61 & 125/130 CE mainly due to building upon demolished remains of previous buildings. Terrace 4 at 1 Poultry raised from 4.80m OD to 6.90m OD (on east bank ground level raised from 6.10 to 7.80m OD at Mansion House (MHO92)); "dark earth" cover "to demolished buildings (250 to 300 CE)	
	BOL94	Bolsa House, 76-80 Cheapside, London, EC2				natural drain SSE to Walbrook			1.35 to 1.55
	IRO80	24-25 Ironmonger Lane, London, EC2						following destruction of 7th building by Hadrianic fire, area covered with dark earth; chalk & ragstone wall lined N side of street, dark earth area to N of it	
Zone C	POU05	36 Poultry, London, EC2		possible paleochannel of a tributary along E side of site		ditches constructed either side NNE-SSW road		mid-1st C dumping gravel & other material to level area	0.70 to 0.80
	WEL79	Well Court, 44-48 Bow Lane, London, EC2				timber drain serving first building: drain along W side of street, late 1st C		extensive levelling slab of beaten brickearth laid over most of site - foundation for street & buildings (70-100 CE); Hadrianic fire debris covered whole site; 1st terrace built on valley slope well to E of N-S street on which 2 stone buildings constructed, prior to Hadrianic fire, 2nd terrace formed for another stone building, terraces required massive dumping activity; dark earth covered site from c250 CE	
	MIL72/MLK76	7-1- Milk Street, London, EC2; 1-6 Milk Street, London, EC				drainage ditch along W side of street between it & buildings - 6 successive ditches, last plank lined		100-120CE whole area covered with brickearth slab except for building in NE corner of site; by 120 CE whole area covered by brickearth slab; area covered by dark earth from 3rd C	
	GSJ06	54-56 Gresham Street, London EC2	*possible Walbrook paleochannel in centre site (evidence inconclusive)*	possibly a Walbrook tributary to NE of this site draining SE towards river				ground levelling followed late 1st C gravel quarrying	
	LBU01	41 Lothbury, London, EC2	gen. vicinity of W bank combined						1.80
	MAR76	St Margaret Lothbury Church, Lothbury, London, EC2	combined stream N to S thru' site						1.00
	GHB06	6-12 Basinghall St & 93-95 Gresham St, London, EC2	W-E paleo-watercourse (Walbrook tributary?)			natural stream re-cut & timber-lined as drain			
	MGX06/MOQ10	8-10 Moorgate; 3-4 King's Arms Yard; 8-10 Telegraph St & 16-17 Tokenhouse Yard, EC2	Walbrook stream oriented just west of south running north to south along E edge of site	tributary running just S of east from NW corner of site to Walbrook at E side of site		NE of site - 3 timber drains, 2 being box drains		dumping to raise ground level	
Zone D	ACW74	1-8 Angel Court, 30-35 Throgmorton Avenue, London, EC2		small tributary (3.2 wide x 0.8m)	timber (late 1st/early 2nd C)			3 stages - 125 to 180 CE then further raising to late 4th C	1.37
	ANT88	9-10 Angel Court, London, EC2	combined		timber piles c 190 CE	cut ditches	yes	dumping - 2ndC	3.27 to 4.67
	THY01	6-8 Tokenhouse Yard, London, EC2		1 or more tributaries crossing SE corner site NE to SW draining towards Walbrook immediately to west		roundwood stake revetted ditch timber box drains (late 1st/ealy 2ndC),; drainage ditches by paths oriented NW towards the Walbrook	Walbrook floodplain; widespread flooding across site - box drains constantly laid & re-laid	early ground raising & many successive raisings to avoid flooding	3.13 to 3.51
	AST87	22-25 Austin Friars, London, EC2	combined		timber	large scale drainage timber lined, metal joints	yes	yes	0.78 to 1.58

Urban Roman Walbrook Valley - Flooding, River Management & Land Reclamation & Re-structuring

Lower urban Roman Walbrook valley - estuarial	Zone A
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Middle urban Roman Walbrook valley - South	Zone C
Middle urban Roman Walbrook valley - North	Zone D
Upper urban Roman Walbrook valley	Zone E

Table 7-1 Archaeological sites in the Walbrook Valley with incidence of flooding and river management (page 3 of 4)

Zone	Site Investigation Reference	Address	Walbrook - river & tributaries					Land cover reclamation & re-structuring	Depth of fill in Roman Period (m)
			Walbrook river	Walbrook tributaries	Revetments	Drainage	Flooding		
Zone D continued	TEL83	8 Telegraph St, EC2			timber pile & plank revetment used to retain dumped material to raise ground level				
	DGT06	Drapers' Gardens, London EC2	Walbrook stream originally meandered across site - later was channelled either side of a N-S road; flora/fauna evidence of pre-Roman, shallow muddy ponds over area		multiple phases of stone/timber revetments to main channel through the site (late 1st/early 2nd C)	ditch & revetted channel across SW of site; later blocked off; NE-SW ditch; timber lined box drains serving buildings	area ponded & flooded but not part of marsh north of wall	flora/fauna evidence Walbrook valley was grassland & water-meadow pre-Roman occupation; organised importation mass material for 2m of dumping to raise land level after which N-S road constructed	
	MRG95/KHS98	Northgate House, 20-26 Moorgate & Kent House, Telegraph St, EC2		significant N-S tributary down E side of site - re-cut & cleaned later in Roman; gentle sweep round to SW; extenive 3rd C use of tributary for dumping waste		timber-lined drainage ditches from W to E down to tributary		early 2nd C brickearth dumping over W half of site, raised to 9m OD; 2nd phase of dumping brickearth in 2nd half 2nd C, land raised to 9.2 to 9.4m OD; London Clay extraction pits close by to feed the local pottery industry	
	MOA99	19-31 Moorgate, London, EC2		tributary known to run through or adjacent to site				late 1st - mid 2nd C dumping	
	CXA06	2 Copthall Avenue, London, EC2		E-W paleochannel flowing towards Walbrook to immediate E of site - infilled pre-Roman occupation	light timber revetments to Roman E-W drainage channel - associated 2nd phase of revetting		sequences of water-logging & flooding	phases of consolidation and reclamation matching flooding sequences - early 1st through to 3rd C	0.60 to 1.56
	COV87	10-12 Copthall Avenue, London, EC2				naturaldrainage channels & drain linear cut agricultural drains	flood deposits lste 3rd C	silt, sand & domestic refuse dumped into channels & on land late 1st/early 2nd C & 4th C	0.68 to 0.78
	WCH95	72 & 74-78 London Wall, London, EC2	W end of site formed E bank of combined N-S oriented Walbrook		2nd phase reclamation E bank timber piled into clay	drainage attempts failed - site water-logged drainage ditch - silted up post-Roman	silting over of area by flood events	brickearth, painted plaster & demolition dumping	1.48 to 1.91
	TGM99	8-10 Throgmorton Avenue, London, EC2					over-bank deposits indicate flooding		1.35 to 1.60
	LOW88	52-63 London Wall, 20-56 Copthall Avenue, London, EC2 (including 60 London Wall)		meandering streams water meadows draining to SE towards off-site Walbrook		re-aligned ditches (1st C); timber box drains (oak & sweet chestnut)		early reclamation work	1.22
	KEY83 (+ OPT81, LWA84 & LDW84)	15-35 Copthall Ave, 45-50 London Wall, 2-3 Cross Keys Court, EC2	NE-SW bending to E to W easterly stream	number of pre-historic tributaries	timber piles & planked revetments	some natural streamlets filled and grid of ditches substituted: timber-lined drains 140-200 CE;		late 1st/early 2nd C - massive dumps of clay, gravel & organic waste; 120-160 CE later dumping mainly of organic waste from households & industry	2.22 to 2.64
	MOG86	49-53 Moorgate, 72-74 Coleman Street, London, EC2		No evidence N-S tributary in MGT87 ever continued into this site		wooden box-section drain		latte 3rd C dumping	0.18
	MGT87	55-61 Moorgate, London, EC2		along E side of site significant tributary NNE to SSW then used to train tributary around towards ESE towards southern end of site	timber post & plank revetments - earliest 100CE second set built 120-140CE	timber-lined drain built last two decades 2nd C	water-lain deposits between 1st & 2nd sets revetments indicates the over-topping of 1st set and need for 2nd set finished at higher level	land raising by dumping behind 2nd set of revetments (120-140CE) dump material - demolition waste & domestic rubbish; early 3rd C dumping covered demolished buildings	1.48 to 1.60

Urban Roman Walbrook Valley - Flooding, River Management & Land Reclamation & Re-structuring

Lower urban Roman Walbrook valley - estuarial	Zone A
Lower urban Roman Walbrook valley - non-estuarial	Zone B
Middle urban Roman Walbrook valley - South	Zone C
Middle urban Roman Walbrook valley - North	Zone D
Upper urban Roman Walbrook valley	Zone E

Table 7-1 Archaeological sites in the Walbrook Valley with incidence of flooding and river management (page 4 of 4)

Zone	Site Investigation Reference	Address	Walbrook - river & tributaries					Land cover reclamation & re-structuring	Depth of fill in Roman Period (m)
			Walbrook river	Walbrook tributaries	Revetments	Drainage	Flooding		
	CAP86	Capel House, 54-62 New Broad Street, London, EC2		E to W stream		cut channels sloped to W towards Walbrook E stream		1.2 m gravel dumping	0.35 to 0.85
	BLM87	Blomfield House, 85-86 London Wall, London, EC2	E bank junction E & W streams braided		yes - E bank Walbrook (Waddington 1925) & clay, gravel sand bank	substantial box drain; clay-lined ditches increased 3rd/early 4thC	successive avulsions E bank Walbrook		0.10 to 1.25
Zone D continued	MRL98	Moor House, London Wall, London EC2	westerly stream of Walbrook nearby to W	stream channels NW-SE entering on N side of site & exiting on E side			prone to intermittent flooding from river nearby & tributaries	wet ground, isolated bodies of standing water & isolated woodland & shrubland - alder, willow, bich, pine, oak & ivy; grassland & waste ground	
	NEB87	35-45 New Broad Street, London, EC2	easterly stream nearby to W along Blomfield Street	2 pre-occupation streams both NNE-SSW orientation		flood deposits dated late 2nd/ early 3rd C indicate natural streams no longer adequate; post-Roman peaty deposits over W of site from marsh	flooding from tributaries carried parts buried skeletons over site	2nd C brickearth landfill between 2 streams; area abandonned late 2nd C level raised post Roman over whole site by successive flooding & dumping of gravel, sand, clay & silt	0.34 to 0.58
	LSS85	Liverpool St Station, Broad St Station, London, EC2	E bank easterly Walbrook; wide braided free flowing		man-made banks of clay & gravel on wattle foundation (c200CE); timber piled revetments	well-drained area initially then marshy conditions developed possible summer drying-out			1.49 to 1.82
	BDC03	6 Broad Street Place, London, EC2		pre-Roman braided channel area; channels infiled & significant channel dug NW to SE across N & E sides of site; channel estimated 6.6m wide & 1.2m deep - banks show many over-toppings & cleaning - was this main Walbrook channel?		water management systems were constructed paleo-channels infilled and drainage channels dug	channel bank condition shows many flooding events	transition open ground to seasonal marshland following building of wall & Walbrook culverting through it; post-wall, whole area used as a dumping ground, even main road covered; much flood erosion on E side of site down to Blomfield St "valley"	0.34 to 2.39
	ELD88	Liverpool House, 15-17 Eldon Street, London, EC2	N-S flowing easterly stream			natural site slopes to W to Walbrook	naturally wet but not marshy until wall		0.14 to 0.67
Zone E	RIV87	River Plate House, 7-11 Finsbury Sqare, London, EC2				possible cut drainage channel to nearby Walbrook		brickearth & rubble dumping	0.12 to 1.27
	VER90	Veritas House, 119-125 Finsbury Pavement, London, EC2	7.6m wide N-S channel authors conjecture that is a tributary of Walbrook (westerly stream?) (se also FBY01 & FIS96)						0.89
	FIS96	127-139 Finsbury Pavement, London, EC1	8m wide, 2m deep channel, slightly uneven profile, oriented north-south, base at 9.86m OD (see also FBY01 & VER90)						0.99
	FBY01	1-2 Finsbury Square, London, EC2	Wide "ditch" identified oriented N-S - almost certainly a continuation of westerly Walbrook stream found at Finsbury Court site to immediate S (FIS96) & (VER90)						0.84

Table 7-2 Incidence of flooding, reclamation & river management activity found at archaeological sites in the URWV

Type of Evidence Found	URWV (URWV)				
	Lower URWV		Middle URWV		Upper URWV (Zone E)
	Estuarine (Zone A)	Non-estuarine (Zone B)	South (Zone C)	North (Zone D)	
Total no. of sites	7	7	8	21	6
Walbrook main channel	No. of sites 4 **57%** DGH86; DOW86; SKN87/CKL88 CON86	No. of sites 4 **57%** BZY10; WFG44&45 BUC87; ONE94	No. of sites 2 **25%** MAR76; MGX06	No. of sites 6 **29%** ANT88; AST87; DGT06; WCH95; BLM87; NEB87	No. of sites 5 **83%** LSS85; ELD88; VER90; FIS96; FBY01
Walbrook tributaries	No. of sites 1 **14%** CCP04/CNV08	No. of sites 3 **43%** WFG44&45; BZY10; ONE94	No. of sites 2 **25%** GSJ06; MGX06	No. of sites 10 **48%** ACW74; THY01; MRG95/KHS98; MOA99; LOW88; KEY83; MGT87; CAP86; MRL98; NEB87	No. of sites 2 **17%** BDC03
Walbrook palaeo-channels	No. of sites 2 **29%** CCP04/CNV08 LYD88	No. of sites 0	No. of sites 3 **25%** POU05; GSJ06; GHB06	No. of sites 1 **5%** CXA06	No. of sites 0
Flooding	No. of sites 1 **14%** DGH86	No. of sites 1 **14%** BZY10 (pre-Roman flooding)	No. of sites 0	No. of sites 12 **57%** ANT88; THY01; AST87; DGT06; CXA06; COV87; WCH95; TGM99; MGT87; BLM87; MRL98; NEB87	No. of sites 2 **33%** BDC03; ELD88
Reclamation (land-raising)	No. of sites 5 **71%** DGH86; SUF94; LYD88 CCP04/CNV08 SKN87/CKL88	No. of sites 5 **71%** WFG44&45; BZY10; WAT78; ONE94; IRO80	No. of sites 5 **63%** POU05; WEL79; MIL72/76; GSJ06; MGX06	No. of sites 18 **86%** ACW74; ANT88; THY01; AST87; DGT06; MOA99; MRG95/KHS98; CXA06; COV87; WCH95; LOW88; KEY83; MOG86; MGT87; CAP86; BLM87; MRL98; NEB87	No. of sites 2 **33%** BDC03; RIV87
Revetments	No. of sites 4 **57%** DGH86; LYD88 SKN87/CKL88; CON86	No. of sites 3 **43%** BZY10; WFG44 & 45; BUC87	No. of sites 0	No. of sites 10 **48%** ACW74; ANT88; AST87; TEL83; DGT06; CXA06; WCH95; KEY83; MGT87; BLM87	No. of sites 1 **17%** LSS85
Constructed drainage	No. of sites 6 **86%** DGH86; SUF94; CCP04/CNV08LYD88; SKN87/CKL88; CON86	No. of sites 3 **43%** BZY10; ONE94; BOL94	No. of sites 5 **63%** POU05; WEL79; MIL72/76; GHB06; MGX06	No. of sites 14 **67%** ANT88; THY01; AST87; DGT06; COV87; MRG95/KHS98; WCH95; LOW88; KEY83; MOG86; MGT87; CAP86; BLM87; NEB87	No. of sites 4 **67%** LSS85; BDC03; ELD88; RIV87

On comparing the archaeological evidence of river channels, flooding and river management activity found in the four stretches of the urban Roman Walbrook, the following observations have been made:

- There is a wide variation between zones in the percentage of sites where the Walbrook and its tributaries have been found, a possible reason being that, within the City of London, archaeological investigation is dependent upon re-development projects and not executed according to a plan focussed on finding the Walbrook.
- There is a low incidence of discovery of the Walbrook's main channel in the middle URWV, particularly in the northern half of the area (Zone D). The land throughout this Zone was flat and contained a large depression in the ground. In many places, the riverbed may have widened considerably over large areas and the main channel may have become less obvious due to anastomising.
- The flat nature of Zone D will have encouraged meandering of streams and this may account for the discovery of a higher percentage of Walbrook tributaries than for its main channel.
- The only example of flooding in the Roman period in Zones A and B is on the DGH86 site and was due to inundation by the Thames, not the Walbrook. Whereas, the incidence of flooding on sites in Zone D and E was 57% and 33% respectively. Evidence of flooding of the BZY10 site relates only to the pre-Roman period, environmental evidence pointing to the source being non-saline, i.e. run-off from surrounding slopes or from the Walbrook. This apparent low incidence of flooding of Zones A and B is supported by the flood-risk analysis (Chapter 6).
- Evidence of land raising (reclamation) was found in a high percentage of archaeological sites within the town wall in all zones. The purpose of land raising in Zone D, on 86% of all sites, was to eliminate or reduce the frequency of flooding. However, evidence of flooding in the Roman period in Zones A, B and C was restricted to a single site. Given the proximity of the gravel terraces to the valley floor in these three zones and the evidence found of marshy conditions, probably due to springs in these areas, it is possible that the land was raised to avoid perennial wet conditions and to prepare the land for development.
- Revetments do not appear to have been linked to the incidence of flooding as they have been found in Zones A and B, where Roman period flooding was not found, as well as Zone D, an area of high incidence of flooding. It is possible that revetments were constructed in order to

protect land that was to be developed, or that had been developed, from encroachment by the river as, at times, storm flows would have been capable of significantly eroding them. The apparent absence of revetments found on the Zone C sites that border on Zone D, is difficult to explain.

- Constructed drainage systems have been found at all but a few of the sites where reclamation has been carried out. This is to be expected as drainage would normally form an integral part of reclamation work.

Archaeological sites that have produced evidence of flooding where one or more river management techniques has been attempted are shown located on the following figures:

- Figure 7-2 Archaeological sites with evidence of flooding
- Figure 7-3 Archaeological sites with evidence of reclamation work
- Figure 7-4 Archaeological sites with evidence of constructed drainage
- Figure 7-5 Archaeological sites with evidence of revetments

Table 7-3 is an illuminating extraction of the data from Table 7-2 which reports the incidence of reclamation and revetments with respect to sites where either the Walbrook or one of its tributaries has been identified and flooding has been found to have occurred.

Table 7-3 Incidence of Reclamation and Revetments on Sites Where the Walbrook or Its Tributaries Have Been Identified and Flooding Occurred

Valley Stretch	Walbrook	Tributary	Flooding	Reclamation	Revetments
Lower *Zones A and B*	DGH86; BZY10		Yes	Yes	Yes
Middle *Zones C and D*	ANT88; AST87; CXA06; DGT06; WCH95; MGT87; BLM87		Yes	Yes	Yes
		THY01; MRL98	Yes	Yes	No
Upper *Zone E*		NEB87; BDC03	Yes	Yes	No

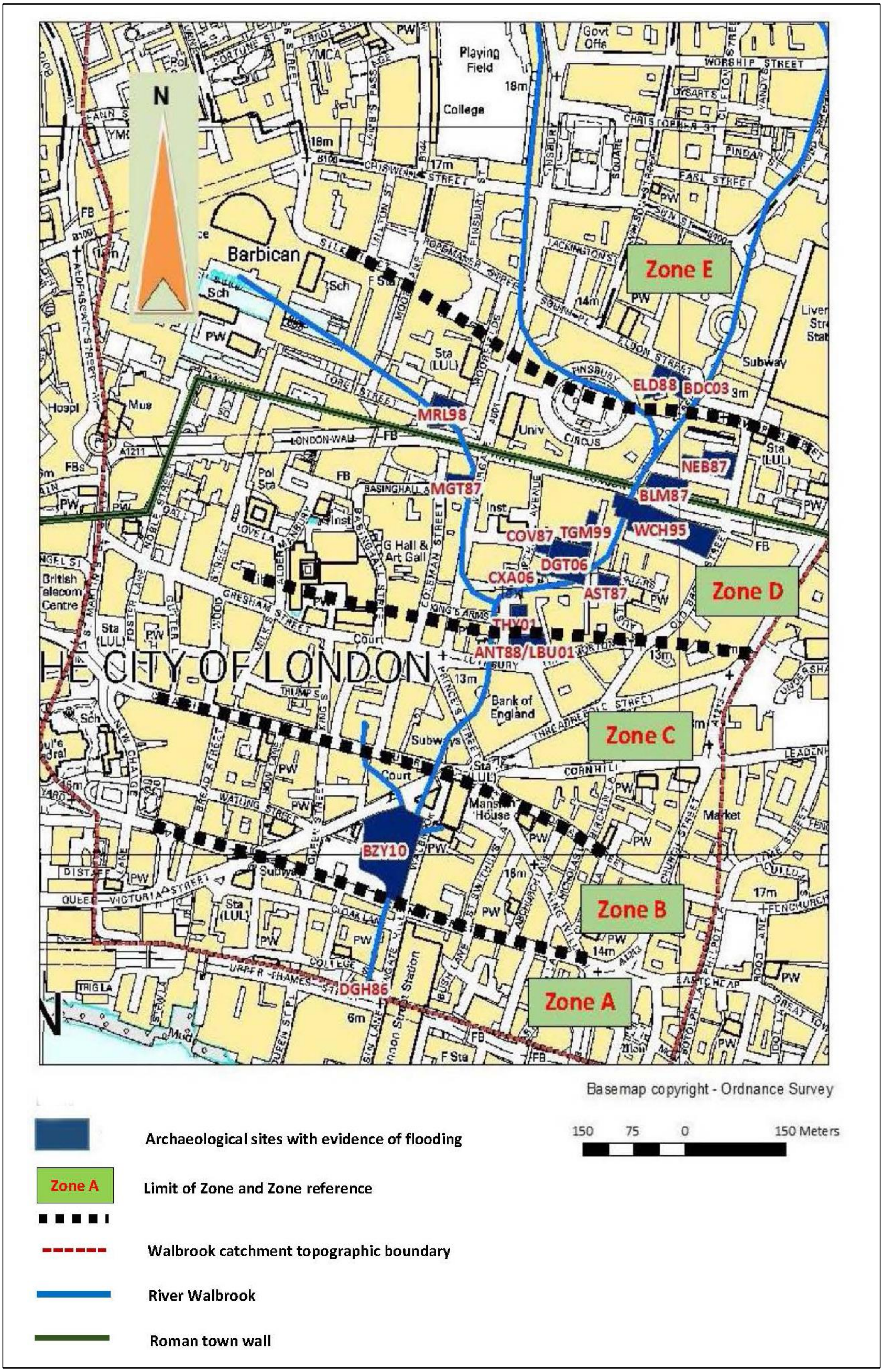


Figure 7-2 Archaeological sites with evidence of flooding

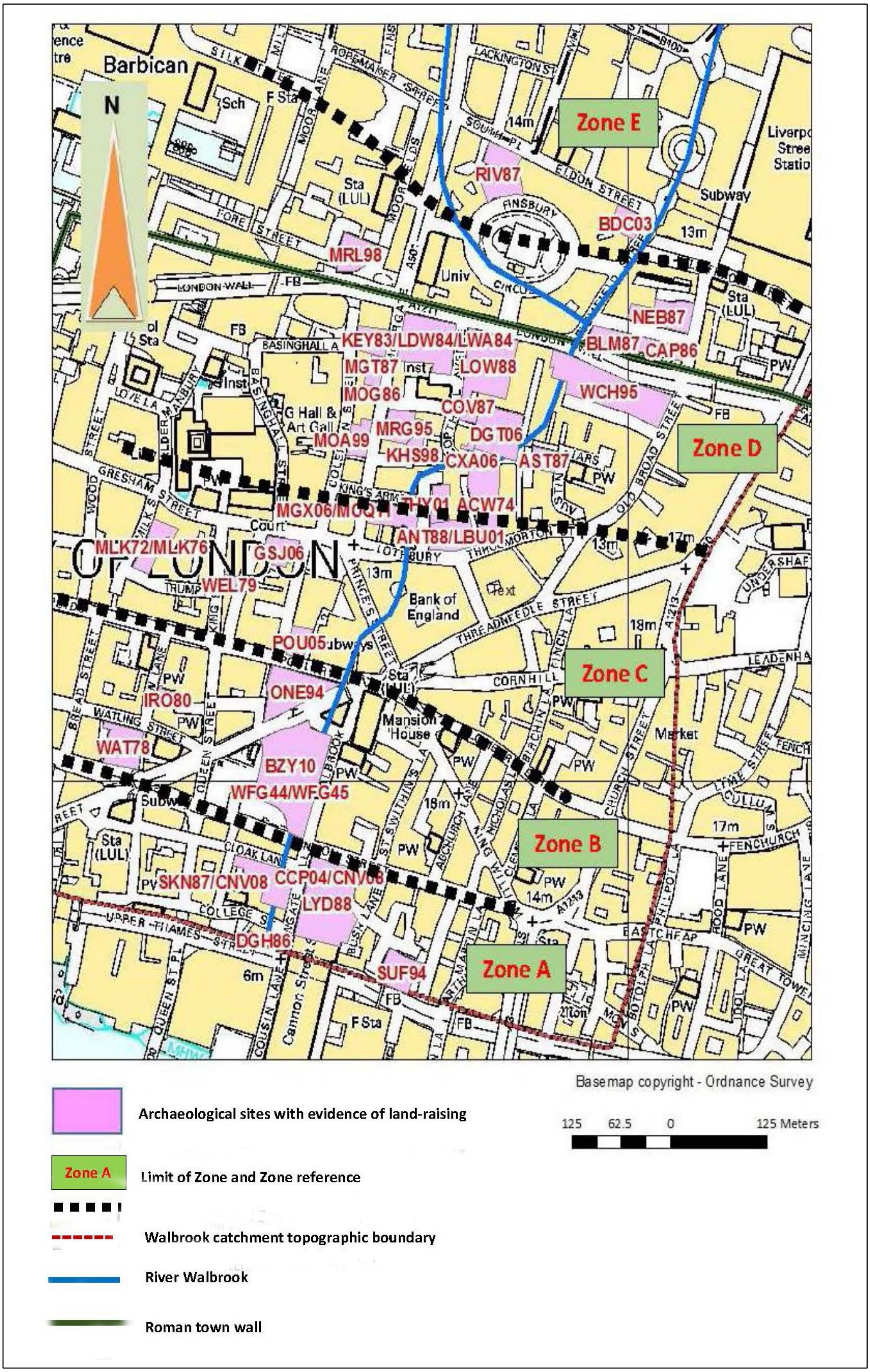


Figure 7-3 Archaeological sites with evidence of land-raising work

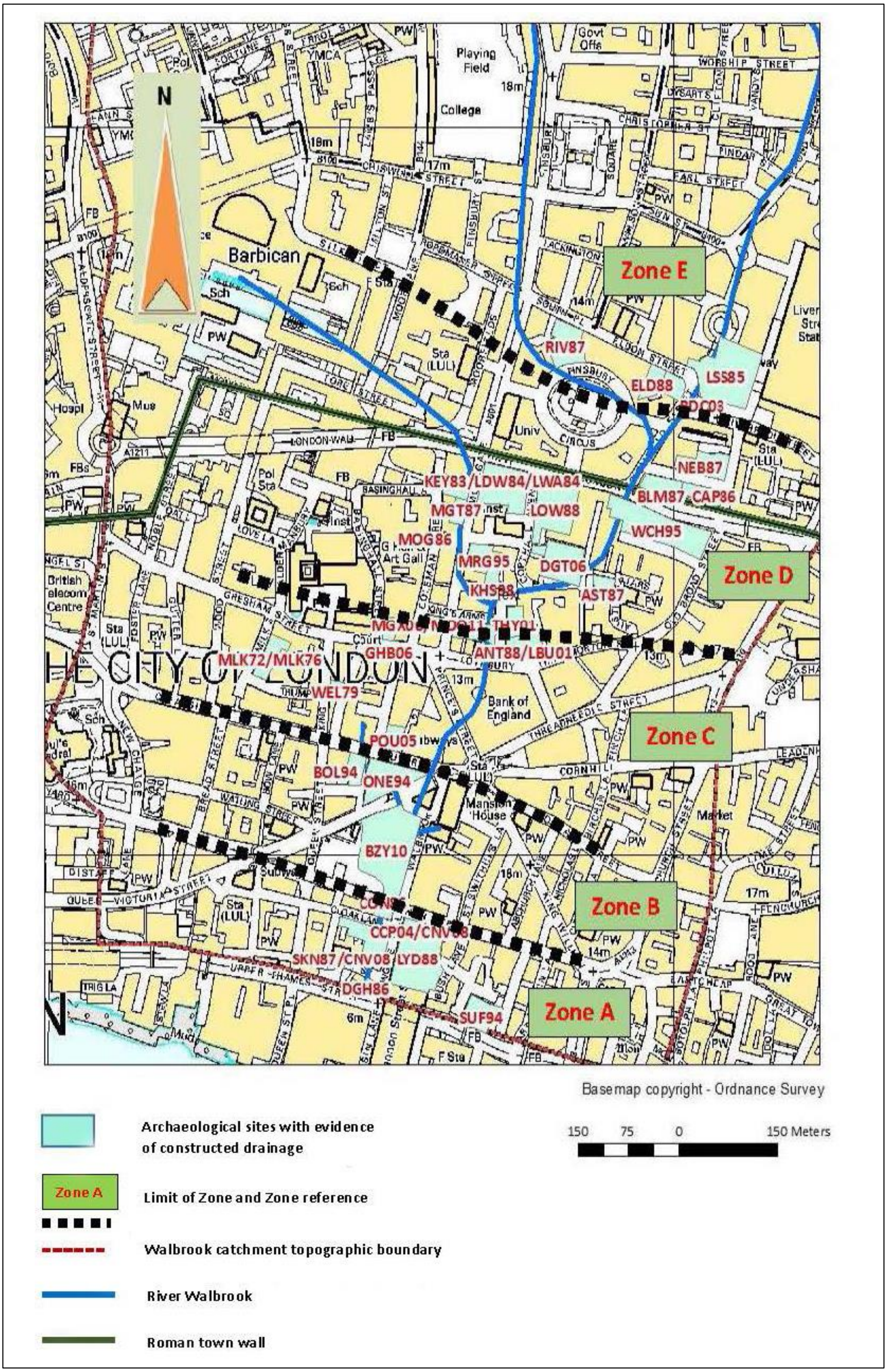


Figure 7-4 Archaeological sites with evidence of constructed drainage

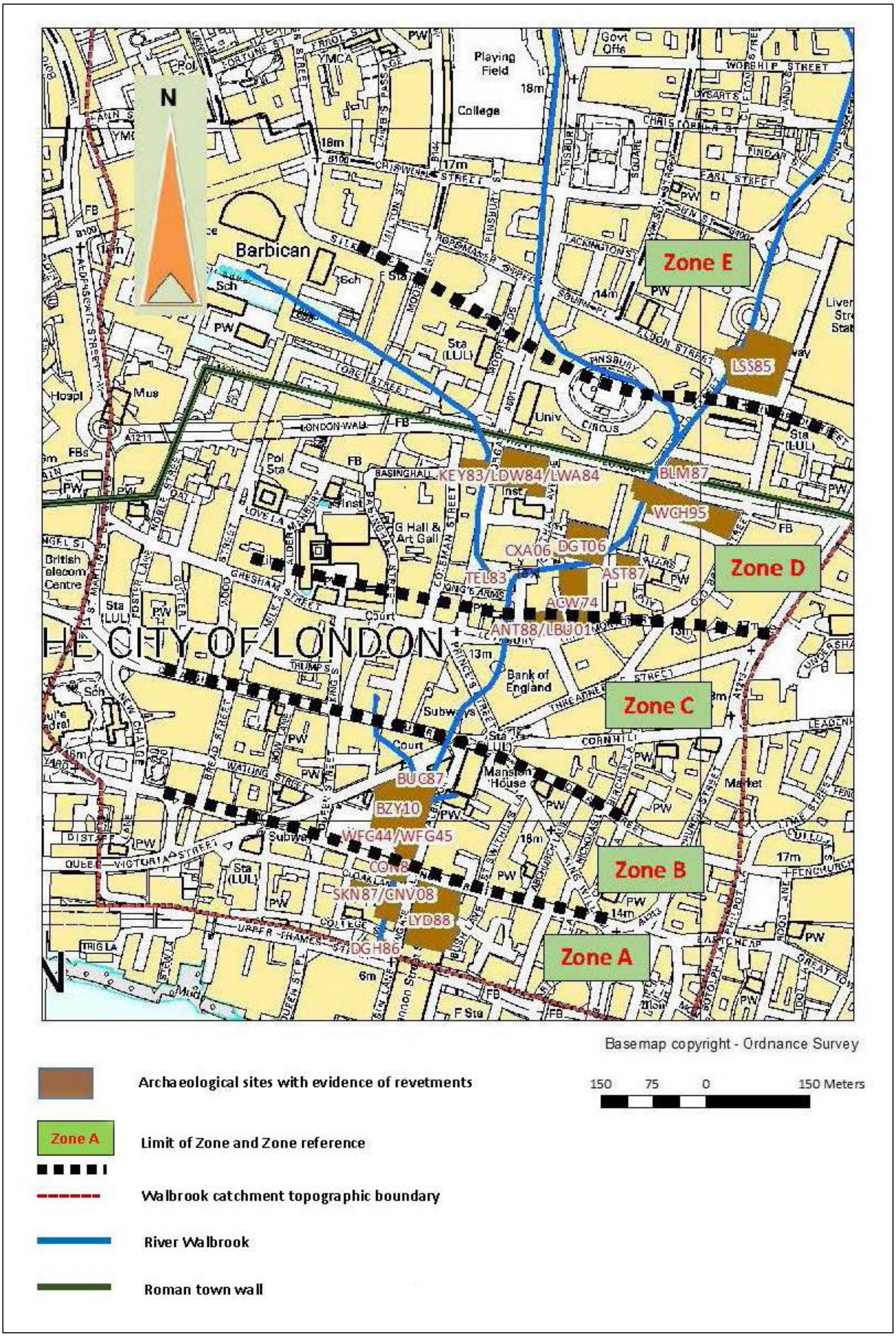


Figure 7-5 Archaeological sites with evidence of revetments

From Table 7-2, it is possible to deduce that where the Walbrook or one of its tributaries has been discovered, flooding occurred and works have been undertaken to raise the elevation of the land. However, revetments have been provided, whether to retain the dumped material used in reclamation or to prevent erosion of the riverbanks, only on stretches of the main river. As no revetments were found protecting tributaries, it would appear that the banks of tributaries either did not need retaining or strengthening or that the consequences of that occurring did not warrant the cost of providing the protection of revetments. It is also a possibility that the velocities of flow in the tributaries were insufficient to have caused erosion.

7.3 Flood Protection and River Management – Case Studies

This section responds to Research Question Q 7.2:

> *What measures were taken to protect land from flooding by the Walbrook and to actively manage the river and were they effective?*

Prior to the construction of the town wall, the three principal methods by which the Romans practised flood alleviation and avoidance were construction of revetments to retain the river within its course, reclamation, including the raising of ground level reclamation, levelling of low and high points in the landscape and river re-alignment. Evidence of land raising has been identified in the course of most of the archaeological investigations carried out along the URWV as listed in Tables 4-8 and 4-9, Section 4.7.3. Investigations have also identified a few places where the river was re-aligned, possibly to reduce flooding of a specific area, although this frequently results in worsening the flood situation downstream. The techniques used to render the marshy floodplain of the urban Walbrook suitable for development, and for which there is archaeological evidence, are described in the following sections:

- Section 7.3.1 Revetments
- Section 7.3.2 Land raising (reclamation) and constructed land drainage
- Section 7.3.3 River re-alignment
- Section 7.4 Flow regulation and the town wall

The basis for the content of Sections 7.3.1 to 7.3.3 has been abstracted from Appendix 7A which describes the river management techniques employed at the individual archaeological sites where they have been found as well as the notes on individual investigations reported in Appendices 2B and 2D.

7.3.1 Revetments

Zone A – Lower URWV - estuarine

Substantial double box revetments constructed from squared-off, large cross-section timber piles and beams and infilled with dumped stone were used to form the quayside along the Thames in front of the low promontory on which was situated the high-status building, formerly known as the Governor's Palace (SUF94 and LYD88). This quayside was continued for a short distance along and around the east bank of the Walbrook's eastern delta arm. It is not known how far to the east this quayside continued along the Thames but the main port for the town, centred about the northern end of the bridge, was only a few hundred metres away. A compacted gravel surface was provided to the quay.

This solid and durable construction was in stark contrast to the much simpler form of bank protection only 60 to 70 metres to the west along the Thames, between the western and eastern arms of the delta (DGH86). Here a clay bank, 6 to 10m wide was raised in the period following the Boudican revolt. However, no attempt appears to have been made to protect the clay embankment from erosion by the Thames' tidal movement and storm surges. The rather informal state of the constructed riverbank, compared with the structural integrity of wharves constructed further eastwards to, and beyond, the bridge, gives rise to a strong impression that the estuarine section of the Walbrook was not used for port activities to the same extent as the areas around the bridge and that they were considered of lesser importance. Silt layers behind the bank suggest that it was breached or over-topped a number of times and at the end of the 3rd C or beginning of the 4th C a large-scale dumping operation raised the top of the bank and land behind it to between 1.50 and 1.70m OD, just above MHWS of the time (Shea, 1987).

The purpose of the bank is uncertain. The width of the berm, when compared with Roman port facilities a short distance to the east   is such that it may have been used for access to informal vessel unloading arrangements. Similar facilities were in use in Europe until at least the late 19th C, Figure 7-6 (Patry, 2015; 110). Timber from oak beams and piles has been found (DGH86) both sides of the embankment suggesting the remains of a jetty-like structure extending out into the Thames. Were this to be the case, it would be further indication that the loading and unloading of goods at the mouth of the Walbrook was not considered as important as the operations at the bridge, where more substantial port infrastructure has been found.

Fragments of a timber revetment along the Walbrook, 50 to 60 metres upstream of its estuary, have been found behind which the land was raised using stone and rubble (SKN87/CKL88).

Figure 7-6 "The Coal Carriers" – Claude Monet, c 1875 (Musée d'Orsay, Paris)

Zone B – Lower URWV – non-estuarine

An early discovery of revetments along the Walbrook was made during the 1950's excavation by W F Grimes of the Bucklersbury House site, now the Bloomberg Development, lying between Cannon Street and Queen Victoria Streets (Grimes, 1968, 92-98). Sections drawn by the WFG44 and 45 investigating team at the time commence mid-stream westwards for some 10 metres, Figure 7-7, a simplified version of which is presented by Grimes (Grimes, 1968, 92-98). Two sets of timber piles driven early in the occupation at about 2 metres from mid-stream are depicted both vertical and at a raked angle with their tops respectively at 1.83m OD and 2.44m OD. However, it is possible that both sets were driven vertically but only to a very shallow depth and that pressure from the weight of silt dumped behind the piles pushed the rear set forward and both sets into the channel of the stream, suggested at this point to have been 4.26m wide (Wilmott, 1991). A second set was driven 4 metres to the west of the first set and were finished off at a level of 3.66m OD, above the level of all but the combination of exceptional storm intensities and high tides.

The level of the platform roughly corresponds to the foundation of the nave to the Temple of Mithras, situated directly opposite on the east bank, shown on another section as being at about 4.00m OD.

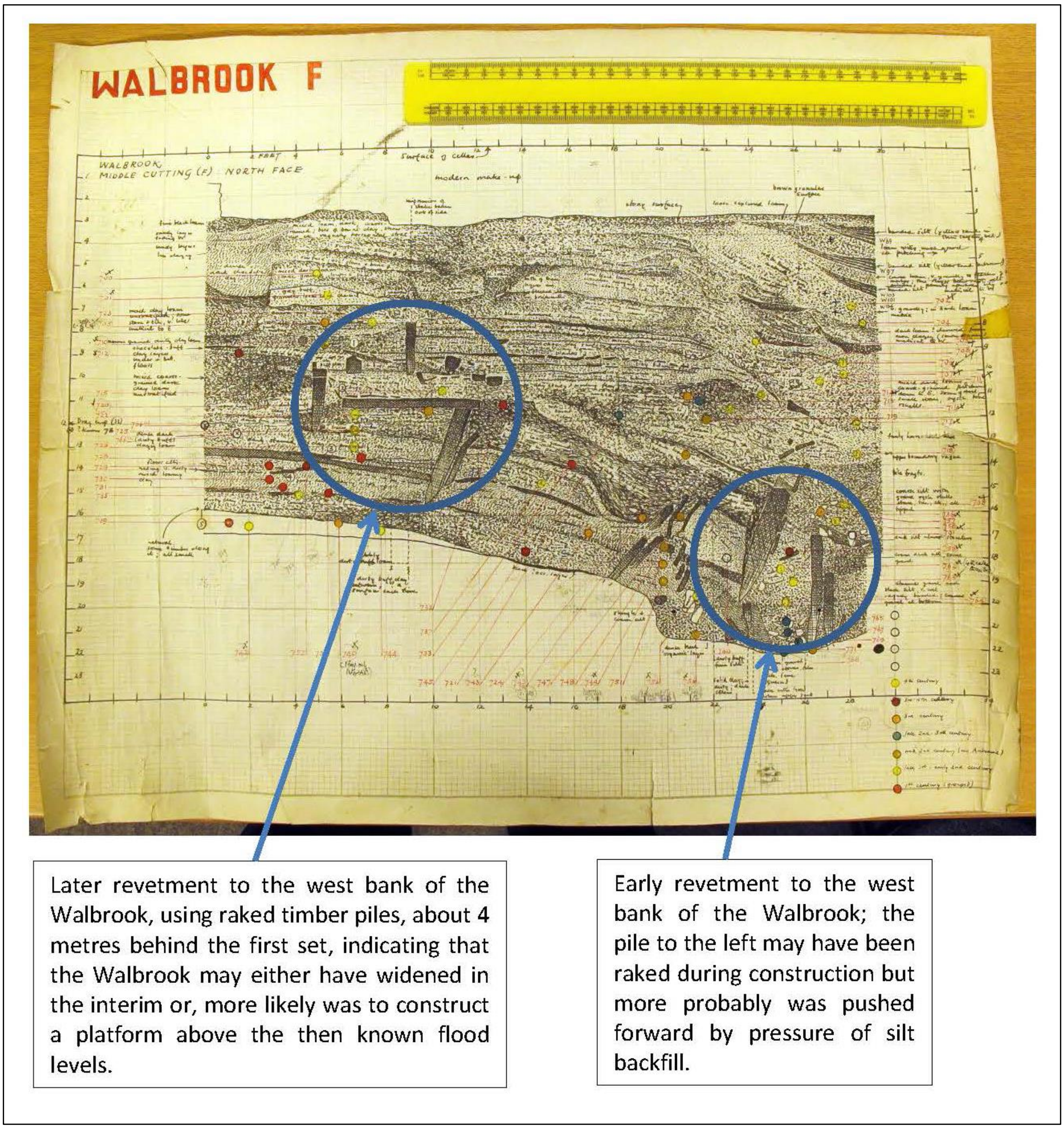


Figure 7-7 Section through Walbrook stream channel and its west bank

(Source: plans of the WFG44 & 45 investigations at LAARC)

The second set of timber piles appears to have been driven at a raked angle of about 20° from the vertical and provided the support to a timber platform as well as protection to the riverbank.

A short length of revetment was found on the west bank of the Bloomberg site, directly opposite where the remains of what may be a mill were found on the east bank and another in the central portion of the site. Both revetments were comprised of vertical oak piles behind which oak planks were wedged horizontally. Horizontal tiebacks of oak beams with lap-joints cut for lock bar timbers and pairs of anchor stakes held the revetment in place against the riverbank, this reinforcement of the structures integrity possibly stemming from poor experience with earlier revetments.

It has been suggested that the last revetment collapsed sometime after the 3rd C and the Walbrook then remained without revetments (Leary and Butler, 2012).

Zones C and D – Middle URWV

A tributary of the Walbrook was observed on a building site at the south end of Moorgate, bordering on Lothbury (Norman and Reader, 1912, 311-317). The bed of the stream was about 6m wide but a total of 8.5m between the banks, Figure 7-8. The banks on both sides of the stream were retained by vertical walls formed from chalk. Although some fragments of Samian pottery were found in the streambed, it is possible that the revetment dates from the medieval period as this type of revetment construction has not been found on any other site in the urban Roman Walbrook Valley.

Further upstream on the boundary between Zones C and D, a tributary of the Walbrook was found on the ACW74 site that had been provided with a simple stake and plank revetment (Figure 7-9).

The west bank of a tributary of the Walbrook was found running north-northeast to south-southwest along the east side of the site, paralleling the line of Moorgate. Two parallel sets of post and plank revetments, were found lining the west bank of the tributary towards the southeastern corner of the site, the two sets being less than 0.5 metres apart.

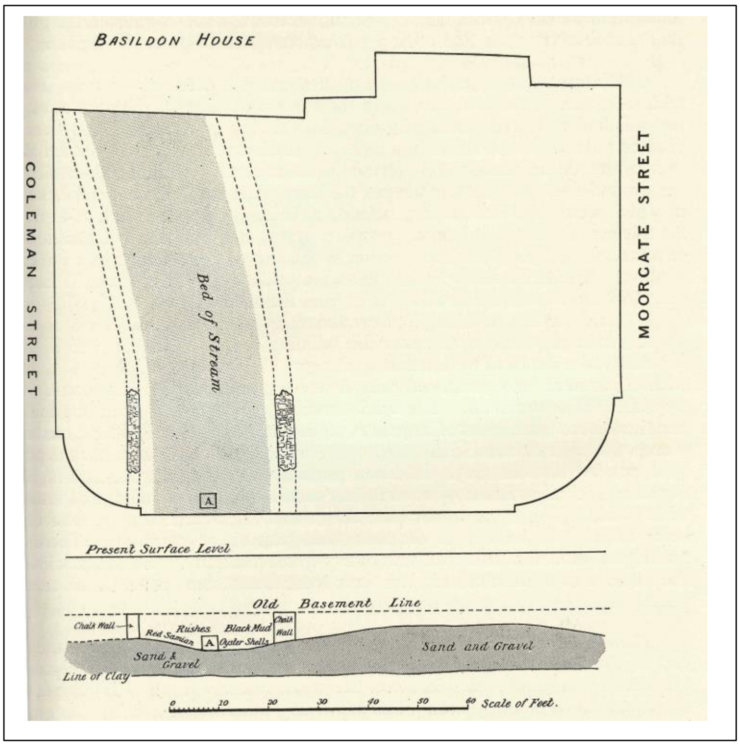
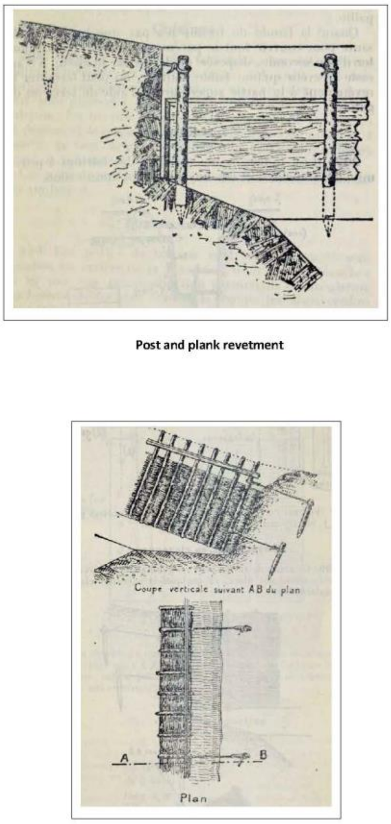


Figure 7-8 Walbrook tributary at the most southerly point on Moorgate (Norman and Reader, 1912, 311-317)



Post and plank revetment

Brushwood revetment

Figure 7-9 Simple post and plank revetment and a brushwood revetment (Grand Quartier Generale 1er Et 3e Quartier, 1915, 160-161)

Both sets of revetment were found in the large trench in the southeast corner of the site. The more easterly, earlier revetment was found at a level of +7.24m OD and was dated to about 100 CE. The second phase of revetment was built about 140 CE, immediately to the west of the first phase and closely followed the same alignment as the first. The second set was found at a level higher than its predecessor, varying between +7.83 and +7.89m OD. It was speculated that these revetments were built to protect the substantial, high-status Roman building uncovered on the adjoining site, MOG86, to the south of MGT87 (Drummond-Murray, 1988, 1). Water-lain deposits behind these two revetments could indicate their regular over-topping. A revetment found in a trench towards the northeast corner of the site, was found to align with the other two to the south and were clearly parts of the same revetment about 16m apart.

Two other post and plank revetments, found in the trench in the southeast corner of the site, were set at right angles to the others, possibly indicating a deliberate re-aligning of the Walbrook. As this directed the tributary towards the east-southeast across Moorgate, there is a possibility that this was the same tributary found entering a nearby site to the south, MGX06/MOQ10, from its northwest corner. Land reclamation dumping took place behind these revetments, possibly as part of preparing the ground for the construction of the high-status building found to the immediate south. The whole of the MGT87 area appears to have been abandoned in the late 2nd or early 3rd C at which time buildings on the site were found to have been covered by thick dumps.

A timber revetment was found lining a Walbrook tributary that passed through the MGX06/MOQ10 site (Maloney, 2012-14) and simple timber post and plank revetments were used to protect the sides of open drains constructed on the KEY83 site (Maloney and De Moulins, 1990).

The original main channel of the Walbrook flowed from east to west across the southern side of the Draper’s Gardens site (DGT06), however its banks do not appear to have been revetted. As described in Section 9.3.3, at the end of the 1st C or beginning of the 2nd C, the main channel was re-aligned and a parallel channel, probably for drainage, was constructed. Both of these channels were found to have been protected by simple timber post and plank revetments.

The east bank of the Walbrook at Blomfield House, 85-86 London Wall (BLM87) was a naturally-formed levee thought to have been gradually built up through the arrival at this point of material resulting from avulsions of the riverbank upstream, possibly deposited from the western Walbrook stream which was directed at the east bank of the eastern stream. This bank was not protected by revetment and was breached at a time unknown, possibly early in the Roman occupation, causing an extensive crevasse splay of deposited material over much of the western half of the BLM87 site.

Excavations at Liverpool Street Station and Broad Street Station (LSS85) uncovered the eastern half of the channel of the eastern stream about 50 to 60 metres upstream of its confluence with the western stream. Initially, a fast-flowing stream, braided and with quieter backwaters. However, following construction of the town wall little more than 100 metres to the south, flora and fauna found in the deposits indicated that the well-defined river channel was subsumed into a heavily waterlogged, marsh-like environment. Possibly in response to a backing up of the river, the banks were raised about 1 metre but, in contrast to sites in the middle URWV, the river was not restrained within revetments probably indicating that the surrounding land was used for farming, possibly alluvial flood meadows, rather than industry and did not warrant the cost involved in bank protection. Although the river continued to flow through the marsh, its tendency to back-up would indicate that the culverts carrying the river through the wall either became blocked, whether due to natural blockage or by design, e.g. using sluice gates to limit flow passing into the urban area.

7.3.2 Land raising and constructed land drainage

As described in Section 4.7.3, a considerable amount of land raising activity was undertaken in the URWV in the latter decades of the 1st century, throughout the 2nd century and into the early part of the 3rd century until completion of the town wall. It is not possible to determine whether this activity, which must have involved significant cost, was carried out by a public administration, military personnel or by those owning land or using it for dwellings or places of industry or crafts. However, as noted in Section 7.2, the objectives of land raising activity were two-fold – to reduce the risk of flooding and to prepare land that suffered from marshy conditions for development. The elimination or reduction of flooding was the paramount objective in Zone D and the elimination of marsh was the predominant objective for Zones A, B and C. When carried out competently, land raising and constructed drainage are complementary and, as shown in Table 7.3, Section 7.2, evidence of the former is frequently accompanied by evidence of the latter.

Table 4-8 in Section 4.7.3 reported the extent of Roman land raising activity based upon 91 datasets from 41 archaeological investigations in the URWV. The average heights added to the land due to this activity for each of the four zones within the boundary formed by the town wall, as abstracted from the table are:

- Zone A 1.7m
- Zone B 1.7m
- Zone C 1.1m
- Zone D 1.5m

In Zone E, outside of the eventual town wall, land was raised an average of just 0.4m. On the twenty-two sites examined in this zone, land was raised less than 0.3m on fifteen sites and on six of these sites there was no difference in the pre-Roman and Roman land levels. This probably reflects the sub-urban nature of the area that was used for cemeteries and agriculture.

Evidence from three sets of revetments found at the Bucklersbury House (Bloomberg Development) site, the WFG44/45 and the BZY10 investigations, has shown that the land was raised in stages, initially to 1.80m OD, then progressively to 2.90, 3.35, 4.57 and finally to 5.49m OD (Grimes, 1968, 92-98) (Shepherd, 1988, 71-75). The material used to raise the ground level was initially silt and silty clay but increasingly this was described as “loamy clay and brickearth” in the archaeological record mixed with building debris and solid wastes, including a significant quantity of stable waste (BZY10). The material was structurally weak and even light timber hut structures had to be under-pinned with piles. On the eastern side of the site, timber cribwork structures were used to provide robust foundations to buildings (Stewart and Smith, 2014, 152-157).

In Zone A, land drains were constructed to serve the area behind the clay embankment constructed along the Thames. Successions of open drains were built, each rendered ineffective due to siltation.

Upstream, on the boundary between Zones C and D, there were three phases of ground-raising activity noted on the ACW74 site, each separated by a layer of silt, indicating flooding events. Reclamation work here began in 125 CE and the last work took place about 180CE, the top of the final stage of revetment being at 8.35m OD. A similar pattern of progressive raising of the land in response to successive flooding events was exhibited by the findings on the ANT88 site adjacent to ACW74.

One of the clearest examples of how the Romans struggled to control flooding and that land was progressively raised in response to recurring flood events was found on the THY01 site (Leary and Butler, 2012), the flooding evidenced by very thin layers of silt. Here, the land was marsh to begin with and the land surface was raised by between just 0.3 and 0.8 metres using organic anthropogenic waste to 5.30m OD. In spite of the installation of a succession of box drains, this level was insufficient to avoid frequent floods and the area soon reverted to marsh. Further material was dumped to raise the land surface to between 5.90 and 6.10m OD and another set of box drains was built but there were at least three more significant flood events. Drainage went through a succession of fashions from box drains, which silted up, to open ditches and back to box drains. This pattern of land raising, flooding and further land raising was repeated through the generations until the middle of the 3rd C by which time the land was at 7.60m OD, more than 2.5mabove its original level. At the time open ditches were used to drain the area, their sides protected from erosion by timber planks retained by driven timber stakes. The land was at just 0.5 metres above the bed of the nearby Walbrook and flooding continued. Towards the end of the 4th C further dumping raised the land by 1 metre.

Box drains were also found on the MGX06/MOQ10 site where the west bank of the Walbrook's main channel was unearthed running north to south on the east side of the site with a tributary entering from the northwest, probably an extension of the tributary found to the north along Moorgate at MGT87. Again ground-raising was undertaken in stages (Cardiff, 2005, 18-33).

Archaeological sites in Zones D and E have discovered land reclamation work, generally dating from the second half of the 1st C through to the end of the 2nd C, at which point the wall was constructed, significantly reducing and probably eliminating flooding of the urban RWV (Section 10.5). Nevertheless, there are a few instances of land surfaces having been raised in this northern suburb in the 3rd and 4th centuries, e.g. THY01. The unevenness of the ground surface raised in the middle and northern URWV is demonstrated by the range of depths of fill both within and between sites. The depth of fill dumped over the whole area in the Roman period ranged from 2.64 metres at the Copthall Avenue sites (KEY83) and 2.39 metres at Broad Street Place (BDC03) to just 0.1 metres at the Blomfield House site (BLM87) and 0.18 metres at 49-53 Moorgate (MOG86). From Table 7-2, Section 7.2, although a high proportion of the sites in Zone D, 18 out of 21 (86%), were subject to reclamation, only 10 of the sites showed evidence of revetments out of the total of 16 sites where the Walbrook (6 sites) and its tributaries (10 sites) were discovered.

A main road passed from southwest to northeast, across the KEY83 site (Maloney and de Moulins, 1990: 26-33) almost certainly an extension of the road that began at the Via Decumana at Bucklersbury, which due to flooding had to laid and re-laid many times to avoid flooding. Starting at a road level of 6.80m OD, its top surface was successively raised to 6.95m OD, 7.18m OD and 7.45m OD before being reconstructed with a brushwood causeway base at 7.90m OD. A path leading off the road was set on piles and had a surface level of 8.16m OD. This is an indication that, supported by evidence from elsewhere in the general location (THY01) that a land surface need to be raised to about 8.00 to 8.20m OD in Zones D and E in order to completely avoid flooding. Such levels were not achieved until into the 3rd and 4th centuries, when there is evidence that the area was at least partially abandoned by industry and left for farming and as a dumping ground for anthropogenic waste carted there from the town.

The 22-25 Austin Friars site (AST87) was subject to considerable land raising works and drainage was one of the features of the archaeological investigations. Three parallel, flat-bottomed ditches were cut into the pre-Roman strata and drained southwest to northeast across the eastern half of the site. These were oriented towards a natural drainage channel found flowing northeast to southwest across the NW corner of the site. This latter almost certainly linked into the drainage channel found in the course of the ACW74 work. Buildings in the southern central part of the site drained their liquid wastes through what has been described in the archaeological record as “a complex timber drainage system” (Blurton, 1975, Figure 2). Before discharging to the Walbrook tributary, the wastes were passed through a tank, apparently to remove solid material from the sewage – a rudimentary treatment plant, the only reference to an attempt at pollution control found in the course of this research.

A 5-metre wide, shallow open ditch was constructed on the south side of the Blomfield House, 85-86 London Wall site (BLM87) which drained west to east towards the Walbrook just beyond the western perimeter of the site (Sankey, 1989). It has been claimed that this ditch marked the northern boundary of the town before the construction of the wall. Six secondary ditches were also found on the site, three on the western half of the site drained to the east to west ditch and three on the eastern half drained towards the Walbrook directly. The main ditch and two of the secondary drains found on this site were unique amongst the drains noted in the archaeological reports reviewed in the course of the research in that they were lined with locally quarried clay. Apart from a mid- to late 1st C building constructed in the Stabbau style, i.e. of wooden staves, more normally associated with the continental, medieval period, and a later more conventional overbuild of wattle and daub, there was little occupation in this area which appears to have been farmed for 200 years and then abandoned.

The 35-45 New Broad Street site (NEB87), lying outside the town wall, formed part of the northern cemetery. Land was raised using brickearth between two tributaries of the Walbrook, which flowed a short distance to the west, possibly for the purpose of burying bodies in relatively dry ground. Re-deposited bones indicate that the western of the two streams may have cut into the fill when in flood. Burials were provisionally dated to between 40 and 200 CE. Waterlain silts over the lower part of the site, dated to late 2nd C to at least mid-3rd C, i.e. overlay the raised land surface implying that the tributaries were backing up from the main river following construction of the town wall and drainage along the tributary was no longer satisfactory. The silt layers became increasingly humic in nature showing that the land was becoming marshy.

Figure 7-10 illustrates the efficacy of the investment made in land raising with respect to a reduction in flood-risk. It is based upon a Manning coefficient of 0.07, considered the most appropriate channel roughness as it represents normal channel conditions. The depth of river channel, i.e. from its bed to the top of the bank, has been taken as increased from its pre-Roman, natural depth by the average height by which the land was raised in each of the zones. As this would have increased the “flow full” capacity of the river channel before its banks were over-topped, the frequency of flooding would have been reduced. For Zones C and B, respectively Lothbury to Bucklersbury and the Bloomberg Development, Figure 7-10 shows that the risk of flooding would have been eliminated. For Zone A, from Cannon Street to the Thames, the occurrence of flooding is shown in Figure 7-10 to have been eliminated with the sole exception of one extreme scenario for which the return period is in excess of 500 years. To put this in perspective, modern designs commonly use a 1 in 100-year storm for flood protection works. In Zone D, where the bed slope would have been at its shallowest and much of the land would have lain within the depression in the ground, land raising activity to reduce flooding would have been least effective. However, whereas flooding could have been expected annually or more frequently in its natural state, even here land raising reduced the frequency of flooding to greater than once in 10 years and, under most channel conditions to once in 50 years.

Figure 7-11 demonstrates the reduction in flood frequency had land raising activity been carried out to average heights greater than was actually the case in Zone D, Draper's Gardens to Lothbury. Two cases are shown, respectively for the average height of land to have been raised by a further 0.5m and 1.0m Each of these would have achieved a reduction in flood frequency, an additional 0.5m would have improved the situation to a flood event once in 20 years and an additional 1.0mof height to once in 50 years. Although these are improvements, they would have entailed considerable extra cost and, as floods had already been significantly reduced by the land raising actually carried out, would almost certainly not have been considered worthwhile.

Conversely, Figure 7-12 shows the increase in flood frequency in each of the four zones had less land raising activity been carried out than was the case. For Zones B and C, the risk would have remained within the acceptable norm, flood frequency not falling below once in 100 years, even for a reduction in land raising activity of 1.0m. In Zone A, the land could have been lower than the level to which it was raised by 0.5m but not by 1.0m to have remained within acceptable limits. However, for Zone D, the most prone to flooding, raising the land to a level lower by 0.5m would have increased the occurrence of floods to once in 5 years and if the level had been lower by 1.0m to once in 2 years. These were clearly not within acceptable norms and the amount of land raising carried out is shown to have been justified.

Figure 7-10 Comparison of flood frequency for the immediate pre-Roman period and following land raising activity for Zones A to D

Greater Walbrook Valley

"Flow full" capacity of Walbrook channel - and consequent flood frequency - comparison of pre-Roman and Roman after land raising activity

All Zones - As actual values for Roman land-raising activity (Section 4.7.3, Table 4-8)

Composite AMC 2 & 3 flows

Manning formula — Velocity of flow in river, $v = 1/n . R^{2/3} . s^{1/2}$ (metric version)

Manning roughness coefficient - preferred - 0.07 — "Flow full" capacity, Q = A.v

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m²)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m³/s)
Zone D - Draper's Gardens to Lothbury - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	3.00	7.00	45	4.24	30.00	15.49	1.94	0.00105	0.72	**21.63**
0.07	2.50	7.00	45	3.54	23.75	14.07	1.69	0.00105	0.66	**15.61**
0.07	2.00	7.00	45	2.83	18.00	12.66	1.42	0.00105	0.59	**10.55**
0.07	1.75	7.00	45	2.47	15.31	11.95	1.28	0.00105	0.55	**8.37**
0.07	3.00	6.00	45	4.24	27.00	14.49	1.86	0.00105	0.70	**18.97**
0.07	2.50	6.00	45	3.54	21.25	13.07	1.63	0.00105	0.64	**13.62**
0.07	2.00	6.00	45	2.83	16.00	11.66	1.37	0.00105	0.57	**9.16**
0.07	1.75	6.00	45	2.47	13.56	10.95	1.24	0.00105	0.53	**7.25**
0.07	3.00	5.00	45	4.24	24.00	13.49	1.78	0.00105	0.68	**16.35**
0.07	2.50	5.00	45	3.54	18.75	12.07	1.55	0.00105	0.62	**11.66**
0.07	2.00	5.00	45	2.83	14.00	10.66	1.31	0.00105	0.56	**7.78**
0.07	1.75	5.00	45	2.47	11.81	9.95	1.19	0.00105	0.52	**6.13**
Zone C - Lothbury to Bucklersbury - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	3.10	7.00	45	4.38	31.31	15.77	1.99	0.01950	3.16	**98.90**
0.07	2.85	7.00	45	4.03	28.07	15.06	1.86	0.01950	3.03	**84.99**
0.07	2.60	7.00	45	3.68	24.96	14.35	1.74	0.01950	2.89	**72.14**
0.07	2.10	7.00	45	2.97	19.11	12.94	1.48	0.01950	2.59	**49.50**
0.07	3.10	6.00	45	4.38	28.21	14.77	1.91	0.01950	3.08	**86.82**
0.07	2.85	6.00	45	4.03	25.22	14.06	1.79	0.01950	2.95	**74.43**
0.07	2.60	6.00	45	3.68	22.36	13.35	1.67	0.01950	2.82	**63.01**
0.07	2.10	6.00	45	2.97	17.01	11.94	1.42	0.01950	2.53	**43.01**
0.07	3.10	5.00	45	4.38	25.11	13.77	1.82	0.01950	2.98	**74.92**
0.07	2.85	5.00	45	4.03	22.37	13.06	1.71	0.01950	2.86	**64.01**
0.07	2.60	5.00	45	3.68	19.76	12.35	1.60	0.01950	2.73	**54.00**
0.07	2.10	5.00	45	2.97	14.91	10.94	1.36	0.01950	2.45	**36.60**
Zone B - Bloomberg Development - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	3.70	7.00	45	5.23	39.59	17.47	2.27	0.01250	2.76	**109.41**
0.07	3.20	7.00	45	4.53	32.64	16.05	2.03	0.01250	2.57	**83.88**
0.07	2.70	7.00	45	3.82	26.19	14.64	1.79	0.01250	2.36	**61.77**
0.07	2.45	7.00	45	3.46	23.15	13.93	1.66	0.01250	2.24	**51.98**
0.07	3.70	6.00	45	5.23	35.89	16.47	2.18	0.01250	2.69	**96.62**
0.07	3.20	6.00	45	4.53	29.44	15.05	1.96	0.01250	2.50	**73.71**
0.07	2.70	6.00	45	3.82	23.49	13.64	1.72	0.01250	2.30	**54.01**
0.07	2.45	6.00	45	3.46	20.70	12.93	1.60	0.01250	2.19	**45.33**
0.07	3.70	5.00	45	5.23	32.19	15.47	2.08	0.01250	2.61	**84.02**
0.07	3.20	5.00	45	4.53	26.24	14.05	1.87	0.01250	2.43	**63.69**
0.07	2.70	5.00	45	3.82	20.79	12.64	1.65	0.01250	2.23	**46.35**
0.07	2.45	5.00	45	3.46	18.25	11.93	1.53	0.01250	2.12	**38.76**
Zone A - Cannon Street to the Thames - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	3.20	8.00	45	4.53	35.84	17.05	2.10	0.01000	2.35	**84.22**
0.07	2.70	8.00	45	3.82	28.89	15.64	1.85	0.01000	2.16	**62.27**
0.07	2.20	8.00	45	3.11	22.44	14.22	1.58	0.01000	1.94	**43.51**
0.07	1.95	8.00	45	2.76	19.40	13.52	1.44	0.01000	1.82	**35.32**
0.07	3.20	7.00	45	4.53	32.64	16.05	2.03	0.01000	2.30	**75.02**
0.07	2.70	7.00	45	3.82	26.19	14.64	1.79	0.01000	2.11	**55.25**
0.07	2.20	7.00	45	3.11	20.24	13.22	1.53	0.01000	1.90	**38.46**
0.07	1.95	7.00	45	2.76	17.45	12.52	1.39	0.01000	1.79	**31.15**
0.07	3.20	6.00	45	4.53	29.44	15.05	1.96	0.01000	2.24	**65.93**
0.07	2.70	6.00	45	3.82	23.49	13.64	1.72	0.01000	2.06	**48.31**
0.07	2.20	6.00	45	3.11	18.04	12.22	1.48	0.01000	1.85	**33.45**
0.07	1.95	6.00	45	2.76	15.50	11.52	1.35	0.01000	1.74	**27.03**

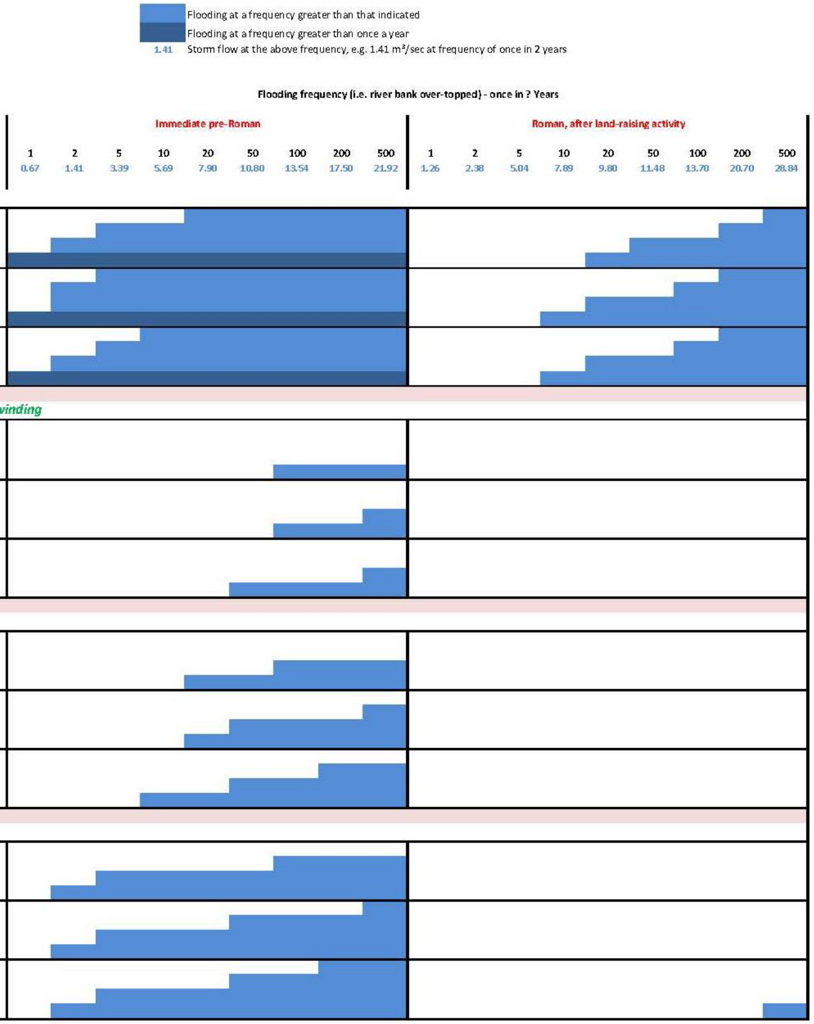


Figure 7-11 Flood frequency reduction in Zone D with increased land raising activity

Greater Walbrook Valley
"Flow full" capacity of Walbrook channel - and consequent flood frequency - comparison of pre-Roman and Roman after land raising activity
Zone D only (Draper's Gardens to Lothbury) - actual land raising activity & effect of additional depth (Section 4.7.3, Table 4-8)
Composite AMC 2 & 3 flows

Manning formula — Velocity of flow in river, $v = 1/n . R^{2/3} . s^{1/2}$ (metric version)

Manning roughness coefficient - preferred - 0.07 — "Flow full" capacity, Q = A.v

Flooding at a frequency greater than that indicated
Flooding at a frequency greater than once a year
1.41 Storm flow at the above frequency, e.g. 1.41 m³/sec at frequency of once in 2 years

Flooding frequency (i.e. river bank over-topped) - once in ? Years

	Immediate pre-Roman									Roman, after land-raising activity								
Years	1	2	5	10	20	50	100	200	500	1	2	5	10	20	50	100	200	500
Flow (m^3/s)	0.67	1.41	3.39	5.69	7.90	10.80	13.54	17.50	21.92	1.26	2.38	5.04	7.89	9.80	11.48	13.70	20.70	28.84

Manning roughness coefficient (n) (no units)	Depth of flow to fill channel (m)	River bed width (m)	Slope of channel sides (degrees)	Wetted length sloping side of bed when full (m)	Area of flow when full (A) (m²)	Wetted perimeter when full (P) (m)	Hydraulic radius (R=A/P) (m)	Slope of river channel (n) (m/ lin.m)	Velocity of flow (v) (m/s)	Flow rate when full (Q) (m³/s)
Zone D - Draper's Gardens to Lothbury - actual land raising activity - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	3.00	7.00	45	4.24	30.00	15.49	1.94	0.00105	0.72	**21.63**
0.07	2.50	7.00	45	3.54	23.75	14.07	1.69	0.00105	0.66	**15.61**
0.07	2.00	7.00	45	2.83	18.00	12.66	1.42	0.00105	0.59	**10.55**
0.07	1.75	7.00	45	2.47	15.31	11.95	1.28	0.00105	0.55	**8.37**
0.07	3.00	6.00	45	4.24	27.00	14.49	1.86	0.00105	0.70	**18.97**
0.07	2.50	6.00	45	3.54	21.25	13.07	1.63	0.00105	0.64	**13.62**
0.07	2.00	6.00	45	2.83	16.00	11.66	1.37	0.00105	0.57	**9.16**
0.07	1.75	6.00	45	2.47	13.56	10.95	1.24	0.00105	0.53	**7.25**
0.07	3.00	5.00	45	4.24	24.00	13.49	1.78	0.00105	0.68	**16.35**
0.07	2.50	5.00	45	3.54	18.75	12.07	1.55	0.00105	0.62	**11.66**
0.07	2.00	5.00	45	2.83	14.00	10.66	1.31	0.00105	0.56	**7.78**
0.07	1.75	5.00	45	2.47	11.81	9.95	1.19	0.00105	0.52	**6.13**
Zone D - Draper's Gardens to Lothbury - actual land raising activity + 0.5m extra depth - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	3.50	7.00	45	4.95	36.75	16.90	2.17	0.00105	0.78	**28.63**
0.07	3.00	7.00	45	4.24	30.00	15.49	1.94	0.00105	0.72	**21.63**
0.07	2.50	7.00	45	3.54	23.75	14.07	1.69	0.00105	0.66	**15.61**
0.07	2.25	7.00	45	3.18	20.81	13.36	1.56	0.00105	0.62	**12.96**
0.07	3.50	6.00	45	4.95	33.25	15.90	2.09	0.00105	0.76	**25.23**
0.07	3.00	6.00	45	4.24	27.00	14.49	1.86	0.00105	0.70	**18.97**
0.07	2.50	6.00	45	3.54	21.25	13.07	1.63	0.00105	0.64	**13.62**
0.07	2.25	6.00	45	3.18	18.56	12.36	1.50	0.00105	0.61	**11.28**
0.07	3.50	5.00	45	4.95	29.75	14.90	2.00	0.00105	0.74	**21.89**
0.07	3.00	5.00	45	4.24	24.00	13.49	1.78	0.00105	0.68	**16.35**
0.07	2.50	5.00	45	3.54	18.75	12.07	1.55	0.00105	0.62	**11.66**
0.07	2.25	5.00	45	3.18	16.31	11.36	1.44	0.00105	0.59	**9.62**
Zone D - Draper's Gardens to Lothbury - actual land raising activity + 1 m extra depth - *Manning No. 0.07 - earth channel; bed lightly-reeded and/or lightly obstructed; winding*										
0.07	4.00	7.00	45	5.66	44.00	18.31	2.40	0.00105	0.83	**36.64**
0.07	3.50	7.00	45	4.95	36.75	16.90	2.17	0.00105	0.78	**28.63**
0.07	3.00	7.00	45	4.24	30.00	15.49	1.94	0.00105	0.72	**21.63**
0.07	2.75	7.00	45	3.89	26.81	14.78	1.81	0.00105	0.69	**18.50**
0.07	4.00	6.00	45	5.66	40.00	17.31	2.31	0.00105	0.81	**32.45**
0.07	3.50	6.00	45	4.95	33.25	15.90	2.09	0.00105	0.76	**25.23**
0.07	3.00	6.00	45	4.24	27.00	14.49	1.86	0.00105	0.70	**18.97**
0.07	2.75	6.00	45	3.89	24.06	13.78	1.75	0.00105	0.67	**16.18**
0.07	4.00	5.00	45	5.66	36.00	16.31	2.21	0.00105	0.79	**28.32**
0.07	3.50	5.00	45	4.95	29.75	14.90	2.00	0.00105	0.74	**21.89**
0.07	3.00	5.00	45	4.24	24.00	13.49	1.78	0.00105	0.68	**16.35**
0.07	2.75	5.00	45	3.89	21.31	12.78	1.67	0.00105	0.65	**13.90**

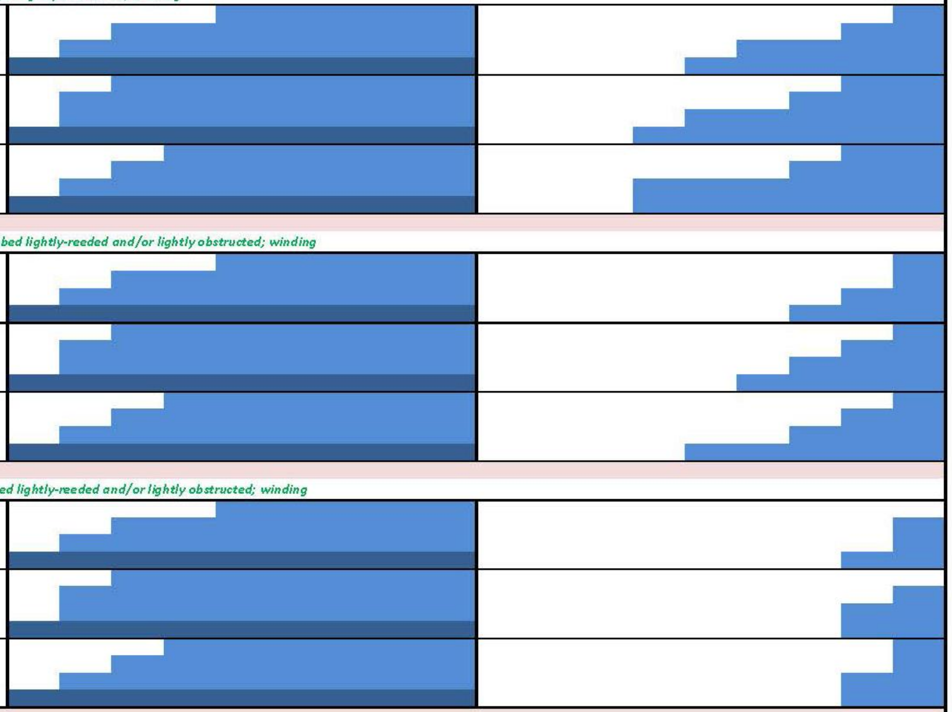
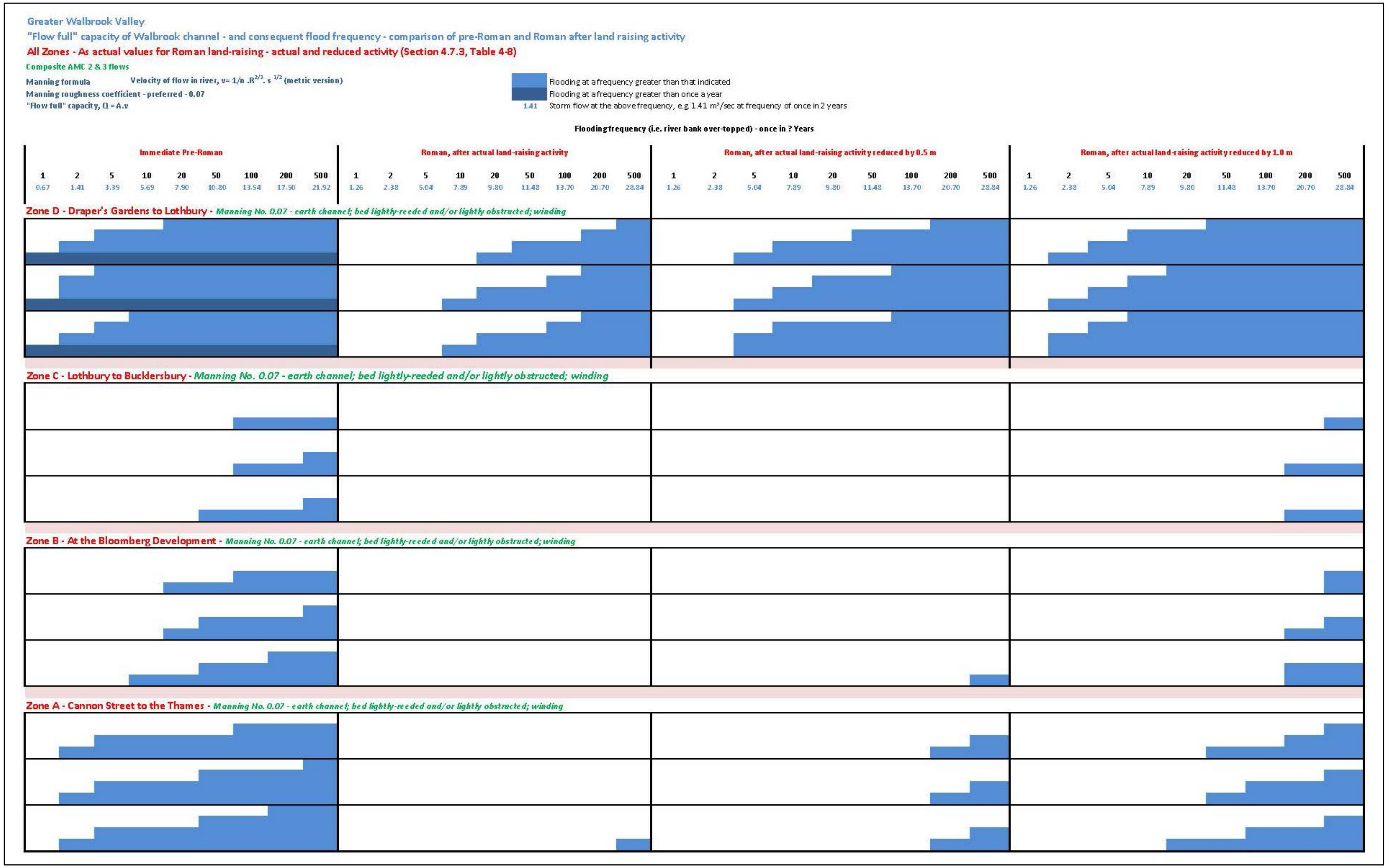


**Figure 7-12	Increase in flood frequency for Zones A to D had level to which land had been raised were lower than actually achieved**



7.3.3 River-realignment

Wherever, the banks of the Walbrook river and its tributaries were strengthened by revetments, it would have been common engineering practice to have straightened those banks and the course of what otherwise would have been a winding river through Zones A, B, D and E. However, this could not be demonstrated by the research as the lengths of streams uncovered in excavations were extremely short. The only site where this could be shown to be the case was MGT86 where two separate lengths of perfectly-aligned, revetted bank were uncovered some 16 metres apart.

Apart from these minor "cosmetic" alterations to the course of the river through the URWV, only two true realignments of the river have been found in the course of the excavations examined in the course of this research. One of these was the estuary of the Walbrook, the western arm of its delta, and on the Draper's Garden site (DGH86), in the northern suburbs, where major re-adjustments to the channel appear to have taken place. The western arm of the Walbrook's delta was realigned from northeast/southwest to a north to south direction. A timber revetment was installed to protect this realignment, although no such protection had been provided to the clay bank raised along the Thames immediately to the east of the Walbrook estuary.

However, it is on the Draper's Gardens site where major realignment works appear to have been carried out – although the reason for them is not clear. The main stream of the Walbrook entered the site from the northeast in line with the channel arriving from Blomfield Street. By the early 2nd C, development of the site for industrial activity was more advanced (see Section 8.4) as were the drainage and road works. On the eastern part of the site, two channels entered from the northeast corner, respectively from the north-northeast and northeast and were immediately confluent, continuing on a constructed straight course in a north-northeast to south-southwest direction to exit the site in the middle of its southern side. The channels varied in width along the lengths uncovered, between 2m and 3m. A short stretch of another channel, about 2m wide, was found aligned with and between 10 and 12m to the west of, the first channel.

A main road, about 9m wide ran between the two sets of streams. It may be that the channel flanking the west side of the road was constructed to conduct run-off from the road to the Walbrook passing east to west on the south side of the site. The northeast oriented stream appeared to be in line with the main stream of the Walbrook arriving from Blomfield Street and it could well be that the western of these two streams, which flanks the eastern side of the road had been constructed to drain water away from it and into the Walbrook.

The straightness of the main channel through the site and the protection of its course with timber stake and plank revetting would suggest that a certain amount of re-alignment was involved in the management of the river through the site. However, as is common with river re-alignment, the action would almost certainly have increased the flood frequency downstream.

By the middle of the 3rd C, the only one channel remained entering and passing down the east side of the site, following the channel arriving from the northeast. The second channel to its immediate west appears to have been built over. This reinforces the proposition that the surviving channel was the Walbrook itself. This channel is in existence at least through to abandonment of the area at the end of the Roman occupation.

7.4 Flow Regulation and the Town Wall

This section responds to Research Question Q 7.3:

> *Could the town wall have been used to limit the Walbrook's rate of flow into and through the urban area and, if so, how would this have impacted upon development within the urban floodplain?*

7.4.1 The wall as a flow regulation device

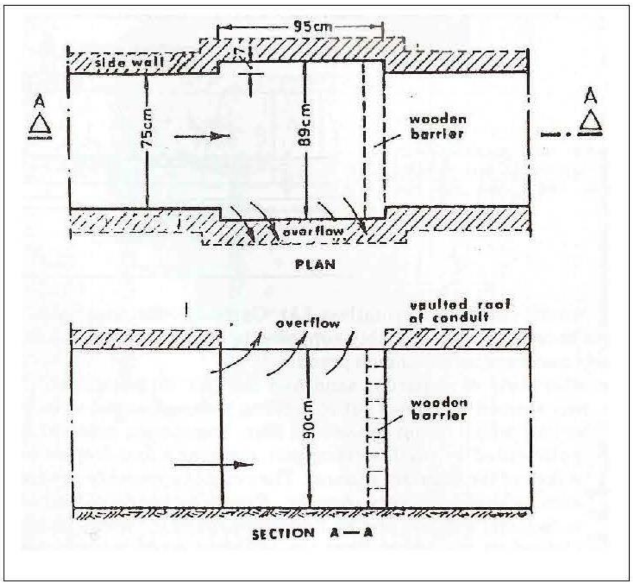
One of the first acts of the Roman population of an "embryonic" London would have been to define the town's boundaries as, in accordance with Roman culture, it would have been important to determine the location of cemeteries, which would only have been permitted outside the town limits (Harward et al, 2015: 2). As indicated by the location of early burials, the northern boundary must have followed a line similar to that of the town wall, built a century and a half later. The town's engineers would have realised from the start that the fen and marsh that constituted the upper and middle urban area close to the River Walbrook was subject to frequent flooding. It is quite probable that, from an early stage in the development of the town, engineers involved in planning and implementing flood alleviation and protection works would have wished that they could hold back the floodwaters of the Walbrook, reducing their rate of flow into and through the urban area. To do this would have needed the construction of a dam across the floodplain, many hundreds of metres long, upstream of what had been designated as the northern town limits.

A decision to construct the town wall, built in the period 190 to 225 CE, would almost certainly have been considered by the engineers responsible for flood alleviation and protection as an opportunity to finally dam the waters of the Walbrook. To achieve this, instead of bridging the river and its tributaries where they crossed the line of the wall into the urban area, they constructed culverts. These culverts, six of which have been identified to date, four of them Roman, had a cross-section that allowed passage of the normal flows without restriction (see later in this section). However, simple sluice gates on the entrance to the culverts would have restricted storm flows such that they would have backed up, flooding the marsh which lay to the north of the wall but not the urban area south of the wall. No remains of sluice gates have been found at the entrances to the culverts but, as they would probably have been made of wood, they may have disintegrated and decomposed. Figure 7-13 shows two forms of flow control, both in use by the 1st CE – a simple timber stop-log device used at Gier, Lyon (Jeancolas, 1978; 179-205) and an adjustable timber and metal sluice gate used at Nîmes (Stubinger, 1909).

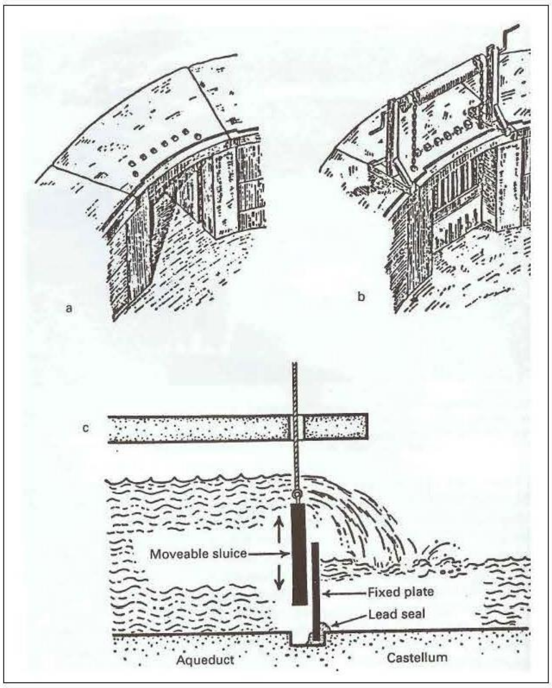
Dr Philip Norman, was perhaps the first to comment that

> *"…….the Roman Wall greatly obstructed the flow of the Walbrook, the culverts made by the Romans through the wall to carry the stream being insufficient and this caused the marshy land at Moorfields"* (Norman and Reader, 1906, 170-184).

It was further surmised that soakage beneath the wall from the Moorfields marsh may also have contributed to a continuation of marshy conditions inside the wall in the upper URWV into the medieval period. Culverts that were constructed by the Romans to convey streams through the town wall have been noted by an ad hoc Committee of the Royal Commission on Historical Monuments (Royal Commission on Historical Monuments, 1928: 86-87; 89) that produced an inventory of London's Roman monuments. Their report and others note the following points at which building and archaeological excavations have discovered these culverts, shown on Figure 7-14:



left:
a simple timber stop-log device for controlling flow into a culvert
- Gier aquaduct, Lyon
(Jeancolas. 1978)



right:
a timber and metal sluice gate used to flow into a culvert -
Nîmes aquaduct
(Stübinger. 1909)

Figure 7-13 Simple wooden sluice gates of types that could have been used to control flow through culverts in the town wall

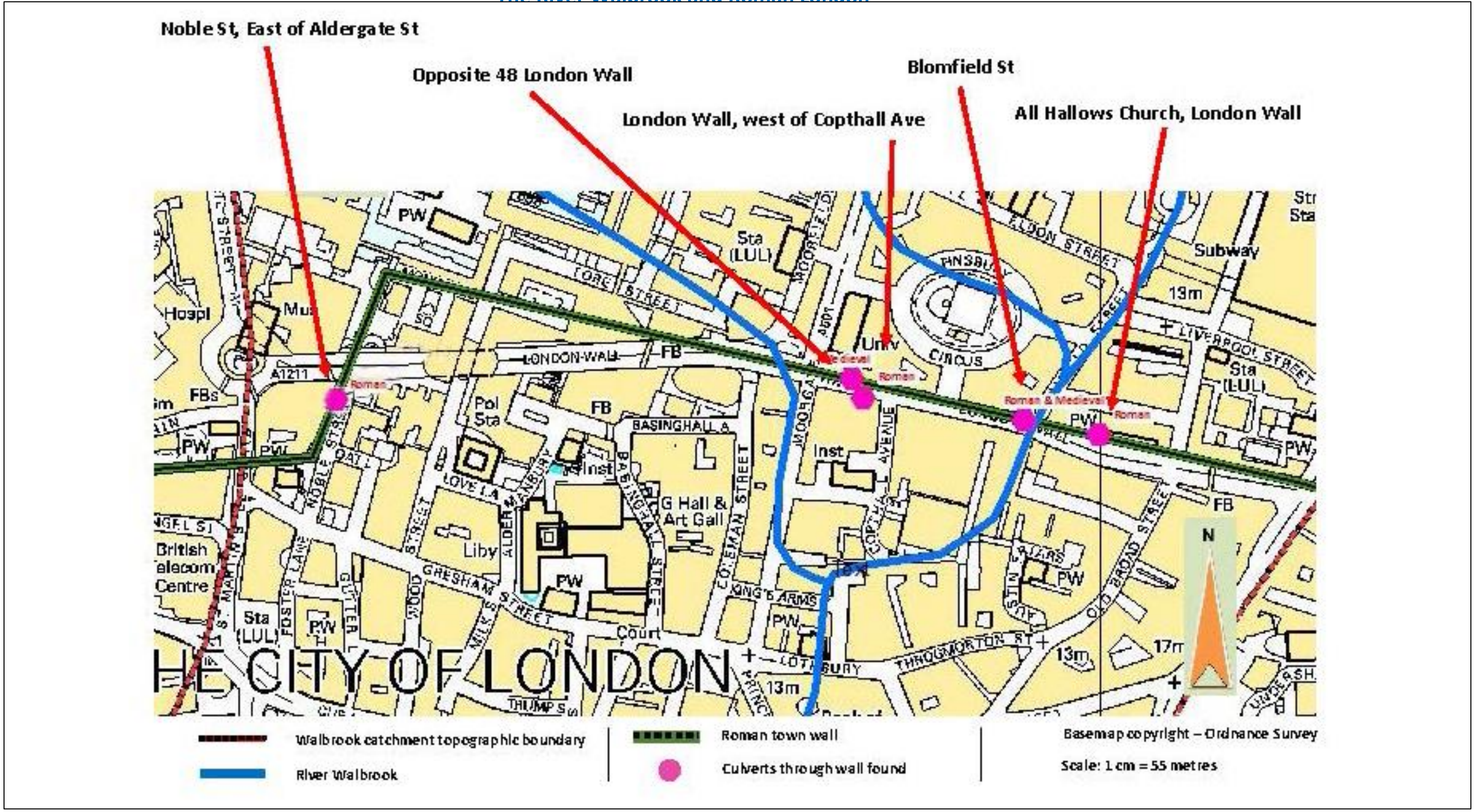


Figure 7-14 Location of culverts carrying the Walbrook and its tributaries through the town wall

a. **London Wall, a few metres to the west of the junction with Blomfield Street.** (RHCM. 1928; 87) Two culverts were discovered at this location, an upper one discovered in the course of sewer construction in 1837 and a lower culvert discovered by C Roach Smith in 1841. The channel invert of the lower culvert was 7.47m below the 19th C ground surface, i.e. at approximately 7.50m OD, this would correspond well with the channel invert of the Roman Walbrook at the southern end of Blomfield Street (BLM87) as estimated in this research. Describing the lower culvert, Roach Smith stated:

> *"In London Wall, opposite Finsbury Chambers, at the depth of 19 feet* (5.80m) *(to the extrados of the arch) what appeared to have been a subterranean aqueduct was laid open. It was found to run towards Finsbury under the houses of the Circus about 20 feet* (6.10m)*. At the termination were five iron bars fastened perpendicularly into the masonry …… At the opening of the work towards the city was an arch 3 ½ feet* (1.07m) *high from the crown to the springing-wall, and 3 ¼ feet (0.99m) wide …….. the spandrels were filled with rag-stone to afford strength to the work."* (Roach Smith, 1842, 145-166)

Figure 7-15 is a sketch of the culvert made at the time of its dicovery.

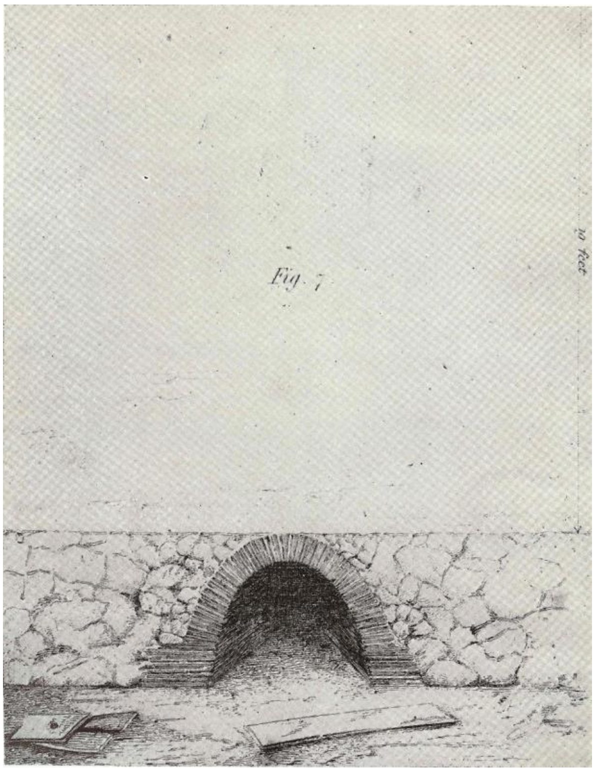


Figure 7-15 Roman culvert, London Wall, W corner of Blomfield Street (RHCM. 1928; Plate 27)

b. **London Wall, All Hallows Churchyard.** (RHCM. 1928; 86-87) The town wall forms the northern boundary of the churchyard and below the plinth of the wall, a culvert was found in 1905.

> *"…… the foundation was pierced obliquely by a brick-lined culvert, 15 in. (0.38m) by 9 in. (0.23m), set in red mortar, in a hollow depression at a depth of 2 feet 4 in. (0.71m) below the plinth. The fall of the drain was from south to north."* (RHCM. 1928; 87)

The discovery is shown in an illustration of the site (Royal Commission on Historical Monuments, 1928), reproduced as Figure 7-16. There are two culverts, one lower than the other, the lower being as described above. It is probable that the upper culvert was constructed long after the departure of the Romans, possibly in the medieval period (see (d), the 48 London Wall example), after the marshy deposits had accumulated. The culvert on the left of the illustration is of a Victorian sewer.

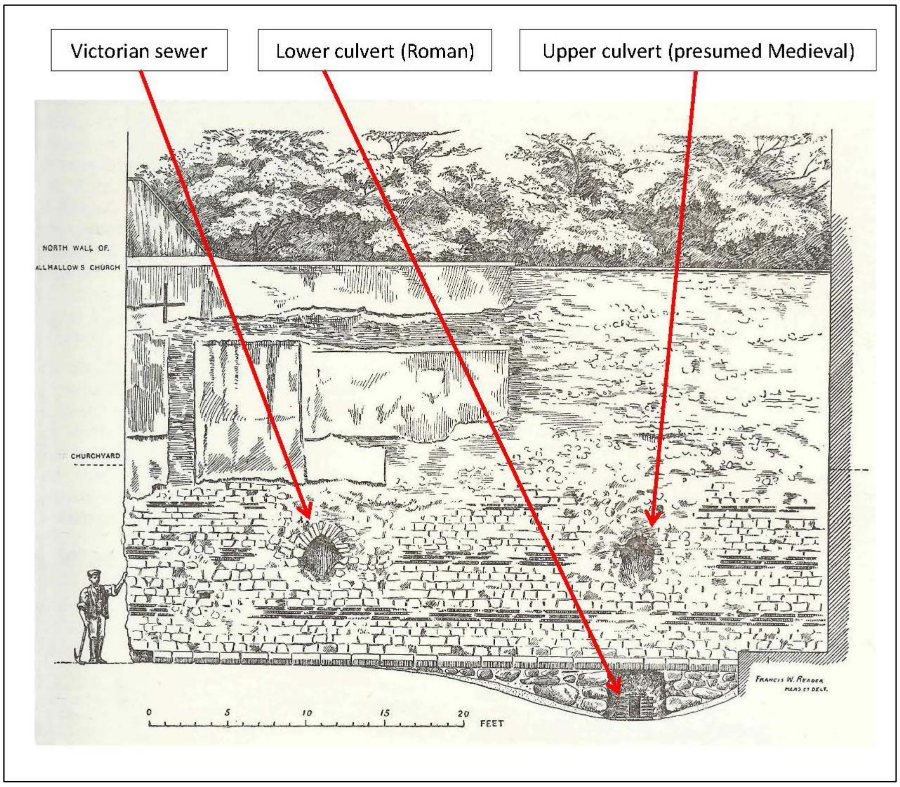


Figure 7-16 Lower Roman culvert and an upper culvert, presumed medieval, that carried the flow of the Walbrook's main stream through the town wall (Royal Commission on Historical Monuments, 1928)

The lower culvert is significantly smaller in cross-section than the one found at Blomfield Street and may have carried a tributary of the Walbrook through the wall into the town, although the direction of inclination of its invert appears to contradict this. The channel invert appears to be at an elevation higher than that of the culvert found at Blomfield Street. The remains of a human skeleton and many pieces of tile of Roman origin were found in deposits, described as stream deposits, below the channel.

c. **London Wall, just west of Copthall Avenue (formerly Little Bell Alley)** (RHCM. 1928; 89) A tributary of the Walbrook is described as passing beneath the town wall at this point and conducting water into the city. It was formed as a red brick arch, measuring 6 feet (1.83m) high by 4 feet (1.22m) wide, with its soffit 18 feet (5.49m) below ground level. This would have meant that its channel invert was a total of 7.32m below ground, at approximately 7.68m OD, similar to the culvert found at Blomfield Street. Writing in The Builder in 1889, J E Price stated that the culvert was *"supported on either side by massive piles of elm between which the river ran"*.

d. **Middle of the road opposite 48 London Wall (LWL87).** Workers excavating a BT shaft found a "well-built arched stone culvert running north to south through the E-W city wall". The stones forming the arch and the invert were built directly into the wall. The culvert sloped very slightly (less than 5°) from N to S so conducting water into the city. The culvert was in the form of an arch, 0.9m high and 1.24m wide, its shape resembling the more pointed half of an ovoid.

The few drawings to scale are a little confusing with respect to the level of the invert of the culvert, variously shown as 10.38m OD and 9.98m OD. The latter is considered more probable as it was measured relative to the "datum bottom of concrete service trench" at 10.28m OD. The level of this culvert would then correspond to that of the upper culvert found in 1837 approximately 100m to the east, close to the intersection of London Wall and Blomfield Street (see (a), London Wall). It is almost certainly of medieval build, and is an exact match with the culvert found at KEY83, 45-50 London Wall, which was positively identified as medieval (Maloney and de Moulins, 1990: 80-81). This would reinforce the view that the upper culvert found near Blomfield Street was also of medieval build and the lower culvert a Roman construction.

e. **E of Aldersgate Street (1922) and Noble Street, NE of St Ann and St Agnes Church (1958-59)** (Journal of Roman Studies. 1959; 126) Another north-south culvert constructed through the town wall was discovered both on its external and internal sides immediately to the east of the Museum of London during excavations respectively undertaken in 1922 and 1958. This was a brick-lined culvert that appeared to date to the late 3rd C. Given its location on the NW extremity of the town, it is difficult to know whether, it flowed south to the Thames or drifted southwestwards towards the Walbrook.

Only the culvert at Blomfield Street would have carried the main stream of the Walbrook, the remainder would have carried its tributaries. It has recently been noted that the restricted cross-section of this culvert could have caused the ponding upstream of the wall (Harward et al, 2015: 68). Four of the six culverts found in the five locations were of Roman construction, one was of definite medieval origin and one, at a higher elevation, at All Hallows Church, London Wall, appears to have been of the medieval period. Although unrelated to the Walbrook catchment, another example of the Romans conveying streams through the town wall in culverts was found at Aldgate. In Jewry Street, Nos 32-35, EC3 in 1861 (RHCM. 1928: 85), as well as in 1933 (Merrifield, 1965), a 23m length of the town wall was exposed. In the later work, it was found that the foundations were cut through by a brick culvert. This conveyed a stream, unrelated to the Walbrook, through the wall (Collingwood and Taylor, 1934, 196-221).

Assuming that the culvert through the town wall, immediately to the west of the London Wall/Blomfield Street intersection, had the dimensions stated by C Roach Smith (Roach Smith, 1842; 152), 0.99m by 1.06 m, its capacity to pass flow before it became submerged can be calculated to have been 2.05 m^3/sec (Blake, 1951, 5.30-35.35) (Nelson, 1983, 21.51-21.52). Referring to Figure 7-10, this flow rate can be seen to be well below the capacity of the Walbrook channel in all of the zones after the land raising activity carried out prior to the construction of the wall. In fact, downstream of Zones D and E, for most channel configurations, it would have been within the capacity of the river to carry this throttled rate of flow without causing flooding even had land-raising activity not been carried out (see Figures 6-5, 6-7 and 6-9).

In practice, friction loss incurred by the passage of water along the 6-metre long culvert would have led to a slightly lower flow capacity than this. However, the friction head loss over such a short length of culvert would not have exceeded 0.1m and the reduction in capacity minimal.

The Romans may have wanted to restrict flows into the urban area to less than 2.05 m^3/second; as stated above, timber sluice gates of simple construction, left partially closed, would have been a simple and appropriate means of further controlling flow into and through the culvert. The metal bars found at some of the culverts would have acted as a screening device and reduced the risk of blockage by logs and other large floating items carried downstream on storm flows.

7.4.2 Beneficial impacts stemming from flow regulation

Whether by design or an unplanned consequence, the very small cross-section of culverts compared with that of the stream channel would have restricted flow into the urban area and that with the addition of a simple sluice gate device could have prevented all flood flows entering the urban area. A number of benefits would have accrued from this restriction on the flow of the Roman Walbrook through the urban area, viz.:

a. The principal benefit would be the complete avoidance of flooding in what would become the former floodplain of the urban Walbrook. There would be no need of further land reclamation that, in places, had limited success in reducing flooding.
b. Having virtually eliminated the threat of flooding, higher-status buildings could be constructed on land close to and in the former floodplain of the Walbrook, significantly raising the value of that land.
c. High rates of flow in the river would no longer erode its banks, undermine river training structures, bridge pier foundations and other riverine structures.
d. River water prevented from passing through the wall would be backed-up into the low-lying area that would eventually become known as the Moorfields marsh creating a reservoir of water that could be used:
    i. to secure a source of water for feeding the gravel aquifer beneath urban Roman London that was the main source of water supply through wells; and

ii. to even out fluctuations in the flow of the Walbrook into the urban area to the benefit of those industries reliant on the Walbrook for their supply of water; in particular, were a water-mill to have existed, a reservoir of water, in effect a mill-pond, would have increased its operational reliability.

e. Port infrastructure at the estuary, no matter how informal, would no longer be at risk of damage from sudden rushes of water and nor would vessels beached, tied up or at anchor in the estuary.

The character of development within the Walbrook Valley appears to have undergone a change in the 3rd C. Culverting of the Wallbrook through the wall, whether planned or not, would have eliminated flooding within the urban Roman Walbrook Valley. With very few exceptions, the site investigation records in Zone D, cited in Section 8.4, comment on the paucity of evidence of industrial activity beyond the end of the 2nd C. A significant reduction in industrial activity would have led to an improvement in the quality of the Walbrook's water. This combination of control over flooding and reduced pollution of the Walbrook would have increased the value of land in the urban Walbrook Valley. There is evidence of the construction of higher status masonry buildings in Zones B, C and D from the 3rd C where, prior to this, construction had been almost entirely of low-status combinations of timber, wattle and daub. An extensive building, dated to the early 3rd C, was found to have been constructed in Zone D on the MOG86 site. Roman tessellated pavements, attributed to villas, have been found in Zone C in 1803 and 1805 in the southwest corner of the Bank of England, a short distance from what would have been the banks of the Walbrook (Roach Smith, 1859, 56-58; Plates XI and XII). It is unlikely that the Temple of Mithras would have been constructed in the mid-3rd C on the east bank of the Walbrook (WFG44 & 45; BZY10), an area previously occupied by market stalls and small-scale industries, had the Walbrook remained heavily polluted at this time.

7.5 Flooding and the Counter-Intuitive Decision to Develop the Walbrook Valley

This section responds to Research Question Q 7.4:

Given that the middle URWV was at risk from frequent flooding why, counter-intuitively, was it used so intensively by industry and craft workshops?

It has been demonstrated in Chapter 6 that flows in the Walbrook were sufficient to cause flooding in the whole of the upper and middle reaches of the URWV, as well as parts of the lower reaches, with a frequency exceeding once a year. The areal extent of the flooding depended upon the physical topography of land bordering the river, the intensity and duration of a storm as well as whether the storm passed along or across the major axes of the Greater Walbrook Valley. Flooding of the whole of the river's urban floodplain would have been a rare event but may well have been experienced by most generations.

The district most at risk of flooding was the depressed "bowl" of marshland bounded by Finsbury Circus, Austin Friars, Angel Court and Moorgate. As previously noted, this area may well have resembled a lake with numerous small islands, formed from the river-borne debris of run-off, the consequence of a major storm or a particularly extended period of wet weather. The depression may by scouring of lighter materials such as clay and silt, common deposits in the area.

The land either side of the estuarine stretch of the Walbrook, Zone A, principally that to the west of the river, from Cannon Street to the Thames, was also marshy. The low-lying land of this stretch adjacent to and closest to the Thames may have been subject to tide-influenced flooding. Lower Walbrook land, north of Cannon Street through to Bucklersbury, i.e. the land represented by the current Bloomberg development site, would have experienced flooding from storm flows, made worse, at times when affected by flow in the Walbrook being backed-up by high tidal water levels at the bridge over the Thames.

Only the short stretch of the Walbrook between Lothbury and Bucklersbury, all but the northernmost part of Zone C, may have escaped flooding due to the increased slope to the bed of the Walbrook through the zone.

Given the marshy nature of the Walbrook's middle and upper urban floodplain, and much of its estuarine section, it would have been understandable had those responsible for developing the town left the area unoccupied. Reclamation of the area, sufficient to render it capable of development, would have needed extensive and costly work to raise the level of ground surface above estimated flood levels. In addition, riverbanks consisting mainly of a readily-eroded gravel, sand and silt mix, would need to be protected and the bed of the river kept clear of obstructions. Even with land levels raised, any eventual buildings, including those of lighter construction, would have needed to incorporate measures to stabilise their foundations given the marshy base to the dumped fill material.

However, in spite of the obvious cost and difficulty of the task, those areas of the URWV that experienced flooding were, indeed, subject to major land raising works. A decision to undertake works of this magnitude and risk would not have been taken lightly but, as no contemporary records exist, the reasons for taking it can only be speculated upon.

Excavations at the ONE94 site found a major road, constructed in the 1st C, striking north from the main east-west road, the Via Decumana, on the west side of the Walbrook. A major road, built using a causeway form of construction, indicative of the need to negotiate marshy conditions, oriented approximately north to south, was uncovered at the KEY83 and LOW88 sites in Zone D of the middle URWV – almost certainly an extension of the ONE94 road. Similarly, a north south road has been found on the east side of the Walbrook (DGH86), probably again having its southern end at the Via Decumana. Construction of main roads attracts development and the construction of this road through the middle and northern URWV may well have been the stimulus for the siting of industry close to it and away from the principal residential areas. Virtually every archaeological investigation in the northern suburbs, Zone D, has found evidence of one or more industries, frequently the types of industry that would have created obnoxious fumes, large volumes of solid waste and polluting effluents.

A start on reclamation and flood protection works was made early in the development of the town, soon after the Boudican revolt. It is possible that its citizens wanted to create an area to which the more obnoxious industrial activities could be located to avoid them adversely affecting the quality of life in the governmental, commercial and residential areas of the urbanised area. London's predominant wind directions are from the southwest quarter and odours from the more obnoxious industries if located in the middle and upper URWV would have been carried away from the main urban area without causing undue nuisance. Most productive industry can benefit from a ready source of water and some, such as butchery and industries stemming from it, cannot function without access to copious amounts of water. The upper and middle stretches of the URWV would therefore have been an ideal choice for an "industrial zone", apart from the nuisance of regular flooding.

There are therefore three reasons for industry to have been located in the middle and upper reaches of the urban valley – remoteness from the main areas of residential and administrative development, ease of access to markets in the main town and proximity to a source of water, being the Walbrook and its main tributaries. If this were to be the case, then reclamation may not have been carried out over the whole floodplain but only as required to construct roads above flood levels and to develop specific plots of land for industries and crafts establishing themselves in the valley.

The two possible explanations for counter-intuitively developing the middle and upper reaches of the URWV are not mutually exclusive. It is probable that a combination of major road construction and a preference for industry to be located away from the administrative and residential areas that lead to the extensive flood avoidance works undertaken in the URWV.

An argument to reclaim the estuarine stretch of the Walbrook floodplain would have been easier to defend than works to reclaim and protect the middle and upper urban Walbrook. The Via Decumana, which carried traffic to and from the administrative centre of the town, the Forum and eventual Basilica, towards the amphitheatre and the Huggin Hill public baths as well as to the west and northwest of the Province, bridged the Walbrook immediately north of Bucklersbury. Another major east-west road bridged the Walbrook at Cannon Street. The distances to the Thames from these two principal roads were respectively just 250m and 100m. Given the short lengths of service roads needed to link the Walbrook estuary to these two main roads, it may have been thought that a secondary port handling river-borne products would have been highly beneficial and relieve pressure on the Port of London infrastructure at the bridge. As an example of the industry that could benefit from such infrastructure, although it may not have been planned from an early stage in the town's development, the Bucklersbury area would prove to be an ideal location for a mill driven by the waters of the Walbrook (Chapter 8, Section 8.7).

However, although a case could perhaps be made for land raising activity in the URWV, there are indications, particularly noted by the investigation team at Angel Court (ACW74), that those involved in developing the middle URWV seriously under-estimated the magnitude of the works of reclamation and flood protection that would be needed. There are clear indications that the land was raised in stages, with subsequent flooding of each stage leading to yet further dumping to raise the elevation of the land. Once committed to a concentration of industry in the middle and upper URWV by road construction, requiring the initial works of reclamation and supporting drainage infrastructure, the town's population would almost inevitably have had to make ever more investment in further works of reclamation and flood protection to achieve their objectives.

7.6 Principal Conclusions – Flooding and River Management

Q 7.1 What was the incidence of flooding, reclamation to raise surface levels, revetments to protect riverbanks and constructed drainage as evidenced by the findings of archaeological investigations?

a. The Walbrook and its tributaries have been found in a smaller percentage of investigations than anticipated. The main river channel was uncovered least in the middle URWV, Zones C and D, probably due to the flat nature of the area leading to meandering and anastomising.

b. As may be expected from the palaeo-stratigraphy and flood-risk analysis, archaeological evidence of flooding by the Roman Walbrook was found in Zones D and E, on 57% and 33% of the sites respectively. The sole instance of flooding in the Roman period away from the northern suburbs and extra-mural area was on the DGH site in Zone A and this was due to inundation by the Thames not the Walbrook.

c. Land raising activity was undertaken in the first two centuries of the occupation in the URWV, probably to achieve two separate objectives. In Zones D and E, the land surfaces were raised in order to eliminate marshy conditions in preparation for development and to reduce the frequency and extent of flooding. Whereas, in Zones A, B and C, where flooding would have been less frequent, springs from the gravel terraces rising rapidly away from the valley floor created marshy conditions at lower levels and, in these zones, land raising appears to have been principally concerned with creating a drier land surface that could be developed.

d. Land raising in Zone D was frequently carried out in stages. Evidence of flooding at all intermediate stages is a common indication that dumping to further raise the land was carried out to avoid subsequent flooding. It would appear that land raising was generally unsuccessful as each new surface still suffered flooding, necessitating yet further land raising.

Q 7.2 *What measures were taken to protect land from flooding by the Walbrook and to actively manage the river and were they effective?*

a. Land raising was the principal method used to reduce flood-risk. There was considerable variation in the depth of fill between sites but, on average, land was raised by 1.7m in Zones A and B, 1.8m in Zone C and 1.3m in Zone D. In Zone, land was raised by an average of just 0.4m, probably reflecting its rural character.

b. Comparison of the flood-risk before and after land raising shows that flooding was eliminated in Zone C and that the risk was reduced to negligible in Zones A and B. In Zone D, the risk was significantly reduced with frequency not exceeding between once in 10 or 20 years, where land raising was completed to a level in excess of 7.2m.

c. Most land raising was undertaken in the period post-Boudican revolt through to completion of the town wall in the early decades of the 3rd century. Materials used to raise the land consisted of waste from quarrying and levelling operations, debris from building demolition and other anthropogenic material, in particular domestic refuse and stable waste.

d. Land raising materials were structurally weak, particularly when they had a high organic content, such as the stable waste used in Zone B. This weakness was evidenced by buildings, even the lightest of structures, having to be provided with stone or timber beam foundations, sometimes under-pinned by timber piles. The banks of rivers formed from these materials had to be retained by revetments, piled to a shallow depth.

e. Post-construction of the town wall, land raising was mostly confined to extra-mural areas and was almost certainly used as a method of refuse disposal.

f. Few examples of river realignment have been found during archaeological investigations, the most notable being on the Draper's Gardens site (DGT06).

g. Post and plank revetments were used to protect and retain riverbanks. They were mostly confined to the banks of the main Walbrook stream but were also used on tributaries where riverine land had been used for siting industrial premises. Box and double box revetments constructed from large cross-section timber piles and beams , although used to provide secure surfaces for wharves along the Thames, have not been found on the Walbrook.

h. Drainage systems were found constructed on almost every site that had undergone land raising. Unlined and timber-lined drains have most commonly been found. Timber box drains suffered frequent blockage and were rapidly replaced by open drains.

Q 7.3 *Could the town wall have been used to limit the Walbrook's rate of flow into and through the urban area and, if so, how would this have impacted upon development within the urban floodplain?*

a. The town wall could have served to control flooding within the urban area. This function may have been built into the wall by design as, instead of bridging the channels, the Walbrook and its tributaries were conveyed through the wall in culverts, each with a very restricted cross-section compared with that of the river channel. Flow may have been further controlled using simple, timber sluice gates. However, although evidence of an iron debris screen to protect one of the culverts has been found, there is none to indicate the presence of sluice gates.
b. Restricting flow from the Walbrook into the town would had a number of benefits. The main benefit would have been elimination of flooding. This environmental improvement would have significantly raised the value of riverine land within the town and may well have been a factor in the upgrading of residential building that ensued from the 3rd C. It may also have led to the siting of the Temple of Mithras on the banks of the Wabrook immediately north of Cannon Street. By avoiding storm surges in the Walbrook, its banks and riverine structures would no longer have been subject to erosion nor would boats using the estuary have been buffeted by them.
c. The town wall would have acted as a dam and created the conditions for an informal, extra-mural reservoir of water. This would have increased the reliability of the gravel terrace aquifers that fed the wells within the town to the benefit of the population and industry. A reservoir would also have increased the working reliability of a Walbrook-powered mill were one to have been constructed.

Q 9.4 *Given that the middle URWV was at risk from frequent flooding why, counter-intuitively, was it used so intensively by industry and craft workshops?*

a. The economic case for land raising activity in Zones A, B and C would have been stronger than for the northern suburb, Zone D. Zones A, B and C were close to the residential, commercial and administrative areas of the town. Zone D was low-lying and not only continuously marshy but also prone to frequent flooding.

b. Two factors may have contributed to the counter-intuitive decision to reclaim the low-lying, flood prone, marshy Zone D. Two main roads were constructed towards the north, one either side of the Walbrook, starting from the main east-west road, the Via Decumana. Both crossed the marshy, flood-prone land of Zone D. These roads offered the advantage of transport links not only into Roman London but also to the main roads to elsewhere in the Province. They would have encouraged the development of industry along their routes. A second factor is supported by the archaeological evidence presented in Chapter 8, which shows that Zone D was the site of industries many of which required a reliable source of water and that produced highly polluting liquid effluents, obnoxious odours and large amounts of solid wastes. The siting of those industries away from, and downwind of, the main urban centre had considerable benefits and may have been the result of a planning decision by the public administration.

Chapter 8 Roman Walbrook – Beneficial Use

8.1 Introduction

Given its propensity to flood and the extensive measures taken to reduce the risk of flooding and to control the Walbrook, there can be little doubt that the river exerted a negative impact on parts of Roman London. However, as a counter to this, given its reasonably constant, perennial flow, the river also had the potential to be a force for good and although, it has not been the prime objective of the research to assess beneficial usage of the Walbrook, it would be incorrect to give a solely negative impression of the river's impact.

A mean base flow rate of 87 l/sec (Section 5.8.3) is of sufficient magnitude for it to have been put to significant beneficial use by the population of what would, today, be considered a small town. It would have had the potential to supply the potable water needs of a far greater population than that of Roman London (Swain, 2008; 33-40) and still have sufficient to supply needs of industry.

The Walbrook arrived at the northern boundary of the town at a level of approximately 7.50m to 8.00m OD and HWST at the Thames ranged between 0.50m and 1.50m OD during the period of the Roman occupation. There was therefore a fall of the river through the town of between 6 and 7 metres, providing a potential head that could possibly have been used to drive milling and water-lifting machinery, both in common use by that time.

The Walbrook therefore had a potential to be of considerable benefit to the population of the URWV.

The following are summaries of more detailed sections contained in Appendix 8C.

8.2 Objectives

Appendix 2E is a tabulation of the significant finds compiled as part of the study of the archaeological records from 51 site investigations in the URWV. The contents of this extensive table provide an insight into beneficial use of the Roman Walbrook.

The principal objectives of this chapter and its related Appendix 8C are therefore to:

- identify what types of beneficial use of the Walbrook could have been practised by the population of Roman London;
- identify evidence of actual beneficial use of the Walbrook;
- determine whether environmental or social conditions influenced whether particular use was concentrated in specific areas of the URWV; and
- identify what use could have been made of the Walbrook for which, as yet, there insufficient evidence to confirm such use.

Beneficial use, potential and actual, of the Roman Walbrook is discussed under the following headings:

- Domestic water use	Section 8.3
- Industrial water use	Section 8.4
- Agriculture and animal husbandry	Section 8.5
- Ritual use	Section 8.6
- Walbrook-powered milling	Section 8.7

As clarification, the research was limited to beneficial use only within the urban Roman Walbrook Valley. It was not an objective of this present research to compare the economic importance of industry, agriculture and animal husbandry found in the Walbrook Valley with other parts of Roman London. The research was also likewise limited with respect to comparison of evidence for domestic water use, ritual use and milling in the Walbrook Valley with elsewhere in Roman London.

8.3 Domestic Water Use

Securing a source of water supply is a fundamental strategic need for armies both on the move and encamped. It is reasonable to speculate that the invading Roman military commanders who viewed the two low hills, Ludgate Hill and Cornhill, on the north bank of the Thames from the vast tidal marshes of the south bank identified them as a good, defensible position on which to establish a camp. This opinion may well have been strengthened by the existence of a stream, the Walbrook, which ran between the two hills in its own shallow valley. In addition to it forming a defensible boundary, the stream may have appeared to the military, at first sight, as capable of providing a useful source of drinking water. However, in the event, the use of the stream as a source of potable water was to prove unnecessary.

The permeable gravels below the soil of urban Roman London resting on impermeable London Clay acted as a reservoir for water.

In the very earliest days of the settlement, carts may have been used to collect water from the banks of the Walbrook for distribution to the population. However, the abundance of groundwater just below the feet of the inhabitants must soon have become apparent as evidenced by an abundance of wells from the period, Figure 8.1. Although local distribution pipes have been found fed from large wells, at least one installation of which with two well shafts was mechanised, no major distribution network has been found. There is evidence that Walbrook water was not considered fit for domestic use without some form of simple treatment found on one excavation, LOW88.

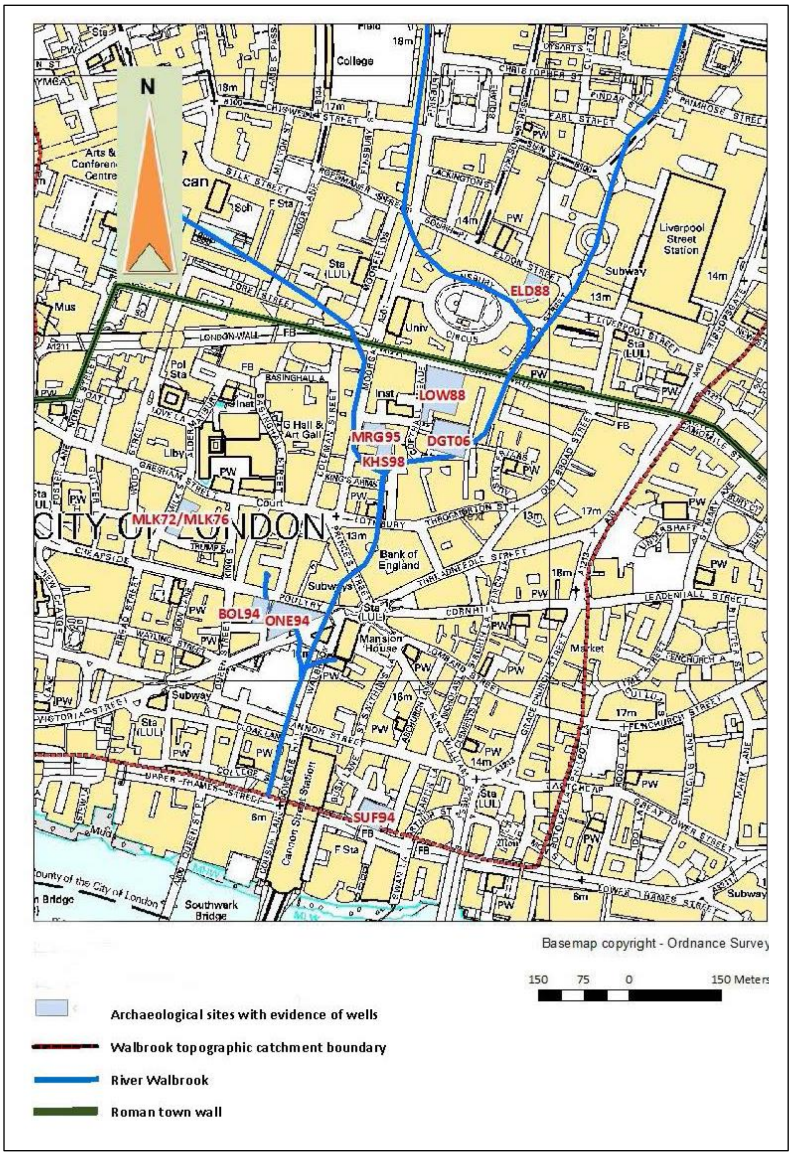


Figure 8-1 Archaeological investigation sites with evidence of wells

Given the abundance of wells and the lack of any networked supply, it is therefore unlikely that the Walbrook was used a source of potable water with the possible exception of the very earliest years of occupation.

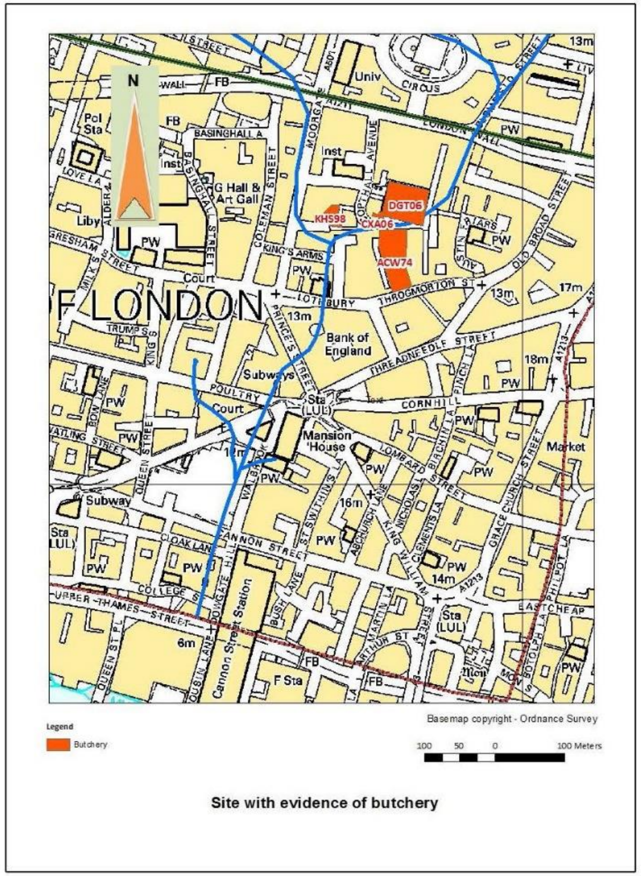
8.4 Industrial Water Use

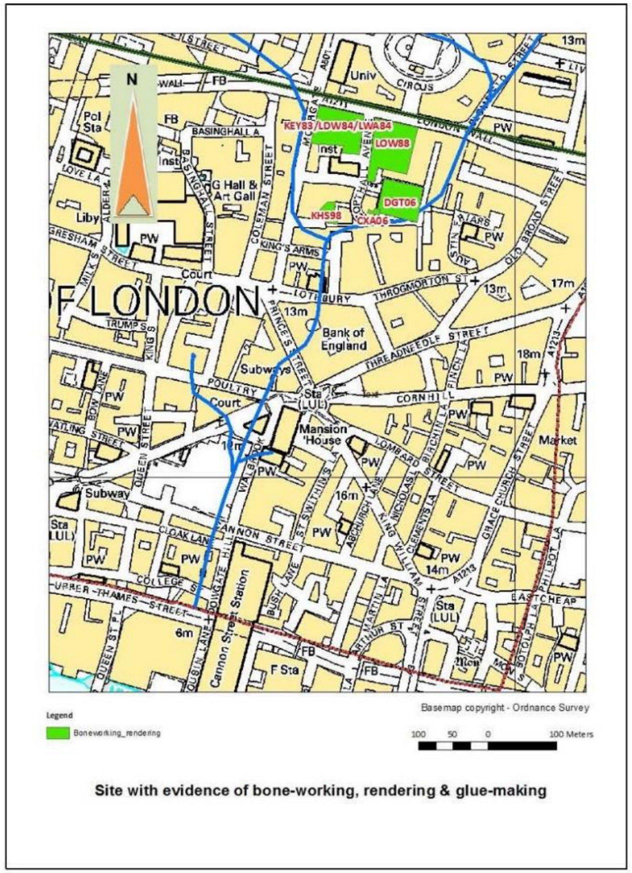
Virtually all industry has need of water in its processes. In some cases, large quantities of water are an integral part of the industrial process, in others water is needed for cooling whilst in others use is minimal, being required just for the cleansing of vessels and floors or by workers for washing. Reports on archaeological investigations in the urban Roman Walbrook Valley claim to have found evidence of industries in all parts of the URWV with the exception of the stretch with the steepest slopes between Lothbury and Bucklersbury. The evidence variously cited in reports and publications on the investigations includes buildings, industrial structures such as furnaces, tools and industry-related artefacts, waste and products associated with the following industries:

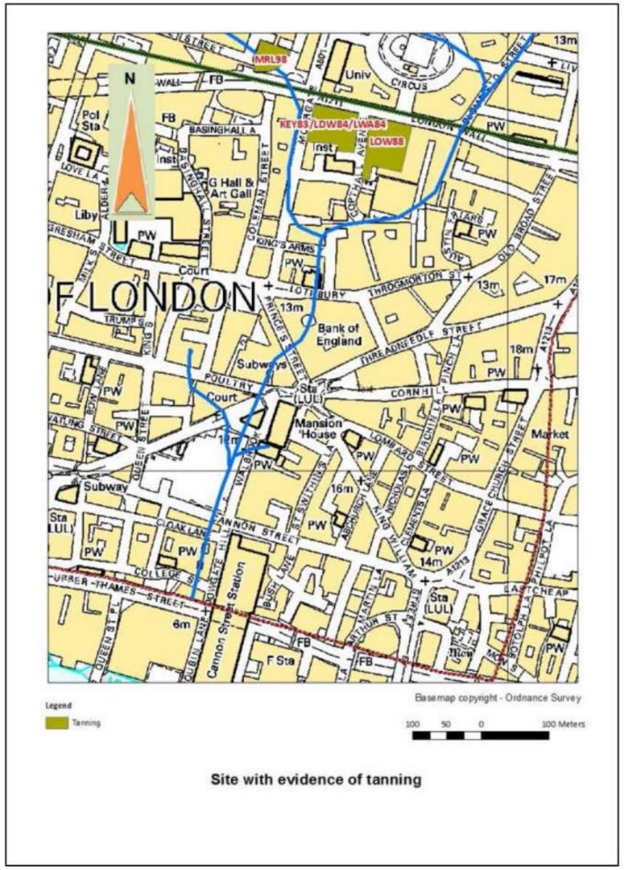
- butchery
- bone working, rendering and glue-making
- tanning
- metal working
- glass manufacture and working
- potteries
- leatherworking and shoe-making
- carpentry, joinery and cooperage

The locations of the archaeological sites included in this research where these industries have been located are shown on Figures 8-2 to 8-9, each industry being shown separately. Larger versions of the location plans are provided in Appendix 8A.

Table 8-1 lists the archaeological sites shown in Figures 8-2 to 8-9 according to the industry claimed to have been identified in the course of each investigation. The sites are listed according to their respective zones in the URWV. The boundaries of the zones referred to in the table have been defined in Figure 4-19, Section 4.5.2. A number of the sites hosted more than one industry; in order to readily identify them, sites with evidence of more than one industry have been listed in coloured font. The four industries that use considerable quantities of water in their processes and that produce polluting effluents have been highlighted by shading in Table 8-1. With the exception of potteries, these industries produce effluents that would cause high levels of pollution, particularly in a small stream such as the Walbrook. It can be legitimately argued that the discovery of waste of industrial origin during an archaeological investigation does not necessarily prove that the industry that generated the waste was on the same site. Table 8-1 therefore distinguishes between sites where industrial premises and artefacts related to industry have been found and those where just the artefacts were discover, the latter carrying the doubt that they could just have been dumped from a remote industry.





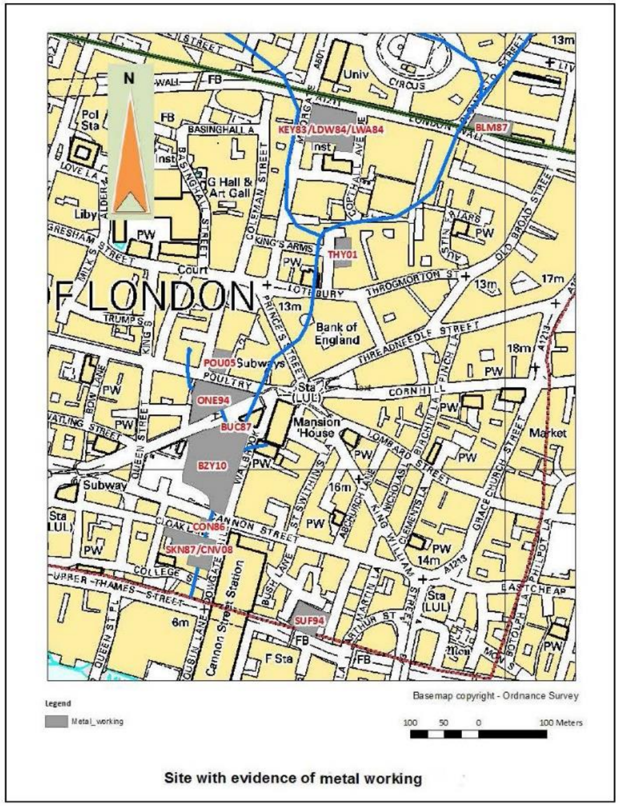


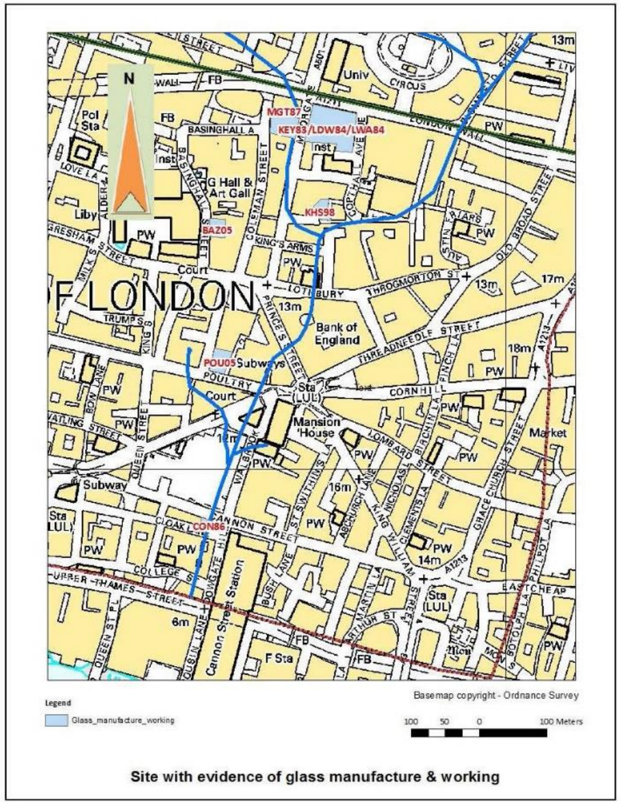
Walbrook topographic catchment boundary | River Walbrook | Roman town wall

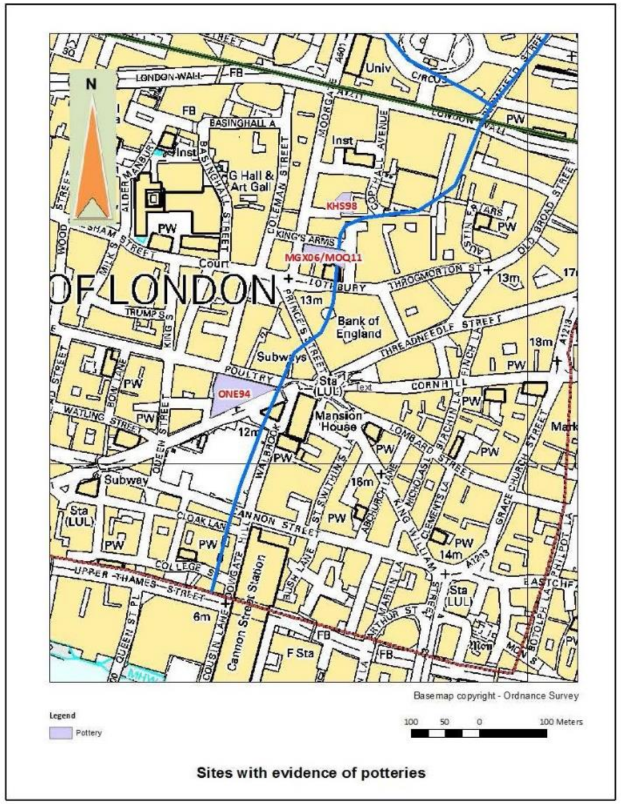
Figure 8-2 Evidence claimed of butchery

Figure 8-3 Evidence claimed of bone-working, rendering & glue-making

Figure 8-4 Evidence claimed of tanning





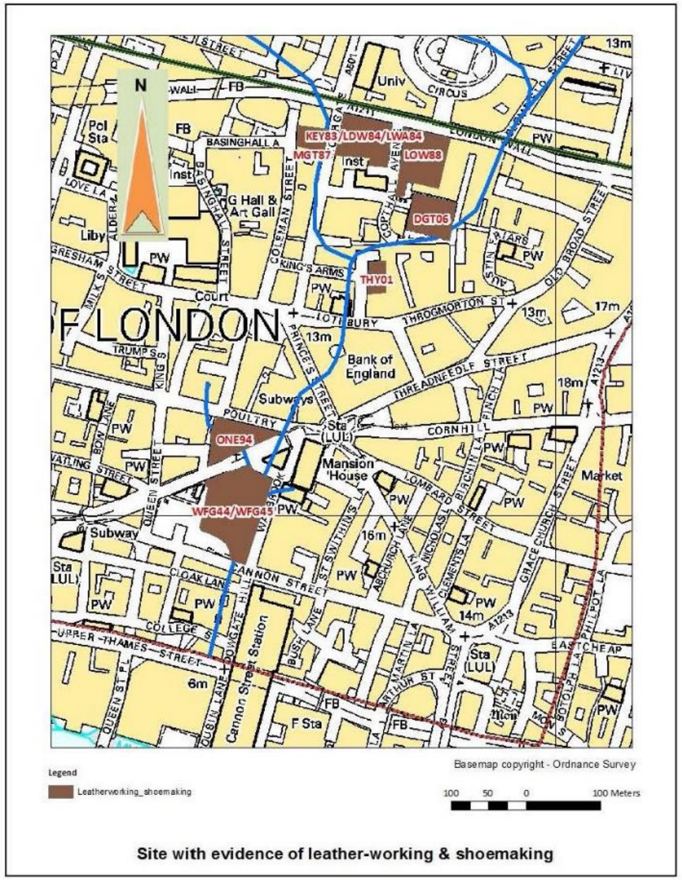


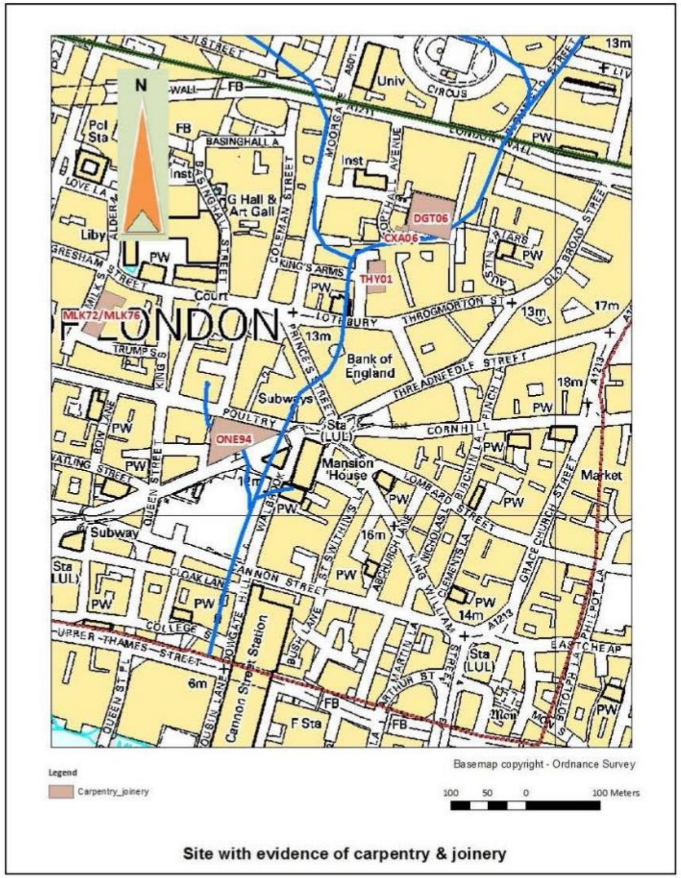
Walbrook topographic catchment boundary | River Walbrook | Roman town wall

Figure 8-5 Evidence claimed of metal working

Figure 8-6 Evidence claimed of glass manufacture and working

Figure 8-7 Evidence of potteries





Walbrook topographic catchment boundary | River Walbrook | Roman town wall

Figure 8-8 Evidence claimed of leatherworking and shoemaking

Figure 8-9 Evidence claimed of carpentry & joinery

Table 8-1 Location of the archaeological sites where it is claimed that evidence of specific industries has been found

Industry	Typical water usage	Location in urban Roman Walbrook Valley (URWV)							
		Lower (Zones A & B)		Middle				Upper (Zone E)	
				South (Zone C)		North (Zone D)			
		Building(s)/ pits & artefacts	Artefacts only	Building(s)/ pits & artefacts	Artefacts only	Building(s)/ pits & artefacts	Artefacts only	Building(s)/ pits & artefacts	Artefacts only
Butchery	Process; vessel cleansing; hygiene					DGT06; CXA06	ACW74; MRG95/KHS98		
Bone-working, rendering & glue-making	Process; vessel cleansing; hygiene					DGT06; CXA06; LOW88; KEY83	MRG95/KHS98		
Tanning	Process; vessel cleansing; washing					LOW88	MRL98		
Potteries	Process; cooling; hygiene					MRG95/KHS98; MGX06/MOQ10			
Metal-working	Cooling; hygiene	SUF94;CON86; SKN87/CKL88; BZY10; BUC87; POU05	ONE94			KEY83; THY01	BLM87		
Glass manufacture & working	Cooling; hygiene	CON86; POU05				MRG95/KHS98; KEY83; MGT87	BAZ05		
Leatherworking & shoemaking	Hygiene	WFG44/45 (BZY10)	ONE94			DGT06; LOW88; KEY83	THY01; MGT87		
Carpentry, joinery & cooperage	Hygiene		ONE94		MLK72/MLK76	CXA06	THY01		

Table 8-1 demonstrates that there are two main concentrations of industry, viz. in the northern half of the Middle URWV (Zone D), between Lothbury and the Wall, and in the Lower valley (Zones A and B). However, with respect to the latter, it is only the specialised craft of gold-working that has been found close to the Thames, in Zone A.

All of the industries, with the sole exception of MIL72/MLK76, where a carpenter's axe was found, are located adjacent to the Walbrook or one of its main tributaries, possibly indicating that a nearby source of water was considered an important factor in developing an industry. Two main roads were constructed northwards from one of the town's main east-west roads, the Via Decumana, early in the post-Boudican era, one either side of the Walbrook. This may have encouraged the development of industry in Zone D.

The three industries with the highest demand for water – butchery, working with animal bones and tanning – were all sited in the northern urban Middle Walbrook Valley, well away from the town centre and higher status residential areas. It is probably no coincidence that these are also the three industries which would have produced the most noxious solid waste and liquid effluents, accompanied by obnoxious and, at times, nauseous odours. In addition to the noise and pollution that these industries would have generated, other industries such as metalworking, glass working and potteries, required the operation of furnaces. In order to reduce the risk of fire in the commercial and residential areas of the town, these industries may also have been encouraged to set up in Zone D, in the lesser-developed, lower status northern suburbs of the Roman town.

As indicated by dating evidence from many of the sites included in Table 8-1, industries in Zone D appear to have been developed and operational from the post-Boudican era to the construction of the wall in the early 3rd C. Very few industries continued in operation in the 3rd and 4th centuries, with those on the Draper's Garden site, DGT06, being a notable exception.

No evidence of industrial processes or premises were found in Zone E, outside the town wall.

In summary, although some of the artefacts found may have been carted to the area from elsewhere in Roman London, it does appear that industries were attracted to the banks of the urban Roman Walbrook and its major tributaries. This was particularly the case for Zone D, Roman London's northern suburbs. In Section 7.5, a decision to develop in this area, which was subject to frequent flooding, was described as counter-intuitive. However, three factors may have contributed to particular industries and crafts being encouraged to establish themselves in this inhospitable area:

- the noxious nature of at least three of the industrial processes – butchery, the working and processing of animal bones and tanning;
- the reduction of fire risk and noise in the residential and commercial districts of the town which would have been posed by the furnaces operated and the noise generated by a further three of the industries – metal working, glass-working and potteries; and
- given the difficulties posed by its environment, particularly until completion of the wall early in the 3rd C, the probability that the land was of low value better suited to industry, crafts and the dwellings of low-status individuals working in the locality.

The latter point may reinforce a view that has recently been expressed concerning the cemetery in the upper URWV (Harward et al., 2015), i.e. that the marshy area of the northern urban suburbs of the Walbrook Valley was the domain of low-status people.

Although outside the scope of this present study, it would of interest to compare the types, number and economic importance of industry identified in the URWV, and its ownership, with industrial activity found elsewhere in Roman London. This would enable the proposition to be tested that obnoxious and highly-polluting industries were encouraged to set up in Zone D of the URWV away from the population centre.

8.5 Farming – Agriculture, Animal Husbandry and Gardens

The location of archaeological investigation sites that provided evidence of farming and gardens are shown in Figure 8-10.

Farming appears to have been generally practised, outside of the urban area, adjacent to or north of the line of the eventual town wall. At MRL98, there was evidence of animal grazing and ploughed land indicating agriculture. It was conjectured that this activity may have begun in the pre-Roman period but certainly continued throughout the Roman occupation.

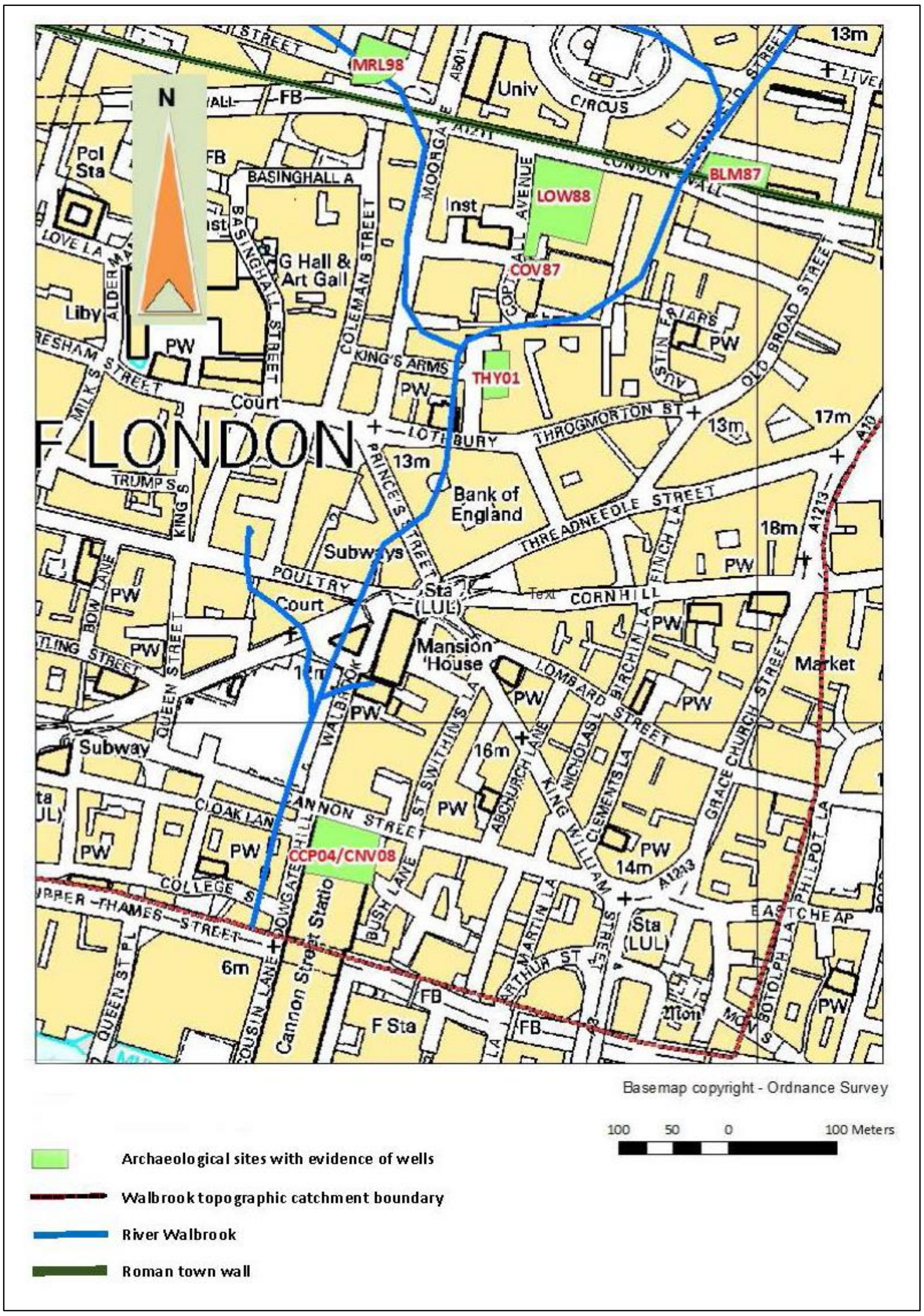


Figure 8-10 Archaeological investigation sites with evidence of farming, horticulture and gardens

The BLM87 site was found to have a complex drainage system and it was claimed that farming activity continued for about 200 years into the second half of the 3rd century. Evidence of farming found on the LOW88 site consisted of a fire-damaged barn, a building with a thatched roof, a number of palisades and out-buildings and huts for storage. However, it was unclear as to whether these were part of a single farm or more than one. Agricultural drains, i.e. shallow, linear ditches, on the COV87 were dated to the 3rd and 4th centuries.

THY01 is exceptional in that it is the only site with evidence of farming activity further inside the walled urban area. In addition to cultivation indicated by a grain storage facility, an animal byre suggests that cattle were raised on the site. A rustic pale and wattle building found on the site would have been an unusual build for the Romans and may indicate low-status persons operating the farm. This could be a further indication that the marshy, northern suburbs were inhabited by people of low-status.

In the lower URWV, Zone A, evidence was found on the CCP04/CNV08 site of a garden and ornamental pool in an extensive inner courtyard associated with the high-status building, formerly known as the "Governor's Palace". The building and its garden were located on a low bluff to the immediate east of the Walbrook and, as a result, overlooked the BZY10 site below it.

There is no evidence to indicate that the Walbrook stimulated the development of farming, although the proximity of a source of water would have been useful in their operation. Certainly, in absence of a pumping installation, the high-status garden on the CCP04/CNV08 site could not have benefitted from watering from the river, having been sited on land approximately 5 metres above the Walbrook,.

8.6 Cemeteries, Burials and Ritual Practices

8.6.1 Cemeteries and burials

The location of archaeological investigation sites that provided evidence of Roman cemeteries and burials are shown in Figure 8-11.

In accordance with standard Roman municipal practice, cemeteries were located outside the boundary of a town or city, its pomerium. In order for this stricture to have been respected, the limits of a town would have been defined early in its development. A broad east-west aligned ditch found on the BLM87 site, immediately outside the eventual town wall at Blomfield Street, has been interpreted as being such a boundary marker. This ditch was discovered immediately to the north of the eventual town wall. A group of simple inhumation burials was found on the eastern side of this site, away from the Walbrook. No evidence was found of coffins or grave goods directly linked to these burials.

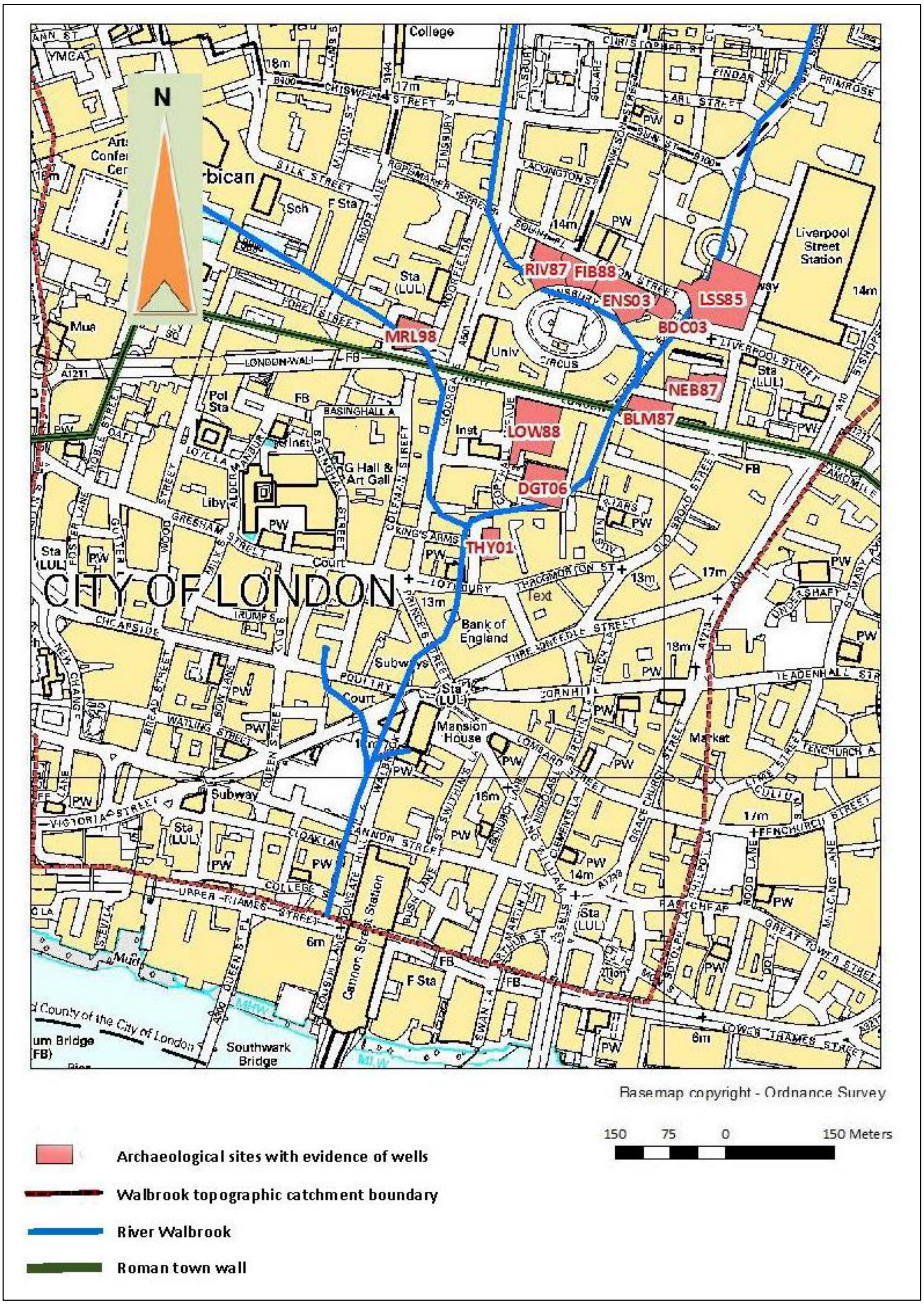


Figure 8-11 Archaeological investigation sites with evidence of Roman cemeteries and burials

A recent study (Harward et al., 2015) has reviewed the findings of six archaeological investigations, linked without a break between them, around the northern half of Finsbury Circus (RIV87; ELD88; FIB88; BSP91; BDC03; ENS03). According to this present research, the western stream of the Walbrook turned to a west to east direction across the southern boundaries of this site to join the eastern stream flowing along Blomfield Street at their easternmost boundary. Evidence of a channel, identified in the investigations as a drainage channel, with this orientation was found on the ELD88 site and may also have been found in recent Crossrail work. The conclusions drawn by Harward study can be summarised as follows:

- the investigations found evidence of at least 125 inhumations and ten cremations, broadly dating to 43 to 400 CE, the main period being 120 to 200 CE;
- this group of sites is situated between the western and eastern Walbrook streams and has been designated the upper Walbrook valley cemetery, a separate entity from the Northern Cemetery located on the east bank of the eastern stream;
- the Walbrook Valley in the area, north of the Roman town, was poorly-drained, marginal land which was prone to flooding; burials appear to have been regularly disturbed by floodwaters eroding the graves and skeletal remains dispersed along the Walbrook channel; the report suggests that the siting of the cemetery in unfavourable land was deliberate and that lack of investment in drainage and reclamation works had left the graves highly vulnerable to disturbance by floodwaters;
- the decline in the use of the cemetery in the 3rd century AD is most likely to have been due to the development of increasingly marshy conditions, due to the town wall, that rendered access difficult and burial impractical;
- the authors of the report conclude that, whilst the dead were accorded the dignity of burial in separate graves, only a very few were accompanied by grave goods of any value; and
- they suggest that this cemetery was used by a section of the population who either lacked the economic means to have access to a more secure burial site, or were unconcerned with attempting to ensure that graves were not disturbed or displaced.

The report adds weight to the possibility that the poor and those of low social status inhabited the flood-prone, northern suburbs of the town.

The choice of the location of the burial site of three neonates in tiny coffins beneath the foundations of a building on the DGT87 site is unlikely to have been influenced by the proximity of the Walbrook stream.

8.6.2 Religion and ritual practices

In addition to finds associated with cemeteries that may have had ritual connotations, e.g. burial of horses, grave goods, skulls deposited in the Walbrook, etc., four of the archaeological investigations included in this research made finds of objects or buildings related to religious and ritual practices – LOW88, THY01, DGT06 and WFG44/45. The location of archaeological investigation sites that provided evidence of religious and ritual practices are shown in Figure 8-12.

The discovery of 23 skulls in the bed of a stream on the LOW88 site may have been ritually deposited, although many other theories have been posited for their strange presence. Merrifield has made reference to the numerous finds in the lower Walbrook of the tools of many trades (Merrifield, 1983), in particular stylii. Many of these were found both upstream and downstream of the bridge at Bucklersbury which carried the main east-west road, the Via Decumana. Some of the items found had been bent or broken and may represent ritual "killing" of items that were no longer serviceable. However, this can only ever be conjecture.

Merrifield suggests (Merrifield and Hall, 2008, 127) that the banks of the Walbrook stream between the Via Decumana bridge and Cannon Street had particular religious significance due to a number of shrines found there pre-dating the Temple of Mithras. These included shrines to Bacchus and Sabazios (Bird, 1996: 125-126) and a shrine of the Dioscuri (Shepherd, 1998, 182-183). Merrifield (ibid) suggests that the population venerated this area for its stretch of water between the two bridges over the Walbrook, the Via Decumana bridge and one carrying the main road a short way to the south along the line of Cannon Street.

The cult of Mithras had no obvious link to water. However a temple originally dedicated to the deity, the Temple of Mithras on the WFG44/45 site (Grimes, 1968, 92-98), now the Bloomberg Development, appears to have been very deliberately sited on the Walbrook's east bank. This temple was built in the mid-3rd C, by which time most of the highly polluting industries of the northern suburbs would have ceased operations and the downstream riverine environment would have been considerably improved. As discussed in Section 7.4, by the time of the construction of the temple, the town wall would have acted to prevent flooding of the Walbrook's urban floodplain.

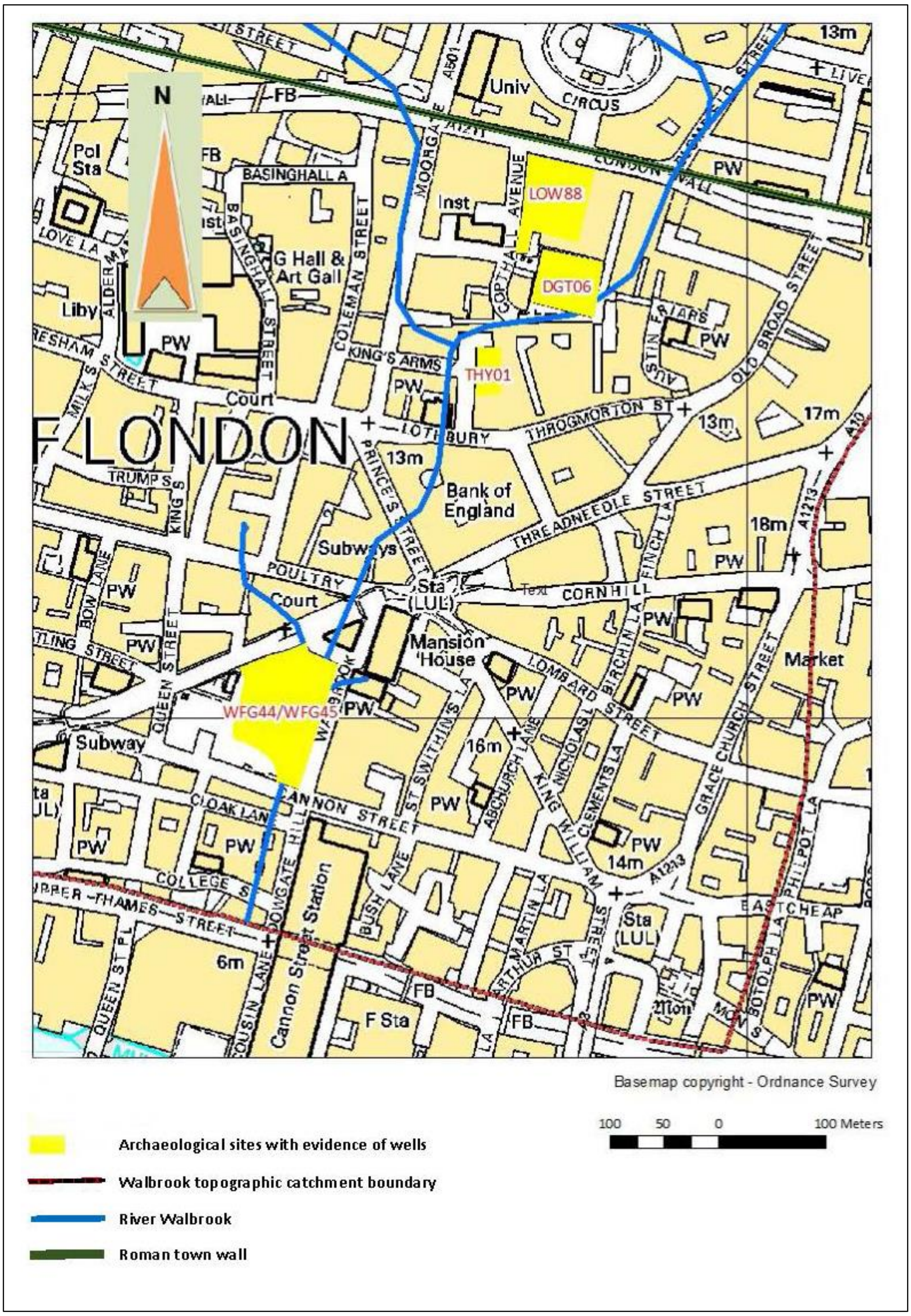


Figure 8-12 Archaeological investigation sites with evidence of religious and ritual practice

It would appear from the foregoing that there is some evidence that the Walbrook acted as a focus for religion and ritual practices, viz. the shrines between the two bridges on the northern and southern boundaries of Zone B and the mid-3rd C Temple of Mithras, later of Bacchus, on the eastern bank of the Walbrook in the same area. However, whether items found in the Walbrook were thrown into it as votive offerings or just to dispose of unwanted items is unproven and will probably remain as such.

8.7 Walbrook-powered Milling

It has been speculated that there could have been a series of water-mills on the Walbrook (Wilmott, 1991). In a lecture to LAMAS on 15 May 2012 (Myers, 2012), it was stated that early indications from this present research were that the base flow in the Roman Walbrook and the topography of urban Roman London combined to create conditions well suited to powering one or two mills, probably located in the general vicinity of Bucklersbury. However, although no building dated to Roman London has been incontrovertibly identified as a water mill, evidence for one is building following finds made at end of 2013 of parts of a timber mill-wheel, crown gear and a possible mill-house on the BZY10 Bloomberg Development site.

The detailed case for one or more Walbrook-powered mills is reported in Appendix 8B, the principal conclusions from which are:

a. Watermills were in use in continental Roman Europe by the time that London was founded and were an established form of milling grain in commercial quantities by the early 2nd century.
b. Given that storage of night-time flows would have been available, the Roman Walbrook had a reliable, perennial mean base flow of 87 litre/second (Section 5.8.3). If night-time storage of flows for 12 hours had been practised, and assuming a maximum of 75% of the flow had been abstracted, flow to the mill would have been 130 litres/second through a 12-hour working day.
c. Ample storage of the Walbrook's base flow would have been available following construction of the wall that could have been used as a dam to control flow into the urban area (Section 7.4).

d. From just upstream of Roman London to HWST in the Thames, the Walbrook offered a potential head to drive a mill of between 5.5 and 6.5 metres.

e. Given the head available, it is probable that engineers would have chosen the most efficient form of mill using overshot wheels, the most common size in the Roman period being the 2.1m diameter wheels used in the early 2nd C at Barbegal, near Arles.

f. The head available would have supported two wheels in series, the upper one feeding the lower.

g. Given a flow of 130 l/sec, each wheel would have generated 1.75 HP and ground 1.1 tonnes of wholemeal flour daily, a total mill production of 2.2 tonnes a day; such a production would have supplied a garrison of about 2,400 or twice as many civilians.

h. A substantial timber platform or floor was discovered during construction of the National Safe Deposit Company's premises, together with a "large quantity of wheat", much of it blackened by fire (Puleston and Price, 1873: 56). This discovery was made close to the east bank of the Walbrook at Bucklersbury. Millstones have been found in the area of Bucklersbury as has a large grain store, milling artefacts and a possible mill-house. This is most likely to have been the engineering location of choice.

Chapter 9

The Walbrook and Roman London – Principal Research Conclusions and Future Research Proposals

9.1 Principal Research Conclusions – A Summary

This research project has built upon the results of the archaeological endeavours of others to re-create the Walbrook and the conditions under which it flowed through Roman London, its catchment, rural and urban landscapes, the efforts of the Romans to manage the river and its beneficial use. Detailed conclusions form part of the respective chapters on each of the research main components, the Walbrook catchment and streams (Chapter 3), palaeo-stratigraphy (Chapter 4), palaeo-hydrology (Chapter 5) and flood frequency analysis (Chapter 6) and the chapters on river and flood management (Chapter 7) and beneficial use (Chapter 8).

The principal conclusions can be summarised as follows:

a. The main sources of water for the perennial Walbrook were the springs and ponds emanating from the gravel on clay that constitute the main superficial deposits of the catchment; the springs were found both as point sources along the Islington ridge that formed the northern boundary of the catchment and diffuse throughout the catchment.
b. The Walbrook's topographic catchment covered an area of 4.7 km^2 and, due to the nature of its geology, its groundwater catchment added a further 2.4 km^2. Its topographic catchment was bounded by those of the River Fleet to the west and the Hackney Brook to the north and east.
c. The river that flowed through urban Roman London had two main source streams. A western stream, 3.4 km long, originated from the springs at Barnsbury, above the Angel, Islington, and at St Mary le Clere at the Old Street intersection with City Road. The eastern stream was fed by diffuse springs on the slopes below Highbury and Canonbury and at Hoxton and Holywell. The point of confluence of the two streams appears to have been in Blomfield Street, immediately east of Finsbury Circus.

d. The combined river flowed through urban Roman for a distance of approximately 0.9 km and into the Thames at Dowgate, to the immediate west of Cannon Street Station.

e. The catchment topography consisted of the slopes from the Islington ridge down to a floodplain that extended south for both streams to Moorfields and the northern Roman urban area to a low east-west ridge at Bucklersbury. The river carved a “knick-point” through the ridge where the land then sloped down to the Thames.

f. The pre-Roman landscape consisted mainly of scrub with the occasional woodland. A seasonal marsh extended from Moorfields through to Bucklersbury. In the Roman period, the urban area covered less than 10% of the catchment and the remaining rural area would have been progressively converted to agricultural land.

g. The river had a mean base flow rate through the urban centre of approximately 85 litres/sec.

h. The Walbrook may have been used to supply water to industry along its banks but water supply to the town was generally from wells dug into the water-bearing gravels. Industry in the northern suburbs would have polluted the river and rendered it unsuited to potable use.

i. Storm runoff from the catchment greatly increased flows in the river. Agricultural activity in the catchment increased storm runoff through the Roman period.

j. Unchecked, before the Roman occupation, storm flows would have led to frequent flooding of the land between the Moorfields marsh and Lothbury more than once a year. The land between Bucklersbury and Cannon Street was also at risk from flooding but far less frequently, probably with a frequency of 20 to 50 years. The low-lying estuarine land would have flooded more frequently, dependent upon tide levels in the Thames at any period. Flood frequency increased, but not dramatically, in the Roman period.

k. The northern boundary of Roman London cut through the middle of the area subject to frequent flooding. A cemetery was sited to the immediate north of that boundary and suffered erosion by storm flows. Small-scale industries were established throughout the northern urban Walbrook Valley in the area subject to frequent floods between the line of the eventual town wall and Lothbury. These industries, which included butchery, bone rendering and working, tanning and glass and metal working were sources of noxious wastes and odours. They may have been sited there on low-value land, away from the administrative, residential and commercial areas, as the result of a deliberate planning decision of the public administration.

l. Attempts were made to manage the river to reduce the frequency and effects of flooding. The banks of the main stream were protected from erosion by post and plank revetments and drainage systems were constructed. In order to protect land occupied by industry and worker's housing, the land surface was raised by an average of about 1.5 metres with mixed degrees of success. Land-raising was carried out in stages through to the end of the 2^{nd} C, possibly to keep pace with increasing storm runoff.

m. Construction of the town wall, completed by 220 CE, provided an opportunity to eliminate flooding of the urban area. Culverts carried the Walbrook and its tributaries through the walls, their small cross-section throttled the flow which was almost certainly further restricted by simple sluice gates.

n. The flow in the river, combined with the topography of Roman London, suggest a potential for the powering of a mill, almost certainly located at Bucklersbury. Based on the mean base flow rate, such a mill could have made a significant contribution to the town's demand for wholemeal flour. Construction of the town wall would have created a reservoir of water in Millfields that would have increased the reliability of the mill and provided the potential to double its milling capacity.

o. A conceptual hydrological model, Figure 9-1, of the Greater Walbrook Valley catchment shows the river's sources and the effect of construction of the wall. A further model, Figure 9-2, shows three landscape situations for each of the five zones A to E, defined in the course of the research, for three time periods, respectively pre-Roman, the 1^{st} and 2^{nd} centuries and the 3^{rd} and 4^{th} centuries, post construction of the town wall.

p. Industrial activity in the northern suburbs reduced significantly from the start of the 3^{rd} C, coinciding with construction of the wall and the elimination of flooding of the urban area. These improvements to the environment appear to have contributed to a change in the character of the lower reaches of the urban Walbrook Valley. Higher status residences constructed from stone were built and the area between the bridges at Bucklersbury and Cannon Street was occupied by at least one major temple and a number of sacred shrines.

q. The Via Decumana, the principal road carried traffic from the administrative, commercial and residential areas on Cornhill and crossed the Walbrook by the bridge at Bucklersbury to the residential area, the amphitheatre and bathhouses located on and below Ludgate Hill and out to the west. The bridge at Bucklersbury would have been a busy hub, with tavernas, markets and craft activities and with the noise and associated movements of the mill below the bridge. From the bridge, the view would have been south over the mill and the markets on the banks of the Walbrook with the Thames in the near distance.

r. Figures 9-3 to 9-5 describe the nature of the Walbrook, flood frequency and the landscape/settlement situation for each of the three periods and within each scenario for each of the five zones, as for the landscape models.

s. The Walbrook was a modest stream that punched well above its weight in its impact on the everyday life of the population of Roman London.

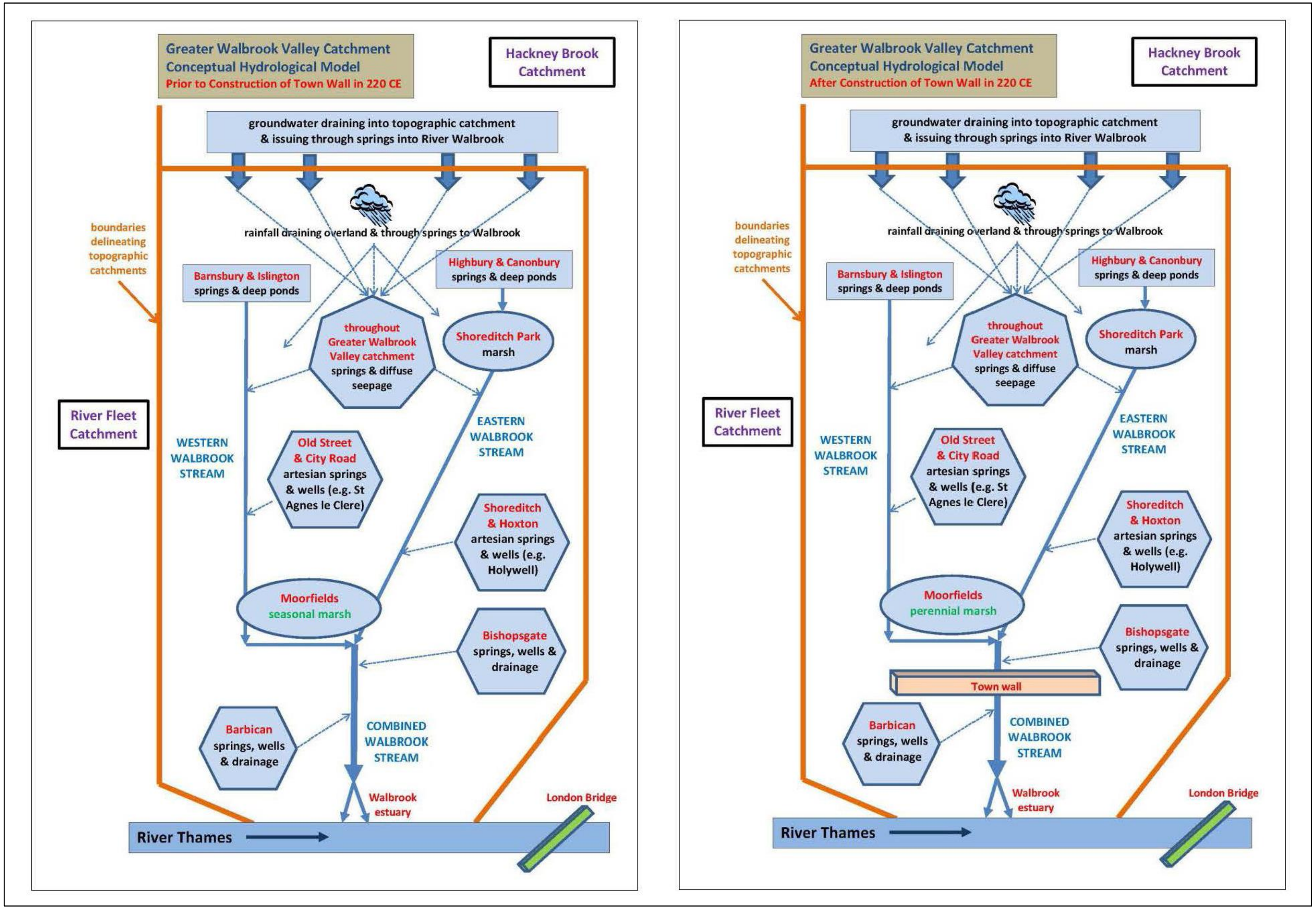


Figure 9-1 Conceptual Model of the Greater Walbrook Valley Catchment

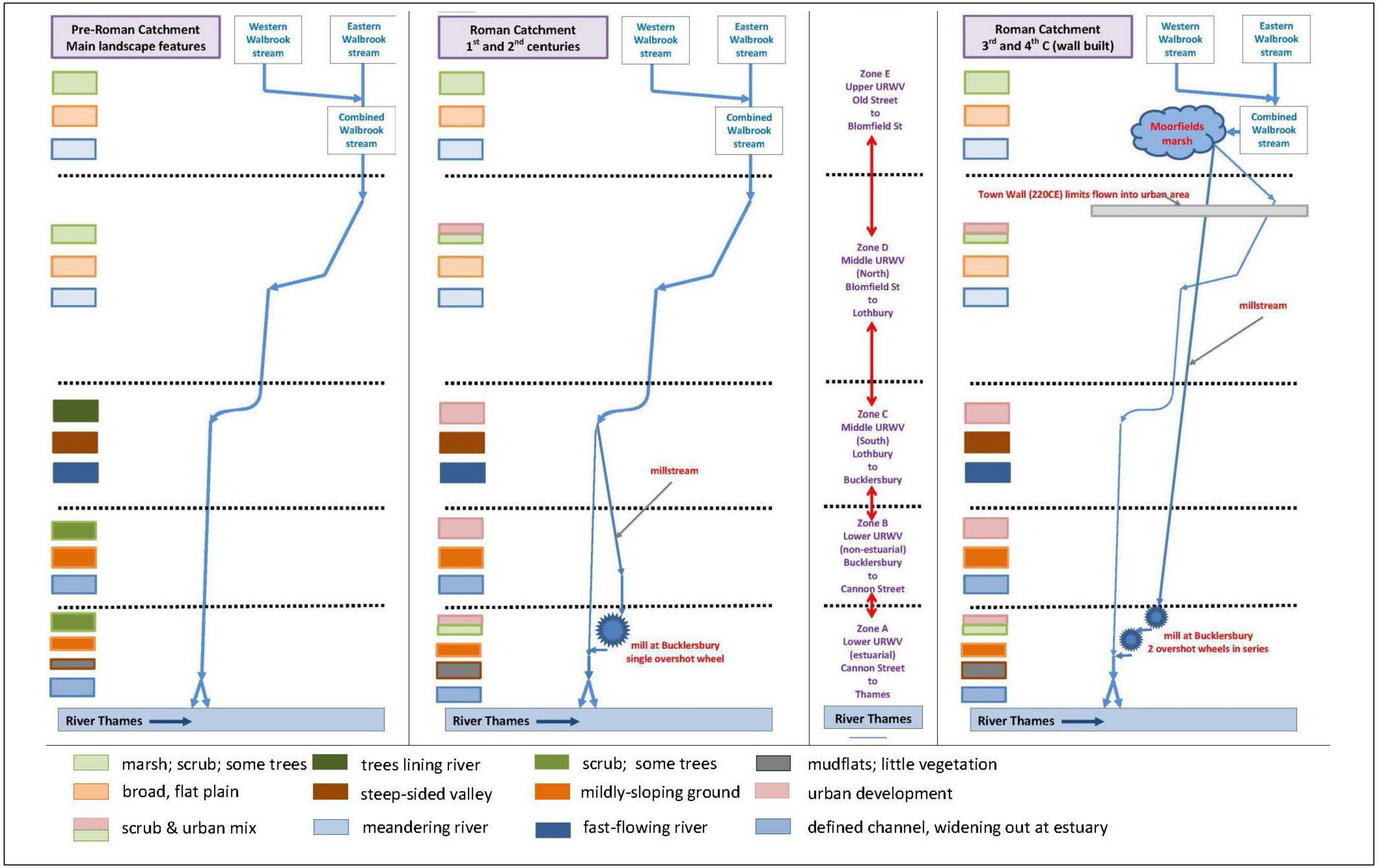
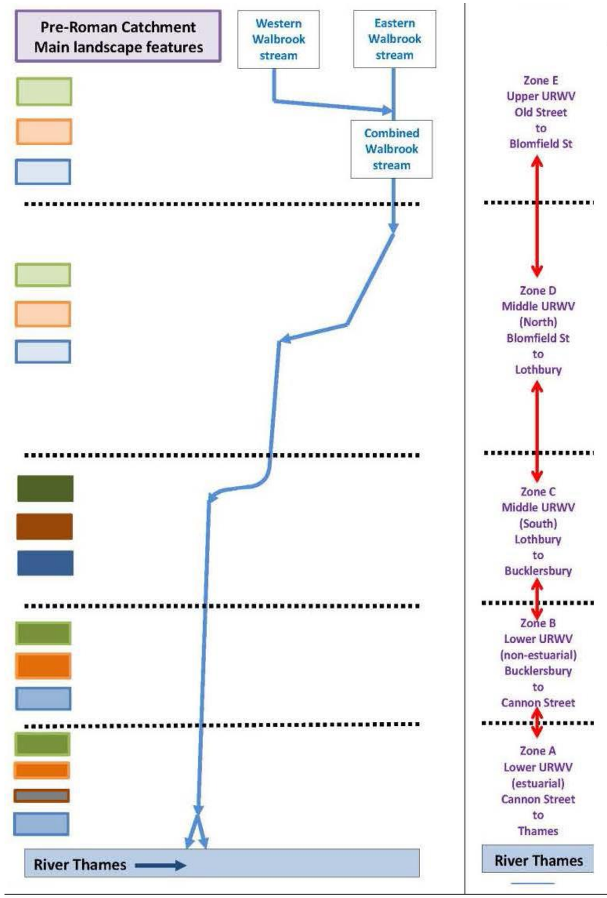


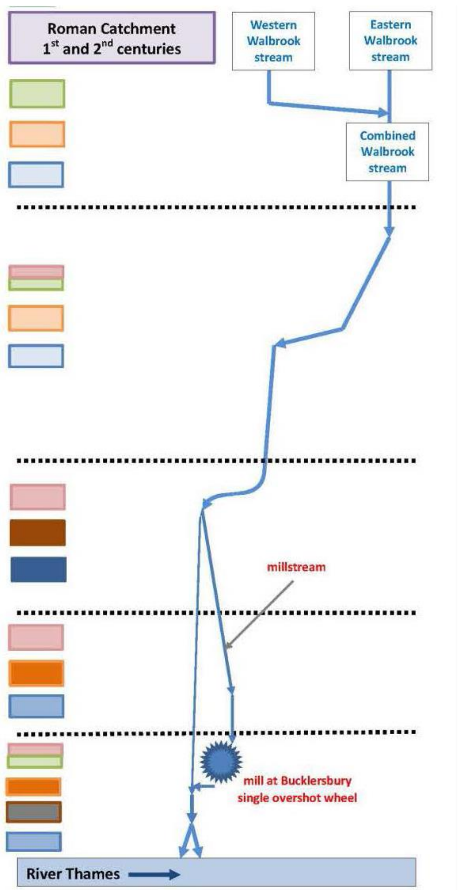
Figure 9-2 Conceptual Model of Three Landscape Situations Relating to Three Time Periods



Nature of the Walbrook	Flood frequency	Landscape/development
The river flowed along a well-defined channel in northern two-thirds of Zone E. After sudden fall in surface, land became flat with seasonal marsh and river meandered.	In the southern third of Zone E, flood frequency was as for Zone D as the topography the same. Flooding occurred less in remainder of Zone but insufficient data to quantify.	Land in the northern two-thirds of the Zone E was between 1 and 2m higher than to the south, the fall being sudden, and was drier with scrub and clumps of oak, beech and lime. In the southern third of Zone E and through Zone D, the land was flat and a seasonal marsh, the ground remaining damp throughout the year. The banks of the river were lined with reeds and sedges with lines of Alder carr in the more swampy parts. The lake that formed in the depression in the ground in the NW quadrant would have been a significant feature.
The land was generally flat and a seasonal marsh. The river meandered through the area with minor sinuosity. A seasonal lake would form in a depression in the surface occupying the NW quadrant of the area and, at times may not have dried out in summer. The river would have flowed into and through the lake.	Channel depth was highly variable over this stretch. Where channel depth was 0.25m or less, flooding occurred more than once a year, at 0.5m depth every 1 to 2 years and at 1.5m depth, between 5 and 20 years. This was the part of the Study Area that suffered the greatest frequency of flooding.	
The river bed steepened considerably. The river would have run fast through a more pronounced valley. At times of storm, the river would have rushed through the stretch.	Due to steepness of river bed, flooding was infrequent, every 50 to 100 years for a channel 1m deep, reducing to between 200 and 500 years for 1.5m deep channel	The broad plain narrowed rapidly and the valley became progressively more pronounced to a "knickpoint" at Bucklersbury. The vegetation would have been sparse – grass, brush and bushes.
The river would have slowed through the zone flowing in a well-defined channel. Pre-Roman, spring high tides reached this stretch.	Flood not more frequent than between 10 to 20 years for 0.75m deep channel, 20 to 50 years for 1.0m deep and 200 to 500 years for 1.5m depth.	The narrow valley broadened to a flat amphitheatre of land formed by the slopes of Ludgate Hill and Cornhill to either side opening towards the Thames in the south.
The estuary may have been a two-armed delta and the river would have slowed as it reached the Thames. Pre-Roman, this stretch would have been diurnally tidal.	Flood frequency increased nearer to confluence with Thames. At Cannon Street no more frequent than 20 to 50 years, near Walbrook estuary frequency increased to 2 to 5 years.	The slope of the land gradually flattened out towards the estuary as did the side slopes on either side of the broadening floodplain. Pre-Roman, the estuarial zone would have been tidal mudflats with sparse vegetation.

marsh; scrub: some trees — trees lining river — scrub; some trees — mudflats; little vegetation
broad, flat plain — steep-sided valley — mildly-sloping ground — urban development
scrub & urban mix — meandering river — fast-flowing river — defined channel, widening out at estuary

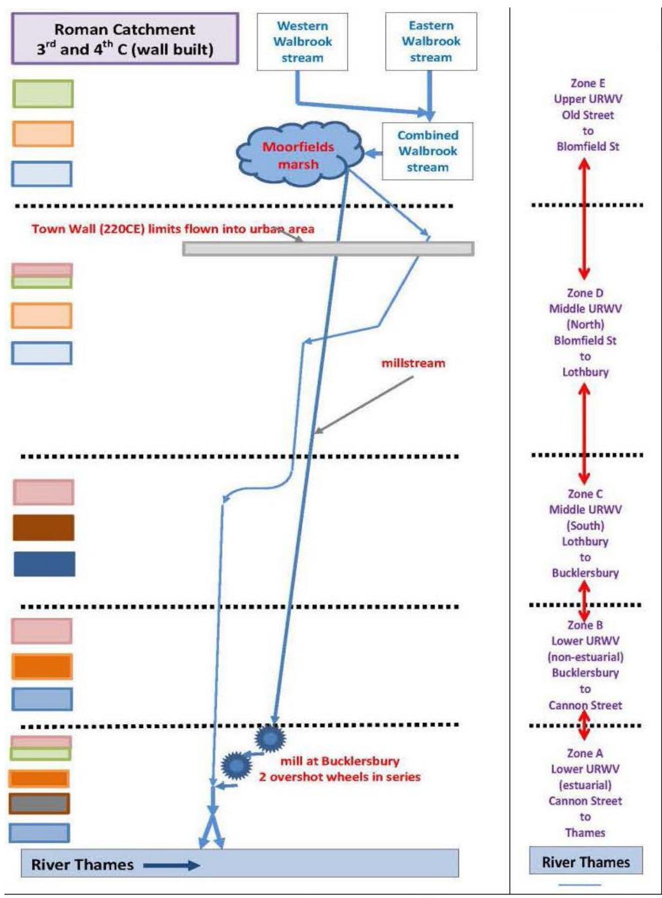
Figure 9-3 Conceptual model of the nature of the Walbrook, flood frequency and landscape/development for each of the 5 Zones A to E – Pre Roman



	Nature of the Walbrook	Flooding/flood mitigation	Landscape/development
Zone E Upper URWV Old Street to Blomfield St	The topography of the area, particularly the northern two-thirds, was little changed from the pre-Roman state. Farming may have levelled the land and made it less marshy in places.	In the southern third of Zone E, flood frequency as for Zone D as the topography the same. Flooding less in remainder of Zone but insufficient data to quantify.	Farming and horticulture developed particularly in the northern two-thirds. Outside the pomerium, the lower third of the area was used for cemeteries – one to the east of the eastern stream and one between the two streams.
Zone D Middle URWV (North) Blomfield St to Lothbury	The Draper's Gardens site was one of the few places that the Walbrook channel was straightened and the channel duplicated. Given the amount of industrial development in the area, the banks of the river were strengthened with post and plank revetments to prevent erosion and encroachment into developments. The river was a repository for solid and liquid wastes.	Runoff increased in the Roman period due to urbanisation and agriculture in catchment. Flood frequency increased to more than once a year for channel depths up to 0.5m; deepest channel 5 to 10 years. Much land raising activity reduced flood frequency but had to reach >7.80m OD to cease.	Post-Boudicca, this area appears to have been designated as an industrial zone. Subject to frequent flooding, it would not have been favoured for housing in general. All investigations that have disinterred sites of industry and crafts found major land-raising activity and drainage works. Often many sequences of flooding, land-raising and subsequent flooding found.
Zone C Middle URWV (South) Lothbury to Bucklersbury	The Walbrook remained as it had been in its natural state through this short stretch. However, given the 4m fall in the river bed, the upstream end would have been suitable for a mill offtake of water.	Due to increased flows and steep river bed, flooding slightly more frequent, every 20 to 50 years for a channel 1m deep, but still only 200 and 500 vears for 1.5m deeo channel	The steep-sided river valley retained its natural state. At the level of the bridge at Bucklersbury, and away from the valley sides, commercial and residential premises, including a grain store, were constructed.
Zone B Lower URWV (non-estuarial) Bucklersbury to Cannon Street	Spring tides reached Bucklersbury for only the first 50 years of the Roman period. From mid-1st C, this stretch was no longer tidal and the Walbrook ran unchecked.	Flood frequency increased to 5 to 10 years for 0.75m deep channel, 10 to 20 years for 1.0m deep and 100 to 200 years for 1.5m deep.	East of the river, a major building was built on a low promontory. A mill stood on its east bank. Market stalls, craft workshops and traders were located east and west of the river.
Zone A Lower URWV (estuarial) Cannon Street to Thames	By mid-1st C, only spring tides would have reached Cannon St but closer to the Thames, at the short delta, it was diurnally tidal. Tides continued to regress to their lowest by the end of the 3rd C when only spring tides would have affected the Walbrook.	Near Cannon Street, flood frequency remained as pre-Roman. Nearer the Thames frequency increased to more than once a year for 0.25m deep channel and to 2 to 5 years for 0.5m deep.	An early quayside along the Thames continued a very short distance along the east bank of the eastern delta arm. A clay bund was built along the Thames and some land reclaimed behind it, probably a site for landing goods from shallow draft river craft.
River Thames			

marsh; scrub; some trees — trees lining river — scrub; some trees — mudflats; little vegetation
broad, flat plain — steep-sided valley — mildly-sloping ground — urban development
scrub & urban mix — meandering river — fast-flowing river — defined channel, widening out at estuary

Figure 9-4 Conceptual model of the nature of the Walbrook, flood frequency and landscape/development for each of the 5 Zones A to E – Roman – 1st and 2nd centuries CE – prior to the construction of the wall



Zone	Nature of the Walbrook	Flooding/flood mitigation	Landscape/development
Zone E	The Walbrook continued to flow as it had done until 220 CE through the northern, higher level two-thirds of the zone. It base flow and storm flow regime would have remained as before. A perennial marsh formed in the lower third of the area due to the stream backing up behind the town wall.	The southern third of the zone, from the wall north to Finsbury Circus, east to Blomfield Street and west to Moorgate was flooded throughout the year from 220 CE until the 15th C and became known as Moorfields.	The cemetery on the east bank of the eastern stream continued in use unaffected by the nearby perennial marsh. The cemetery between the two Walbrook streams may have come wetter and may have been abandoned. The marsh may have acted as a reservoir and an offtake point for the Bucklerbury mill.
Zone D	Following construction of the town wall and the culverting of the Walbrook through small cross-section conduits, flow in the river would probably never have been permitted to exceed its natural base flow. It would have continued to flow along the channels directed and protected in the pre-wall period.	If Walbrook flow was left unchecked by sluice gates on the upstream side of the wall, it would have been possible during storms less frequent than every 2 years for those parts of the river with banks lower than 0.5m to experience flooding.	Whether as a result of a poorer economy or by administrative edict, there appears to have been a major reduction in industrial activity in this zone compared to the pre-wall era. As a result, the Walbrook would have been much cleaner downstream of the wall than had previously been the case.
Zone C		Zones A to C would be completely protected from flooding by the Walbrook following construction of the town wall.	A combination of less industrial activity, less pollution and elimination of urban flooding by the Walbrook, the status of residences improved in this area, stone being used for the first time.
Zone B			The improved environment appears to have resulted in a substitution of commercial development by sacred places, including a Temple of Mithras, later Temple of Bacchus, and others.
Zone A	From start of 3rd C, tides would only have affected the short delta stretch and my mid-3rd C only spring tides would have entered the Walbrook.		The bund along the Thames was damaged in this period, remaining unrepaired and flooding took place over the estuarial area. This gives the impression that this area remained undeveloped to a great extent.

marsh; scrub: some trees — trees lining river — scrub; some trees — mudflats; little vegetation
broad, flat plain — steep-sided valley — mildly-sloping ground — urban development
scrub & urban mix — meandering river — fast-flowing river — defined channel, widening out at estuary

Figure 9-5 Conceptual model of the nature of the Walbrook, flood frequency and landscape/development for each of the 5 Zones A to E – Roman – 3rd and 4th centuries CE – post-construction of the wall

9.2 Implications of the Research for Roman London Archaeology

This research has defined quantitatively, for the first time, the flow regime of the Roman Walbrook, its base flow and storm runoff pattern. This, in turn, has enabled a re-assessment of river management techniques employed by the Romans to mitigate flooding as well as their beneficial use of its waters. The research demonstrated that the Roman Walbrook, although a modest stream, had a flow regime that would have ensured it exerted a significant impact upon the lives and activities of Roman London's population.

There being no contemporary descriptions of the Walbrook and Roman London, the influence of the river on Roman London and the converse can only be a matter of conjecture, albeit informed conjecture based upon outputs from this research combined with the results of archaeological investigations. The principal implications of the research and impacts of the river in this respect on Roman society and the environment close to the river may be summarised as follows:

a. In the earliest days of the settlement that would evolve into Roman London, the Walbrook constituted its western boundary at the foot of Cornhill. However, from the middle of the 1st C, the Walbrook would have become an increasingly noticeable feature in the daily life of Roman London, when urban development began to extend from its west bank up the gentle slopes of Ludgate Hill. These lower and central parts of the urban area were its most densely-developed, a little less so from the 3rd C onwards. Communication between the two halves of the town was only possible via two bridges that crossed the Walbrook. The main one at Bucklersbury carried the principal east-west road, the Via Decumana, which linked the two halves of the town. From 75 CE, this road would also have carried spectators going to the amphitheatre in the north-west corner of the town. A second bridge crossed the Walbrook at Cannon Street. Nearer the Thames, this road was probably more used by commercial traffic accessing the jetties on the Thames west of the Walbrook and the general populace using the Huggin Hill bath house.
b. It is now considered probable that a mill powered by water from the Walbrook was located immediately downstream of the Bucklersbury bridge on the east bank of the river. The powering of the wheels by water cascading from its leat and the clanking and grinding machinery would have provided consistently loud background noise at the bridge

throughout its long working day. The mill would have led to the construction of related premises about the area for maintenance of the milling machinery and storage of the grain and the processed flour. The mill would also have generated considerable traffic related to the transport of the grain and flour. Customers of the taverna on the west side of the bridge would have appreciated the mix of semi-rural views of the Walbrook tempering the noise of the people and traffic of commerce milling around this busy hub.

c. The Walbrook would have been tidal only for the first 50 years of the Roman occupation as far as the Bucklersbury bridge and then only under spring tide conditions. Any ideas that the Walbrook would, during parts of the tidal cycle, be navigable for river craft would have been short-lived as tide levels rapidly regressed through the first half of the 2nd C remaining low for the rest of the occupation. Given the polluting nature of industry located in the upper urban reaches of the river, the muds exposed at low tides from Cannon Street southwards may well have been foul-smelling, with prevailing winds carrying noxious odours towards the town. Although there were no formal wharves along the Thames to the west of the Walbrook estuary, there does appear to have been at least one wooden jetty out into the main river close to the mouth of the Walbrook. This may have been used by river-going vessels to bring in grain and other foodstuffs and manufactured products to the mill and the town.

d. There would have been a constant traffic and movement of people across the Bucklersbury bridge and those crossing would have been aware of the river flowing beneath it. From their elevated view, looking south downstream, they would have been able to see and hear the water-driven mill close by as well as noting the market stalls, crafts and small-scale industries occupying the land along and close to the banks of the river. Looking to their left, their view would have been dominated by a large, stone-built government building on a low promontory that overlooked the Walbrook and the Thames. From the middle of the 3rd C, they would have been aware of the sacred shrines located between the two bridge crossings, in particular the imposing structure of the Temple of Mithras. The sight of moving water appears to have tempted many to cast objects into it from the bridge, possibly as sacred offerings. Turning to look north upstream would have provided a view of a very different nature. The valley through which the river passed at this point narrowed northwards for a short distance, broadening out again before Lothbury, and was more pronounced with slopes more rural in character than urban. Close to the river, clumps of alder and willow grew. The slope to the riverbed being steeper, its waters would have coursed faster and more noisily through this short stretch than elsewhere on the urban river. Following the most intense of storms, this stretch of the river would have become a raging torrent, the force of the water sufficient to sweep away anyone foolish enough to attempt to ford its stream.

e. In its natural state, the Walbrook had the capability to flood areas close to its banks south of Bucklersbury but only quite infrequently, possibly every twenty years or so. Land in this area was raised in level by dumping very early in the occupation and the river channel was most likely to have been kept clear of obstructions in the central populated areas. Under these managed conditions, flooding would have occurred only infrequently for all but the lowest-lying areas flanking the Thames.

f. Upstream of Lothbury, north of a very low east-west ridge of land that divided the populated area from the semi-urban area to the north, the landscape took on a completely different character. It opened out into a broad, flat marshy floodplain, with the river slowly meandering its way through it in a general north to south direction. The marsh would have been a haven for wildfowl. Seasonally, the area would have varied in nature. In winter, the river would have flowed through a series of channels, with islands of higher ground dotted throughout the area, and its north-western area would have been a lake. In the summer period, the lake may have disappeared or been reduced in area and the river would have flowed along its main channel. Alder carr would have lined the main channels and vegetation would have been reeds and sedges in the marshier parts, giving way to scrub and the occasional oak and lime tree on higher, drier ground away from the marsh. In its natural state, this area would have flooded frequently, probably more than once a year.

g. Two of the earlier cemeteries were located in this bleak area, to the north of the eventual line of the town wall, and roads were laid northwards on either side of the Walbrook to provide a route northwards and to access the cemeteries from the main town. The upper urban Walbrook Valley Cemetery, was situated in the north-west corner of the junction of the western and eastern stream. The land was known to be unstable and subject to flooding and this led to erosion of the graves, some of the skulls being carried along the streambed. It was, consequently, the cemetery for those of the lowest status. Land on the east bank of the eastern Walbrook stream was at a higher level and drier and was the site of the second cemetery, the Northern Cemetery. This site was not subject to the same poor conditions as its neighbour on the western bank.

h. In spite of its marshy environment subject to frequent flooding, a number of industrial and craft premises were established in this northern area within the line of the eventual town wall. These included some of the most polluting industries of the period, viz. butchery, bone-working and rendering and glue-making, small-scale tanneries, glass-working and potteries. Solid wastes and liquid effluent from these industries and their associated dwellings were discharged directly to the Walbrook and polluted the river on its passage through the town to the Thames. Land was raised in an attempt to reduce flood frequency often unsuccessfully resulting in further land-raising activity. These industries were first sited in this unsuitable area towards the end of the 1st C but, in the main, were not operational later than the completion of the town wall c220 CE. The siting of industries in this worst of areas appears enigmatic. However, it could be an indication that there was a form of municipal administration governing development of the town. These industries were capable not just of polluting the watercourse, they were also the producers of nauseous and noxious odours. Given the prevailing winds from the southwestern quadrant, it is possible that these industries were allocated in this low-value land by the authorities to ensure that, for most of the time, they did not pollute the air of the residential, administrative and commercial centres. As water supplies for the town were drawn almost exclusively from the ground, it was immaterial that the industries polluted the Walbrook.

i. To the north of the cemeteries, the landscape remained rural throughout the Roman period and would have been intensively farmed for cereal crops, animal husbandry and horticulture to serve the needs of the town.

j. Construction of the town wall provided the engineers responsible for its design and the town administration with an opportunity to eliminate flooding of the urban area by the Walbrook. Small-sized culverts were used as a device to throttle and limit flow into the town at times of storm. As the river backed up behind the culverts, it formed a marsh which evetually became known as Moorfields. On completion of its construction c220 CE, the effect on the town and its inhabitants was dramatic. No longer subject to the threat of flooding, land in the southern half of the former floodplain increased in value and high-status, stone residences were built there for the first time. The formation of a marsh outside the walls would have created a reservoir of water to improve the reliability of the milling operation and, making use of the increased head available, provided an opportunity to construct a second wheel. Whether influenced by this new riverine situation or a worsening economic environment, industries no longer operated in the northern area and the Walbrook became less polluted. As a result, the general environment between the Bucklersbury and Cannon Street bridges improved and the Temple of Mithras and other places of worship were constructed on the banks of the Walbrook.

k. Prior to completion of the wall around the town, the whole area north of Lothbury would have had a wet inhospitable feel to it. It is unlikely that the general populace would have ventured into it unless they had to for business related to industries sited there, to hunt wildfowl on the marsh, to visit the cemeteries or travel through it to the north. Following construction of the wall, the threat of flooding of the town was eliminated and the general urban environment was rendered more pleasant as a cleaner river now passed through the town. Passage through the northern areas to the cemeteries and to roads leading north was also considerably improved.

9.3 Implications of the Research for Archaeological Science

As was the case for Roman London, many ancient towns and cities throughout the world were founded by the banks of a river or stream. Such towns may have just evolved around a bridgehead but most will have been deliberately sited to take advantage of the river as a source of supply of water for drinking, for horticulture or for industry and crafts. The river may also have been viewed as a source of power and a safe means of transportation of people and goods. Conventional archaeological investigations may produce evidence by which the influence of the river on ancient society and the converse may be inferred. However, in absence of contemporary writings or a hydrological analysis of the river's flow regime, it can be difficult to discern the full beneficial use potential of the river and to determine whether and to what extent the river may have flooded the urban area.

Prior to this research, this was the situation with respect to interpretation of the findings of numerous archaeological investigations of the Walbrook in the Roman period, when London was first founded and developed. As an example, one of the most recent investigations, the Bloomberg Development

(BZY10), found artefacts by the Walbrook channel that were related to milling and a water-driven mill mechanism but archaeologists interpreting their finds were uncertain as to whether there had been sufficient flow in the river combined with sufficient head to drive a mill. The current research has produced the base flow data and the topographical details of the river in the Roman period that will now enable the investigators to assess the viability of a mill and to estimate its output. As another example, several investigations in the northern middle urban Walbrook Valley found evidence that could be interpreted as indicating that the Walbrook was capable of causing flooding without there being any certainty that this actually took place. The flood frequency analysis carried out as part of this research demonstrated not only that flooding was possible but also that it may well have occurred more than once a year in parts of the urban area before land-raising activity was carried out.

The Walbrook was a significant topographical feature of London from the Roman period through to the 15th C. By the end of the 16th C, the river had been completely covered over and had passed from public consciousness. No contemporary description of the Walbrook in the Roman period exists and descriptions of the Walbrook in the medieval period are brief and qualitative. The situation represented by the Walbrook is not an unusual one. As a town expands, formerly rural areas are urbanised and, in the process, it is common for streams and rivers to be culverted and covered over for use as drains for both surface runoff and foul sewage.

The methodology developed for, and successfully applied in, this research for “re-creating” an ancient river that no longer exists can be adopted or adapted for application elsewhere with similar circumstances. Its application depends upon defining the following checklist of data:

- the extent of the topographic catchment and, where they do not coincide, the groundwater catchment;
- the principal watercourses constituting the river system;
- the catchment topography, in particular the morphology of the ground surface and the longitudinal profile of the river in the period being assessed;
- geology, soil, vegetation and other catchment descriptors relevant to a hydrological analysis, including the extent of settlements and urban areas;
- in order to estimate base flow, either river flow metering data over a period of at least 30 years or equivalent surrogate river flow data as a proxy; and

- rainfall data including, if flood frequency assessment is important, the rainfall intensity, duration and return period relationship.

This research was able to draw upon a considerable amount of good quality archaeological data to formulate the morphology and pedology of the study area before and during the Roman period and to generate the longitudinal profile of the Roman Walbrook. This data was supplemented by a considerable amount of literature that, amongst other matters, permitted vegetation and other catchment descriptors to be developed. Long-term, modern data for rainfall and suitable surrogate rivers was available and, as climate in the Roman period was assessed as being similar to that of today, could be used to develop base flow in the river and storm runoff.

In absence of the data used, proxy data would need to be developed and it is recognised that this will not always be possible and therefore limits the use of the method. However, it is probable that sufficient actual or proxy data will be available for its further application throughout the UK, western Europe and the USA. It will also probably be available selectively in specific countries in eastern Europe, the Middle East and Asia.

9.4 Future Research Proposals

This research is entirely based upon the use, application and interpretation of existing data, much of which has been drawn from the records of archaeological investigations and publications. The data have not been originally compiled with a view to it being used in one of the principal components of this research, the palaeo-stratigraphy. In addition, the research suffered from the lack of a contemporaneous description of Roman London and, in particular, the landscape of the Greater Walbrook Valley both prior to and during the Roman period. As such, although data have been applied commensurate with the ability and professional experience of the researcher, the results of the hydrological aspects of the research must be considered as capable of refinement.

It is therefore proposed that when further archaeological investigations are carried out in the URWV, consideration be given to the compilation of data that would assist in refining its hydrology in the Roman period.

The research has assessed the effectiveness of flood control measures and river management techniques practised in Roman London as drawn from archaeological investigations in the URWV. However, this assessment would need to be reviewed were there to be significant changes to the hydrological data used in this research.

A comparison of the relative importance of the crafts and industries sited in the Middle and Upper Roman Walbrook Valley and the same types of industry elsewhere in Roman London is outside the scope of this current research. Consequently, it has been noted that the reasons for the establishment of industry in the northern suburbs of the URWV, a counter-intuitive decision given its marshy condition and frequent flooding, can only be speculative. A research project that undertook that comparison could determine whether the siting of specific crafts and industries in the northern suburbs was planned or unplanned and if planned whether this was related to the noxious nature of those activities, the status of those involved in them or other reasons.

The results of this research project have provided evidence that the Walbrook was capable of driving a mill that could have made a significant contribution towards the milled flour demands of Roman London. Work to determine whether finds in the northeast corner of the BZY10 site are evidence of a water-powered mill is ongoing at the date of printing of this thesis. The MoLA team working on the reporting of their investigation should be made aware of the results of this investigation, particularly with respect to the base flow of the river.

There follows a brief description of the various aspects of the palaeo-hydrology that would benefit from further investigation.

9.4.1 Landscape – influence upon Curve Number

The magnitude of storm flows in a river are significantly influenced by the rate at which rain falling on land drains from it. This is represented in the HydroCad software by a factor termed Curve Number, which is itself a combination of soil permeability and land cover. The palaeo-stratigraphy has provided sufficient data to be confident of the soil permeability used in the research, however, the types and mix of land cover throughout the Roman Walbrook Valley would benefit from more data. Was there a pre-Roman settlement at the Angel, Islington and, if so, its land coverage? Were there any other pre-Roman settlements or farms in the Greater Walbrook Valley? To what extent was the pre-Roman valley wooded? How much of the land outside the urban Roman town was used to grow crops and for animal husbandry? With the exception of the LSS85 investigation, detailed environmental studies have only been included in archaeological investigations in London over the last decade or so and these have been reported upon only recently. It is most probable that future investigations will considerably enhance the definition of the pre-Roman and Roman landscapes of the Greater Walbrook Valley.

9.4.2 Hydrological features

The watershed delineating the catchment of the Walbrook from those of its neighbours, the Fleet and the Hackney Brook, is readily apparent both on maps and on the ground for much of its length. The western boundary from the Thames through to its northern extreme above the Angel, Islington along the ridge to Canonbury and Highbury and its northeast edge down to the Regent’s Canal in Shoreditch can be accurately defined. This is also the case from just north of Liverpool Street Station through to the Thames. However, it is more difficult to define the watershed between the Walbrook and the Hackney Brook between the Regent’s Canal and Liverpool Street Station. A best estimate of this stretch of the boundary has been made but would benefit from further study. Changes to the line are likely to be small and should not make a significant difference to the hydrological analysis.

The contours of the land suggest that there may have been a marsh in the general area of Shoreditch Park. This would have slowed run-off from the Canonbury ridge to the eastern stream of the Walbrook, probably reducing the magnitude of storm flows. Likewise, for the same reason and probable outcome, there may have been a marsh close to the City Road Basin of the Regent’s Canal, which would have affected the magnitude of storm flows on the western branch. Stratigraphic investigation at these locations would determine whether either or both of these marshes existed.

There is a definite ridge of land, about 1.5 metres above the surrounding area, immediately north of City Road/Old Street intersection with its western boundary along the east side of Vestry Street. If this is an ancient natural ridge, it would have definitely acted as a barrier to further eastward travel of the western branch of the Walbrook. However, borehole logs from this ridge could be interpreted as showing the ridge to have been dumped material, possibly debris from the Great Fire of 1666. Further examination of the borehole cores, if they still exist, or analysis of new boreholes could determine whether the material was dumped and, if so, was the area a former marsh or pond. If the latter, it would be extremely useful to attempt to determine the point at which the western branch would have left the pond to continue its course.

9.4.3 Point of confluence of the western and eastern streams

There is sufficient evidence to justify the existence of a substantial, hitherto unknown, western branch of the Walbrook. However, as set out in Section 3.4.5, the point of confluence of the western and eastern streams is more difficult to determine with confidence. Future archaeological investigations in the floodplain of the Walbrook between Eldon Street/Finsbury Circus and Lothbury should examine their findings with the objective of firming up on the point of confluence of the two streams. As an example, recent work on Crossrail at Finsbury Circus appears to have found a channel traversing the area from west to east. Was this the link between the two streams? Was it a natural channel or constructed channel? If the latter, can the date of construction be determined?

9.4.4 Climate

Changes in average ambient temperature can affect the amount and pattern of rainfall, which, in turn, has a direct effect on the magnitude of storm flows in a river. Tidal levels in the Thames have been reported as having fallen significantly through the first two centuries of the Roman occupation, after which they returned to their original levels by the time of their departure early in the 5th century. This could be an indication of a cooling of the climate and a consequent increase in the extent of glaciation and ice accumulations at the poles. It would be of interest to determine whether there was such an alteration to the climate just before and during the Roman period and, if so, whether that change extended to the southern parts of Britain. If there had been a general fluctuation in temperature, it would be of interest to determine what effect this may have had on the magnitude and pattern of rainfall in the London region.

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