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Mapping London's Water Companies and Cholera Deaths

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Abstract

John Snow has become a legendary figure partly for his use of spatial data to support his once controversial theory that cholera is a water-borne disease. For his study of London south of the Thames, Snow used data compiled by William Farr for the Registrar General during the 1853-4 epidemic. Using a larger data set compiled by William Farr in 1868, we use geographical information system (GIS) based software ArcGIS to spatially illustrate the cholera mortality rate in London subdistricts during the Asiatic cholera epidemics of 1848-9, 1853-4 and 1866. We then map the waterfields of London's eight water companies allowing us to highlight the connection John Snow saw between the rate of cholera mortality within a subdistrict and which water company operated within that particular subdistrict. Our maps also show the connection between the rate of cholera mortality in each subdistrict and average subdistrict elevation, a variable which Farr initially believed was more significant than water source.

Introduction

The role that London's water supply played in John Snow's theory of cholera transmission is well known. Snow's investigation and mapping of cholera mortality in the Broad Street pump area is particularly famous. Less well known, but considered more important by Snow, is his study of cholera mortality rates in south London and a comparison of subdistricts receiving their water supply from different companies.¹ Snow's work has been of particular interest to epidemiologists, so much so that Ralph R. Frerichs refers to him as "an historical giant in

epidemiology” and has created a rich and detailed web site dedicated to John Snow’s own publications and other material about John Snow and cholera.² This web site reproduces six maps of nineteenth-century London around the time of the cholera epidemics, including one by Robert Mylne showing the districts supplied by each of the water companies.³ More recently, the increasing sophistication in spatial technology has made the use of maps in the past a topic of renewed interest; books by Pamela Gilbert and Tom Koch include chapters on John Snow and reproduce Snow’s map of cholera mortality rates in south London.⁴ Gilbert and Koch explain that John Snow was not alone in his use of maps to illustrate patterns in the data on cholera mortality. Yet, as Koch notes, ‘The work of Acland, Cooper, Farr, Whitehead, and the other nineteenth-century researchers is forgotten today by all but a few medical historians. What we remember is John Snow and his maps’.⁵

While John Snow is remembered today, he could not have created his maps alone. Snow obtained much of his data from William Farr who, in his role as Compiler of Abstracts for the Registrar General’s Office (1837-80), was instrumental in developing the collection and use of vital statistics including data on cholera mortality. Farr was himself a contributor to the debate over the transmission of cholera. As D. E. Lilienfeld explained in 2007, on the 200th anniversary of Farr’s birth, ‘Farr's contributions to epidemiology are myriad. They range from systems construction to the “Farr's law of epidemics” (the latter refers to Farr's observation that the risk of cholera is inversely related to altitude). ... Farr occupies a prominent role in the epidemiologic investigations into the means by which cholera spread’.⁶ Our paper strengthens this recognition of William Farr’s role in understanding cholera and incorporates his data into maps of London subdistricts created in geographical information system (GIS) based software ArcGIS.

Initially, Farr was convinced that cholera was a miasmatic disease because of the statistical connection he found between elevation and cholera using data from the 1848-9 epidemic.⁷ The importance Farr placed on the need to gather and use accurate data, made him generous in sharing data with others, including John Snow with whom he disagreed. Farr provided the data that allowed Snow to undertake his investigation of mortality in south London during the 1853-4 cholera epidemic. When Snow's analysis of the 1853-4 data convinced Farr that the particular water company providing service within a subdistrict had a stronger correlation with mortality rate than average subdistrict elevation, Farr soon changed his mind about the way in which cholera was transmitted.⁸ Fully persuaded by Snow's theory of cholera transmission when London suffered unexpectedly high mortality during the 1866 epidemic, Farr wrote a detailed report covering the 1848-9, 1853-4 and 1866 epidemics to provide a detailed defense of Snow's theory that cholera was a water-borne rather than miasmatic disease.

This paper connects data from 'Table 27: London subdistricts' of William Farr's 1868 report on London's cholera epidemics with a newly-created ArcGIS map of London subdistricts during the mid-1800s.⁹ This allows us to show the spatial distribution of each water company's service area (called 'waterfields' by Farr), the average elevation of each subdistrict, and rates of cholera mortality for each of the three epidemics. The maps were created as part of a larger research project focusing on London's history of water provision during the nineteenth century. These maps complement recent literature on the role of cartography and spatial analysis in our understanding of disease and contribute to our understanding of Victorian London. The creation of the maps in ArcGIS provides a tool that may be used to enhance our understanding of other

aspects of London's history such as the connection between disease mortality and population density. This paper also responds to a renewed interest in the history of water supply as we face increasing pressure on urban water sources, aging infrastructure, and concerns about chemical pollutants in wastewater. It follows a recent paper in this journal by Joseph Hillier revisiting our understanding of the transition to a constant water supply.¹⁰ Section 1 locates the paper within the literature on the use of maps by John Snow and his contemporaries. Section 2 explains the methods used to create the map layers. Section 3 presents the maps and explains how they illustrate William Farr and John Snow's understanding of the transmission of cholera.

1: Related Literature

The use of maps to present disease data is not new: maps played an important role in nineteenth century debates over the transmission of cholera. Pamela Gilbert and Tom Koch place John Snow's well-known map of the 1854 cholera outbreak in Soho and his less well-known map of south London into the context of the large number of contemporary disease maps.¹¹ As Tom Koch notes, by the mid-nineteenth century 'mapping was becoming an accepted element of official studies'.¹² As one amongst a number of contemporaries producing cholera maps, Snow was able to draw upon the work of others to support his own arguments. Of particular note is a density map of the 1849 cholera epidemic created by Richard Grainger and reproduced by Tom Koch.¹³ Grainger's map includes subdistrict boundaries, elevation numbers, and shading for the intensity of cholera mortality; it does not include information on water supply.

Tom Koch argues that John Snow's maps form the heart of his study of cholera and his efforts to persuade the scientific community. Both Koch and Gilbert argue that Snow considered his south London map, showing the different rates of cholera mortality in subdistricts supplied by the Southwark and Vauxhall Water Company and the Lambeth Water Company, more important than his Soho map for persuading members of the scientific community that cholera was transmitted between people through the ingestion of water contaminated with evacuations from cholera patients. Nevertheless, Koch believes that Snow was not fully satisfied with his map and failed in his goal of mapping the connection between water company and cholera mortality at the subdistrict level: 'Snow's text tables detailed districts (table V) and subdistricts (table VI) on the basis of population, deaths, and water source. ... It was this that Snow had hoped to map (and calculate) not at the course scale of the water company but at the finer scale of the subdistricts themselves. It was this that he failed to accomplish in either map or table'.¹⁴ This paper uses William Farr's data to produce such a map.

William Farr also produced maps of London's cholera epidemic to accompany his reports of 1852 and 1868. In his 1852 report, Farr presents the argument that elevation is the most significant variable to explain cholera mortality at the subdistrict level.¹⁵ In his 1868 report, however, William Farr uses data and maps to explain his change of mind and to support Snow's theory that cholera is transmitted person-to-person via cholera evacuations in water. Tom Koch reports on Farr's disagreement with Snow and reproduces his 'table map' of district-level cholera mortality rates, elevation, and water source.¹⁶ Because Koch focuses only on cholera mapping for the 1832, 1848-9, and 1853-4 epidemics, he does not extend his discussion to Farr's 1868 report and only briefly mentions his change of mind. Pamela Gilbert also reproduces William

Farr's 'schematic map' from his analysis of the 1848-9 outbreak. Gilbert discusses Farr's change of mind and acknowledgement that Snow was correct but does not reproduce Farr's map of the 1866 cholera epidemic. This paper uses Farr's data to show why Farr believed the maps supported his change of mind.

Maps have continued to play an important role in our understanding and representation of data and the recent explosion of digital mapping technologies revitalized interest in the historical as well as contemporary use of maps. The London Mapping Festival 2011-12 was a response to this renewed interest. Cassettari et al's book *London in maps: a changing perspective*, published as part of the London Mapping Festival, features Mylne's map of the 'Metropolis Water Supply'.¹⁷ This map is one of three produced by Robert Mylne on the geology, water supply, and sanitation of the metropolis. It highlights the districts supplied by each of London's water companies, the location of water works infrastructure, and contour lines for the metropolis. We used Mylne's map of contour lines to map London's elevation in ArcGIS.

2: ArcGIS Methodology

Our goal in turning to GIS-based software ArcGIS was to be able to spatially portray William Farr's data on cholera mortality, elevation, and water source at the subdistrict level. The first step was to locate a map that would provide the boundaries for London subdistricts around the period 1848-1866. We selected Arrowsmith's 1843 map *The Registration Districts of the Metropolis*.¹⁸ Although produced in 1843, this map included boundaries for most of the subdistricts included in Farr's 1868 data, with only Hammersmith, Putney, Streatham, Norwood, Dulwich, Sydenham,

Eltham, Woolwich Dockyard, Woolwich Arsenal, Plumstead and Stamford Hill excluded. We obtained a copy of this map from the histpop.org web site. For the subdistricts beyond the boundaries of Arrowsmith's map, we used a map produced by Robert J. Cook & Hammond and included in Cripps 1892 report to the London County Council on London's Water Companies.¹⁹ Finally, we used Francis Bolton's 1884 *Map Shewing Districts Supplied by the London Water Companies Together With the Limits of Supply under the Various Acts of Parliament* to check the western and eastern extension of the Thames.²⁰ Throughout the process, each of the maps was georeferenced to the Ordnance Survey National Grid.

To allow us to highlight the debate between Snow and Farr over the relative importance of water supply and elevation in influencing the level of cholera mortality in a subdistrict, we added another map layer. For this we used Robert J. Mylne's 1856 *Map of the Geology and Contours of London and its Environs* with contour lines representing 10 feet altitudes.²¹ Using Mylne's map fit well with the elevation data provided by William Farr because both use elevation above the Thames High Water Mark, Trinity standard.²² The contour lines provided by Mylne give much greater detail about elevation within a subdistrict than Farr's figures for average elevation. Contours were hand-traced using the edit tool in ArcMap rather than scanned due to the large amount of colour in Mylne's map, which made it impossible to easily isolate the contour lines. Mylne's map excludes the southern parts of Streatham, Norwood, Dulwich, Sydenham, Lewisham Village, Lee, Eltham, and the western part of Plumstead. As a final check of the contours from the Mylne map, we used a Digital Elevation Model (DEM) image of London's elevation from the ASTER Global DEM, a data file created from satellite imagery of present day elevations; there was a close alignment between the contour lines and the ASTER DEM model.²³

Despite georeferencing each of our maps, there remained some discrepancy in the location of the Thames on each map, particularly at the eastern and western edges of the metropolis. We used a topographic basemap from Esri, using the British Grid as a reference, for minor spatial adjustment of our layers, keeping them in existing relation but fitting the edges of the Thames to the British Grid map.

Once the map layers were complete, we attached data provided by William Farr in “Table 27: London subdistricts” of his 1868 report with subdistrict as point of reference.²⁴ We imported data on cholera mortality rates for 1848-9, 1853-4, and 1866, on elevation, and on water companies that provided supply within each subdistrict, including data on a second water company where relevant. This data allows us to show each of the eight water companies’ primary waterfield along with those subdistricts with more than one company providing supply. This is something included in Bolton’s 1884 map of London’s water companies but not in Mylne’s 1856 map.²⁵

3: Understanding Cholera: Elevation vs. Water Supply

When the first Asiatic cholera epidemic hit England in 1832, very little was known about the source, form, or transmission of the disease. There were many competing theories that could explain the facts observed in a specific location but counter-examples that challenged each theory could be found in other locations. When the second epidemic arrived in 1848, the scientific debate intensified. William Farr was responsible for tabulating the mortality data for the 1848 epidemic and writing an official report published by the Registrar General in 1852.

Four variables that Farr reported as potentially significant determinants of cholera mortality were: 1) water source, 2) elevation, 3) population density, and 4) wealth or poverty.²⁶ Farr's own conclusion, based on his statistical analysis and published in the *Journal of the Statistical Society of London*, was that "the elevation of the soil in London has a more constant relation with the mortality from cholera than any other known element."²⁷ To illustrate the connection between cholera mortality and elevation, Farr included a diagram in the Registrar General's 1852 report showing the boundaries of each district, average subdistrict elevation, and deaths from cholera to every 10000 inhabitants.²⁸

Using Farr's data, Figure 1 below provides an accurate map of London's subdistricts with information on average elevation and cholera deaths per 10,000 for the 1848-9 epidemic. The high mortality rates in the low-lying subdistricts just south of the Thames suggest why Farr would later write: 'I showed that the parts of London near the warm infected Thames suffered in an unusual degree during the epidemic of 1849.'²⁹ Supplementary Figure 1 provides a hill-shade for London based on Robert Mylne's 1856 contour map along with Farr's measure of average elevation for each subdistrict. This map reinforces the low-lying location of those subdistricts with a high rate of cholera mortality while also showing the different elevations within some subdistricts.

Figure 1: Cholera Mortality 1848-9 and Elevation

Following the 1848-9 epidemic, England faced another Asiatic cholera epidemic in 1853-4. The overall rate of cholera mortality for London fell from 62 to 46 per 10,000.³⁰ This fall in cholera

mortality for the metropolis as a whole is an average that is representative of the fall in mortality for some subdistricts but does not reveal the increase in others: cholera mortality declined in most subdistricts north of the Thames, while south of the Thames the outcome was mixed with some subdistricts experiencing a sharp fall in mortality and others an increase. Figure 2 shows cholera mortality at the subdistrict level for the 1853-4 epidemic.³¹ The concentration of cholera deaths south of the Thames is evident. Supplementary Figure 2 indicates whether subdistricts experienced an increase (values above 100%) or decrease in cholera mortality in 1853-4 compared to 1848-9. In both figures, the north-west subdistrict of Golden Square stands out; this was the location of the Broad Street Pump.

The differences in cholera mortality rates across subdistricts south of London provided John Snow with just the natural experiment that he needed to support his theory that water played a crucial role in the transmission of cholera. In his *Mode of Communication of Cholera* Snow used a fairly detailed study of cholera mortality in those south London districts supplied by the Southwark and Vauxhall and Lambeth water companies.³² Snow showed that the customers of the Lambeth Water Works Company experienced lower mortality rates than customers of the Southwark and Vauxhall Water Company. In 1852, the Lambeth had finished moving its intake upriver from Brixton to Long Ditton and completed construction of its sand filter plant.³³ Snow argued that the lower mortality rates amongst customers of the Lambeth were because the Company's intake at Long Ditton was now above the outlets of London's sewers. The Southwark and Vauxhall withdrew its water from the Thames at Battersea having purchased land there in 1845 and opened its new works there in 1852. That same year, the Southwark and

Vauxhall had made plans to move further upriver to Hampton but had not yet finished construction when cholera hit in 1853-4.

Figure 2: Cholera Mortality 1853-4

Figure 3: Water Company Boundaries of Supply

Figure 3 shows the waterfields for each of London's eight water companies. Viewing this map alongside Figures 1 and 2 makes clear the fall in rates of mortality in the Lambeth waterfield compared to that in Southwark and Vauxhall Company subdistricts. To some degree Figures 1 and 2 (and Supplementary Figure 2) understate the difference in mortality rates because some subdistricts were supplied by more than one company; subdistricts with overlapping networks are identified in Figure 3 with the alternative water company identified by an overlaid pattern.³⁴ Where waterfields overlapped, cholera mortality was shown by Snow to be higher in those streets supplied by the Southwark and Vauxhall than those supplied by the Lambeth Water Company.³⁵ Supplementary Figure 4 combines Figures 2 and 3, showing cholera mortality in 1853-4 for each subdistrict along with each Company's primary waterfield. This map comes close to achieving what Snow had hoped to depict: the connection between water company and mortality rate in the Lambeth and Southwark and Vauxhall waterfields.

In 1868, Farr would write: 'The final report of the scientific community proved conclusively the extensive influence of water as a medium for the diffusion of the disease in its fatal forms'.³⁶ Snow's analysis of mortality in south London following the 1853-4 epidemic ultimately

persuaded Farr that water source was a more significant determinant of cholera mortality than elevation. The Lambeth Water Company had been an industry leader by requesting Parliamentary approval to move its intake above the tidal reach of the Thames in 1848.³⁷ The Metropolis Water Supply Act of 1852 required all companies to follow suit and move their intake above Teddington.

When Asiatic cholera next reached London in 1866, all water companies drawing water from the Thames had moved their intake above Teddington and were filtering their water prior to distribution. William Farr argues that this, along with the improved organization of public health officers, meant that in 1866 the scientific community expected cholera to be ‘confined within narrow limits’.³⁸ As Figure 4 showing cholera mortality rates for the 1866 epidemic reveals, this expectation proved accurate for most of London. North-east London stands out as experiencing unexpectedly high rates of cholera mortality. Looking at the map of the companies’ waterfields (Figure 3) in connection with Figure 4, the concentration of cholera deaths in the East London Company’s subdistricts is apparent. This proved a final test of the accuracy of Snow’s theory of cholera transmission.

Figure 4: Cholera Mortality 1866

In addition to the requirement that companies drawing water from the Thames do so above Teddington, the 1852 Metropolis Water Supply Act had required all companies to filter their water prior to distribution and to use only covered storage reservoirs. In 1866, the East London Waterworks Company illegally connected its old, uncovered, reservoir at Old Ford to its covered

reservoirs containing filtered water. Although illegal, the Company argued that connecting to its old reservoir was done to provide sufficient water in the covered reservoir to prevent damage to the pumping engine.³⁹ In addition, when the covered reservoir was almost empty its close proximity to the River Lea and the lower elevation of the reservoir compared to the river allowed water to enter the reservoir unfiltered directly from the river. Water quality in the river Lea had deteriorated since 1854 due to the addition of sewers discharging from Stratford and West Ham in addition to those from East London. This resulted in mortality rates higher than in 1853-4 in those East London subdistricts supplied with water from the Old Ford reservoir.

Conclusion

Using ArcGIS we have brought together data on cholera mortality, elevation, and London's waterfields gathered by William Farr for the Registrar General's office with maps of London subdistricts during the mid-nineteenth century. Our series of maps shows how a natural experiment improved contemporary understanding of the transmission of cholera. In 1848-9, the connection between cholera mortality and elevation is strong as observed by William Farr. By 1853-4, the lower mortality rate in subdistricts supplied by the Lambeth Water Company compared to those supplied by the Southwark and Vauxhall Company suggests a connection between waterfield and cholera mortality. The maps illustrate why the spatial distribution of cholera deaths ultimately persuaded William Farr that John Snow was correct to argue that cholera mortality had a stronger correlation waterfield than with elevation. It is arguable that had Snow produced maps similar to those produced here, he may have had more success persuading

a larger number of his contemporaries. By 1866, the concentration of cholera deaths in the East London waterfield show why Farr considered any scientific debate to be over.

In his 1868 report, William Farr included information on population for each subdistrict, along with data on number of houses, average property value, poor relief, and deaths from diarrhea at the district level. In 1852, William Farr considered population density and wealth or poverty to be a potentially significant variable in predicting cholera mortality although he ultimately rejected them in favor of elevation. Using modern regression analysis, population density remains significantly correlated with cholera mortality even after accounting for water source and elevation; the significance of Farr's measures of wealth or poverty is less clear.⁴⁰ Using the subdistrict polygons we have created in ArcGIS will allow for the creation of maps showing population density across London during the cholera years. At the district level, maps could show whether deaths from diarrhea also correlated with water source.

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- ² Ralph R. Frerichs, *John Snow site* <<http://www.ph.ucla.edu/epi/snow.html>> [accessed 27 February 2013].
- ³ Robert W. Mylne, *Map of the Contours of London & Its Environs Shewing the Different Areas Supplied by the Different Water Works* (1856); Ralph R. Frerichs, *Map of London Waterworks 1856* <http://www.ph.ucla.edu/epi/snow/watermap1856/watermap_1856.html> [accessed 27 February 2013].
- ⁴ Pamela Gilbert, *Mapping the Victorian Social Body*, (New York, 2004), 59; Tom Koch, *Cartographies of Disease* (California, 2005), 93; Tom Koch, *Disease Maps: Epidemics on the Ground* (Chicago, 2010), 183.
- ⁵ Koch, *Cartographies*, 130.
- ⁶ Lilienfeld, D.E., ‘Celebration: William Farr (1807–1883)—an appreciation on the 200th anniversary of his birth’, *International Journal of Epidemiology* 36:5 (2007), 985-987 (986).
- ⁷ William Farr, ‘Influence of Elevation on the Fatality of Cholera’, *Journal of the Statistical Society of London*, 15:2 (1852), 155-183.
- ⁸ Margaret Pelling, *Cholera, Fever and English Medicine 1825-1865*, (Oxford, 1978, 229), references John Simon, *English Sanitary Institutions* (1897, 261) in arguing that it was William Farr who “apparently suggested the wider inquiry into the influence of London water supply made by [John] Simon in 1856” on behalf of the Board of Health’s Committee

for Scientific Inquiries. Pelling refers to Farr's 1868 report but notes that it falls outside the period covered in her book.

⁹ William Farr, *Report on the Cholera Epidemic of 1866 in England*, (1868), 62-75.

¹⁰ Joseph Hillier, "The Rise of Constant Water in London", *The London Journal*, 36:1 (2011), 37-53.

¹¹ Gilbert, *Mapping*; Koch, *Cartographies*; Koch, *Disease Maps*.

¹² Koch, *Cartographies*, 79.

¹³ Koch, *Cartographies*, 87.

¹⁴ Koch, *Cartography*, 92.

¹⁵ William Farr, *Report on the mortality of cholera in England, 1848-49*, (1852).

¹⁶ Koch, *Disease Maps*, 173.

¹⁷ S. Cassettari, F. Cocks, C. Going, N. Jones, *London in maps: a changing perspective*, (2011).

¹⁸ J. Arrowsmith, *The Registration Districts of the Metropolis in the Fifth Annual Report of the Registrar General of Births, Deaths, and Marriages in England*, (1843). Available at: <http://www.histpop.org/ohpr/servlet/PageBrowser?path=Browse/Registrar%20General%20%28by%20date%29&active=yes&mno=800&tocstate=expandnew&tocseq=13400&display=sections&display=tables&display=pagetitles&pageseq=first-nonblank> [Accessed October 2012]

¹⁹ R. J. Cook & Hammond, *London Water Companies Map Illustrating the Extent of Competition Among the London Water Companies Already Authorized by Parliament. Westminster*. In H.L. Cripps, *The Position of the London Water Companies Considered from a Parliamentary and Legal Point of View*, (1892).

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- ²⁰ Francis Bolton, *Map Shewing Districts Supplied by the London Water Companies Together with the Limits of Supply Under the Various Acts of Parliament*, (1884). In P.A. Scratchley (ed.), *London water supply, including a history and description of the London waterworks, statistical tables, and maps*, (1888). While Bolton's map clearly shows the each water company's actual and legal supply districts along with their areas of overlapping supply both north and south of the river Thames, it does not includes subdistrict boundaries.
- ²¹ R.W. Mylne's *1856 Map of the Geology and Contours of London and its Environs with some introductory remarks by Simon Morris*, (1993).
- ²² Trinity high water mark was a mark set at high tide by Trinity House in the City of London in 1800 and was commonly used during the nineteenth century as a reference for elevation.
- ²³ Aster Global Digital Elevation Model available at
<<http://www.jspacesystems.or.jp/ersdac/GDEM/E/2.html>> [Accessed February 2013]
- ²⁴ Farr, *Epidemic of 1866*, 62-75.
- ²⁵ Mylne does include an area of overlapping supply by the Kent and Plumstead Water Works which is not included in our maps or Farr's data; the Kent Company took over the Plumstead's works in 1856 and was not considered an area of particular relevance to Farr's analysis of the transmission of cholera.
- ²⁶ Farr, *Cholera in England, 1848-49*, lvii-lxviii.
- ²⁷ Farr, *Influence of Elevation*, 158.
- ²⁸ Farr, *Cholera in England, 1848-49*, clxv; reproduced in Koch, *Disease Maps*, 177.
- ²⁹ Farr, *Epidemic of 1866*, xiv.
- ³⁰ Farr, *Epidemic of 1866*, 63.
- ³¹ Figure 2 does not include subdistrict elevation since these remain the same as in Figure 1.

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- ³² John Snow, *Mode of the Communication of Cholera* (London: John Churchill, 1855).
- ³³ Farr, *Epidemic of 1866*, 295.
- ³⁴ Supplementary Figure 3 shows this more clearly with each company's primary waterfield identified by a coloured shading of the perimeter and secondary waterfields identified by a pattern in the same colour. Farr, *Epidemic of 1866*, Table 27, also includes information on domestic wells as an alternative source of water in some subdistricts and includes a third water company, the Kent Water Company, supplying water to Peckham in addition to the Southwark and Vauxhall and Lambeth companies.
- ³⁵ Snow, *Mode of Communication*, 74-81.
- ³⁶ Farr, *Epidemic of 1866*, xi.
- ³⁷ On James Simpson's role in recommending this move see Gwilym Roberts, *Chelsea to Cairo-- 'Taylor-Made' Water Through Eleven Reigns and in Six Continents: A History of John Taylor & Sons and Their Predecessors* (2006), 167-169.
- ³⁸ Farr, *Epidemic of 1866*, xi.
- ³⁹ Farr, *Epidemic of 1866*, xviii.
- ⁴⁰ Nicola Tynan, "Innovation by London's Water Companies: Internalizing the Health Externalities", Working Paper (2013).