

# Navigable waterways and the economy of England and Wales: 1600-1835

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## 1. Introduction

*“The advantages resulting from canals, as they open an easy and cheap communication between distant parts of a country, will be ultimately experienced by persons of various descriptions: and more especially by the manufacturer, the occupier or owner of land, and the merchant. The manufacturer will thus be enabled to collect his materials, his fuel, and the means of subsistence, from remote districts, with less labour and expense; and to convey his goods to a profitable market. As canals multiply, old manufactures revive and flourish, new ones are established, and the adjoining country is rendered populous and productive.”<sup>2</sup>*

In a single paragraph, this anonymous contribution to an encyclopaedia published when canal building was at its height (circa 1806) encapsulates the interrelated benefits of navigable waterways. Numerous scholarly attempts have been made to specify the relationship between navigable waterways and economic growth in England and Wales. Typically, these have focused on the period between 1600 and 1835, when the network expanded most. However, with some notable exceptions, these studies are insufficiently grounded in the changing geographical and material realities of the time.

To help fill that gap, this paper uses a new technology, GIS (Geographical Information Systems) Modelling, to lay foundations and explore more rigorously the relationship between navigable waterways, demography and economic growth in England and Wales.

The paper proceeds as follows. The next section relates the expansion of the navigable waterways network in England and Wales to population growth and urbanisation. Then, the GIS Waterways model developed by the Cambridge Group for the History of Population and

Social Structure is described. Fourthly, the constraints imposed on navigable waterways by the physical geography of England and Wales are discussed. Next, the growth and development of the navigable waterway network from 1600 to 1835 is described. Sixthly, the economic significance of English and Welsh navigable waterways is evaluated. Lastly, conclusions are drawn.

## 2. Population growth, urbanisation and navigable waterways

The expansion in English and Welsh waterways is associated with a substantial increase in population and, even more, in urbanisation. As Table 1 shows, the population of England increased by 164 per cent from 1600 to 1800. Meanwhile, towns with at least 5,000 inhabitants increased six-fold while the population of smaller towns and the countryside doubled. The combination of population growth and urbanisation led to a massive increase in demand for food, fuel and raw materials. This placed a huge strain on the existing transport facilities and enormously incentivised their expansion and improvement.

**Table 1. Population Growth and Urbanisation in England 1600-1800**

	1600		1800		Per cent increase 1600 -1800
	People (000's)	%	People (000's)	%	
<b>Population in towns with 5000 inhabitants</b>	335	8	2,380	27	610%
<b>Population in smaller towns &amp; the countryside</b>	3,827	92	6,291	73	108%
<b>Total Population</b>	<b>4,162</b>	<b>100</b>	<b>8,671</b>	<b>100</b>	<b>164%</b>

From: E.A. Wrigley, *The Path to Sustained Growth* (Cambridge, 2016), 49

In the pre-railway era, navigable waterways were the most efficient way of carrying low value, bulky, non-perishable goods (like coal and grain). This can be illustrated by comparing the typical load that a one-horse wagon could carry on a pre-turnpike road with the typical load that a single-horse barge could haul on a broad canal. As Table 2 shows, one horse on a broad canal could haul the same load as eighty one-horse wagons. The number of horses required for transportation was crucial because, like today, horses were a major capital

investment and their food and upkeep was expensive. As the canal network expanded, horses were released from road transportation; this allowed them to be applied to other productive purposes. Hence, in 1811, Parkinson argued that the building of canals, "Promotes the purposes of agriculture very much by keeping their (the farmers') horses at liberty for that purpose".<sup>3</sup>

**Table 2: Typical loads carried or drawn by a single horse before 1750**

<b>Mode of Transportation</b>	<b>Tons</b>	<b>Horses needed to draw the same weight by wagons on soft roads</b>
Barge on broad canal	50	80
Barge on narrow canal	30	48
Barge on river	30	48
Wagon on iron rails	8	12.8
Wagon on macadam roads	2	3.2
Wagon on soft roads	0.625	1
Pack-horse	0.125	-

From: Skempton, 'Canal and river navigations before 1750',

Cost differentials between modes of transportation had a major effect on the usage of certain bulk goods during our period. When buyers had a choice of raw materials - such as wood, peat and coal - the availability of cheap carriage via a navigable waterway could determine which commodity was used. Coal, for example, could not be sold profitably if it had to be transported more than fifteen miles by road<sup>4</sup>; consequently, waterways massively increased the relative competitiveness and consumption of coal when it had to be transported over long distances.

In 1782, the agriculturalist William Marshall vividly illustrated the impact of cost differentials when he described the carriage of chalk marl from Thorpe near Norwich to Woodbastwick in Norfolk. The fields of Woodbastwick lay seven to eight miles away from the chalk pits of Thorpe by road. Yet, compared to the cost of road transportation, it was still

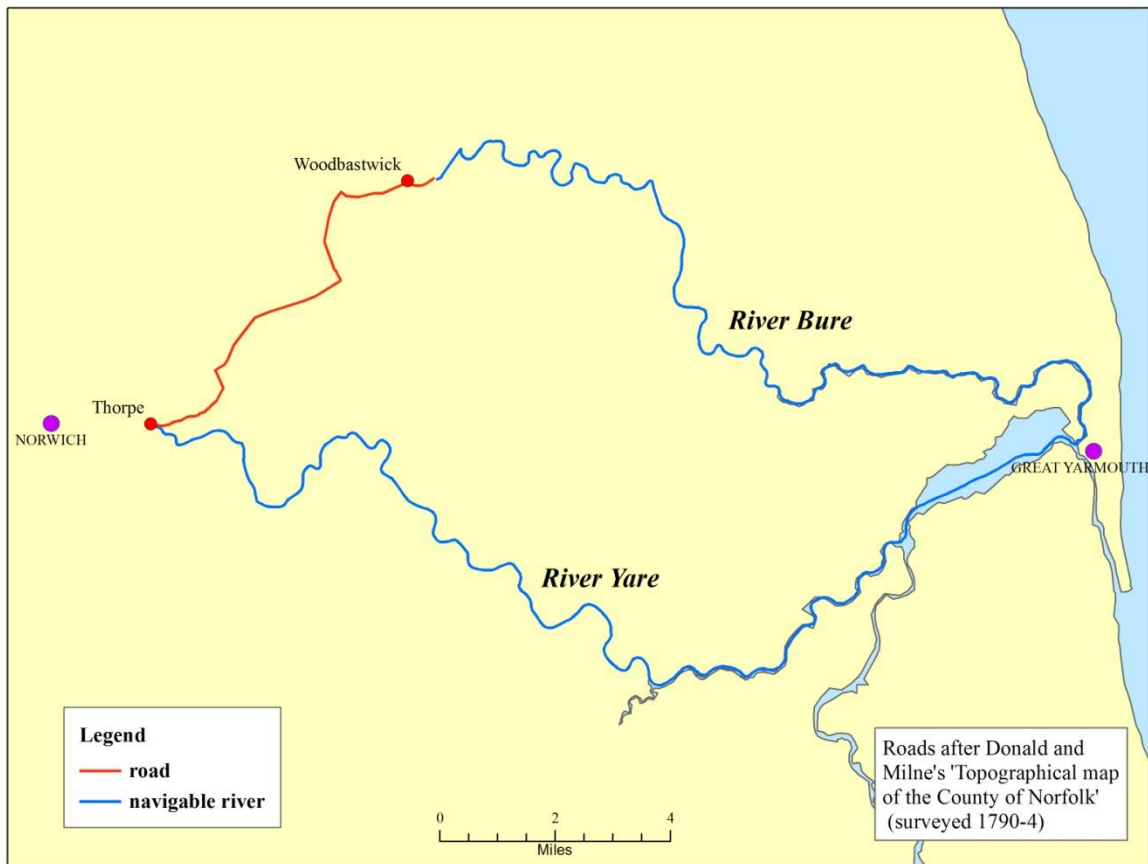
cheaper to load the marl onto a lighter and ship it 48 miles down the River Yare to Yarmouth, then ship it up the River Bure to Woodbastwick and, finally, to offload and cart it half a mile to the fields (see Map 1).<sup>5</sup>

The differences in the cost of road and water transport from Thorpe to Woodbastwick are particularly stark because the Yare and Bure are tidal rivers so vessels did not incur tolls and did not require horse haulage because they were propelled by the tide.<sup>6</sup> Many rivers did not have these advantages. For instance, in 1767, when coal of the same weight as the marl carried to Woodbastwick was transported sixteen miles on the River Lea from Bromley to the Kings Weir at Wormley (Hertfordshire) tolls of 2s 6d had to be paid in addition to the costs of horse haulage.<sup>7</sup>

Nevertheless, the economic advantages of water transportation were still considerable so the network expanded rapidly. In 1600, England and Wales had about 950 miles of navigable waterways. By 1760 this had increased to 1400 miles, which was mainly navigable rivers. In 1835, when the Birmingham and Liverpool Junction Canal had been completed (the last significant expansion), the total waterways network was around 4,000 miles - with most of the increase being due to canal building.

The larger network also had implications for the transportation and marketing of higher value-added goods like cheese and textiles. The higher value to weight ratio of such goods meant they could be carried considerable distances by road; however, if part of the journey was by water, it was possible to market them at still greater distances. For example, in 1704 cheese for the London market was carried by road from Cheshire and Lancashire to Doncaster in the West Riding of Yorkshire, then by the rivers Don, Ouse and Humber to Hull and, finally, by ship along the coast and up the Thames to London.<sup>8</sup> As this example illustrates, proximity to navigable waterways widened the domestic market in England and Wales and fostered Smithian economic growth.

### **Map 1: Travel from Thorpe to Woodbastwick by road and water in 1782**



### **3. The GIS Waterways Model**

Hitherto, the extent and expansion of navigable waterways in England and Wales could only be established in a very laborious way. Estimates of national mileage at various dates had to be used, salient information had to be extracted from the regional studies of Hadfield *et al* and a variety of paper maps of varying accuracy and utility had to be consulted.<sup>9</sup> The creation of the first dynamic Geographical Information System (GIS) model of the English and Welsh waterway network has fundamentally altered our capacity to study this important transportation system. The author achieved this in stages between 2006 and 2016 through a series of grants held by Dr Leigh Shaw-Taylor.<sup>10</sup>

A word needs to be said about the way GIS works. Put simply, the GIS software enables the location of every navigable waterway to be mapped accurately and data can be linked to

each waterway. For example, the tonnage and frequency of vessels that travel on a waterway can be stored and linked. Once data on the relevant variables have been captured en masse, this database can be compared systematically with other datasets stored in the GIS - such as population, mineral resources, wealth and climate. Furthermore, the inclusion of dates related to the opening, expansion and closure of waterways enables temporal analyses to be made.

Although the most important variables are included consistently in our GIS model some data is not. For instance, we cannot currently capture how the tides and the seasons may have affected the functioning of the waterways network and we do not yet capture improvements to rivers that were *already* navigable in 1600. Also, the GIS model does not include navigation schemes that failed - such as the numerous proposals to the Crown and Parliament in the seventeenth and eighteenth centuries that never progressed beyond the planning stage or were abandoned before opening.<sup>11</sup> The future inputting of this type of data into the GIS model will enable a series of valuable, counterfactual analyses to be made.

#### **4. The Impact of physical geography on English and Welsh waterways**

Even though the importance of water travel was recognised by contemporaries in 1600, geography determined that most communities were far away from a river that was, or could be made, navigable. Transport historians use the term '*natural river*' to denote a river that has a sufficient depth and width of water to allow vessels to travel unimpeded, whilst rivers that have been enhanced in some way to make them navigable are called '*improved rivers*'. The limited navigable capacity of the natural rivers in England and Wales was evident in the medieval period when, on major natural rivers (like the Thames) few vessels had a carrying capacity beyond 25 tons, and, on minor natural rivers (like the Parrett in Somerset), loads were limited to one or two tons.<sup>12</sup>

The depth, width and flow of a river depends on the rain falling into its catchment area and on water lost due to trans-evaporation or seepage. Of the 200 river basins in England and Wales, very few are navigable naturally over long distances because of the steep river gradients found in most of Wales, the South-West and parts of the northern England as well as the modest levels of annual precipitation. Furthermore, historically, many rivers were dominated by

boulder stream courses, riffles, pools, and numerous bare rock outcrops, which made navigation all but impossible. These geographical constraints meant that only about a quarter of the *main stem rivers* (the primary downstream segment) of England and Wales were navigable (either naturally or by improvement) in 1835.<sup>13</sup>

Furthermore, even if a river was navigable, water haulage was rarely feasible all year round. During the late summer months, even major rivers like the Thames, Severn and Trent had reduced water levels that impeded haulage. Whilst water transportation was possible continuously in the deeper sections of such rivers, it was both difficult and impossible in the shallower upper reaches. Hence, in the late eighteenth century, insufficient water meant that Coalport - the Severn's upper navigable limit - could only be reached on 146 days of the year.<sup>14</sup>

Freezing temperatures further reduced navigability by making rivers ice-bound and impassable. The impact of this factor was moderated by local air temperatures, water salinity and the speed of flow. Hence, more saline and faster running rivers were less predisposed to freezing than deadwater canals. Freeman is the only scholar to have estimated the number of inland water transportation days lost to frost. Using climactic data for Lancashire from 1771 to 1831,<sup>15</sup> Freeman estimated that the time lost to frost was considerable; 33.3% of the years lost 20 to 30 working days per annum whilst 16.6% of the years lost more than 30 days. The worst winter occurred in 1813-14 when it is estimated that 36.5 days were lost.

Freeman's analyses are based on temperature data from Walton near Liverpool, which has a very mild climate due to its position on the Lancashire Plain and its proximity to the Gulf Stream. Consequently, Walton suggests there were, on average, 30 days of air frost per annum from 1961 to 1990. However, when gridded air frost data (provided by the UK Meteorological Office) is used that spans the entire waterways network, it appears that the average was higher than Walton indicates - see Table 2.

Map 2 shows that most waterways in England and Wales would have experienced many more days of frost than Freeman suggests. Nevertheless, this does not mean waterways were

**Table 3: Navigable Waterways: Average number of days with air frost 1961-1990**

Days of air frost	Miles of waterways	% of all waterways
5-15	11	0.2%
16-30	165	3.1%
31-45	1678	31.2%
46-60	3458	64.3%
60-75	63	1.2%
<b>TOTAL</b>	<b>5374</b>	<b>100%</b>

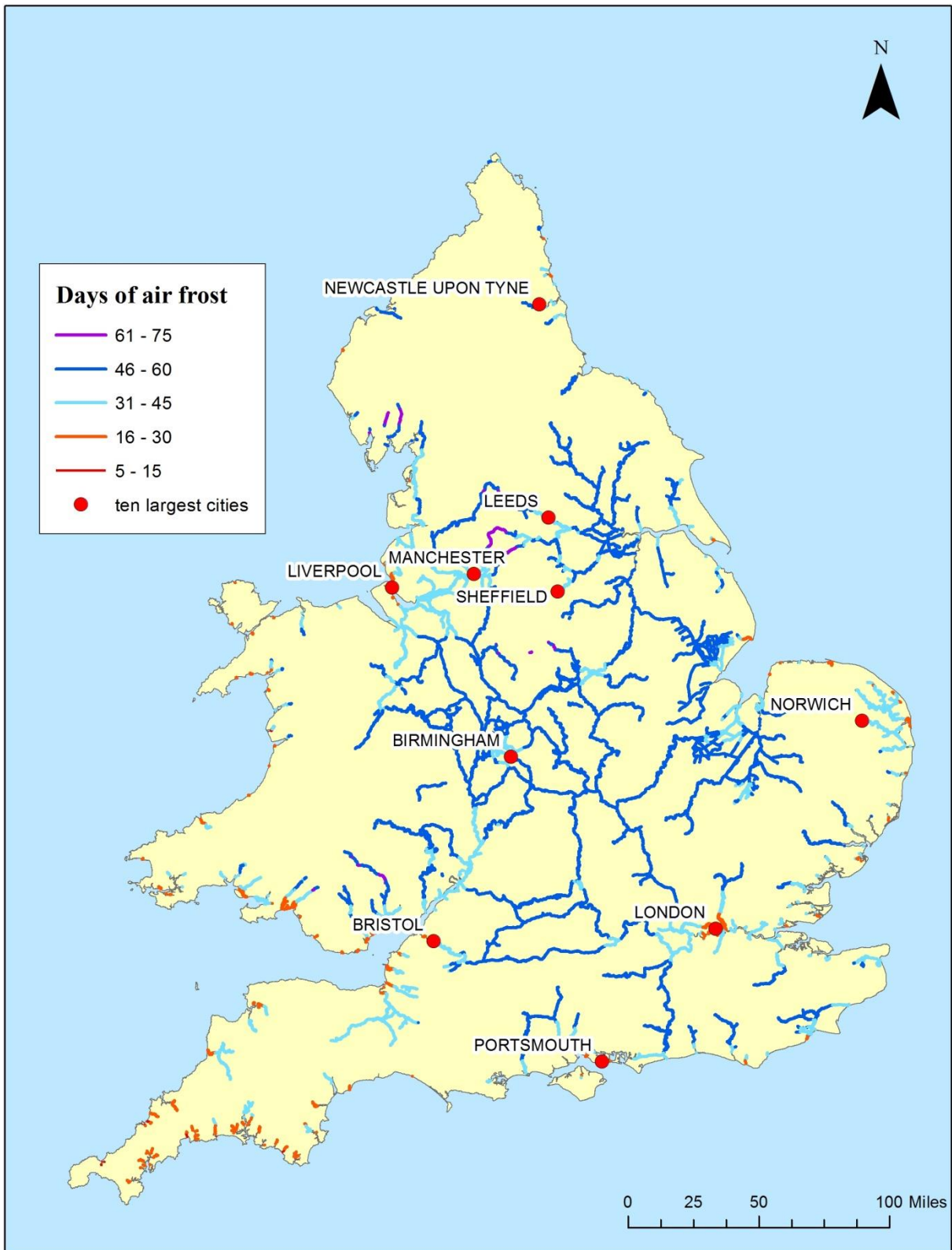
Source: MET Office: UKCP09: AirFrost\_1961\_1990\_LTA; Waterways GIS

more icebound and impassable. In fact, the number of working days lost to frost may have been less than Freeman indicates. Special vessels, known as ice-boats, were used to keep canals clear and these may have been used more generally on the waterways.<sup>16</sup> Also, the thickness of ice on waterways is strongly determined by the number of *successive* days that frost occurs.<sup>17</sup> This key variable was absent from Freeman's analysis. A more nuanced idea of the importance of frost is gained when documented canal closures are compared to daily temperatures over time.<sup>18</sup> For example, the 33-day closures of the Trent and Mersey rivers in the winter of 1813-14 and the 30-day closure of the Birmingham Old Main Line in the winter of 1819-20<sup>19</sup> are both correlated significantly with the historic daily temperature series published by Legg *et al.* This time series shows 32 successive days when temperatures were below freezing in the winter of 1813-1814 and pretty much 23 successive days below freezing in 1819-20.<sup>20</sup> Clearly, the whole issue of working days lost due to frost needs to be revisited.

The navigability of waterways of England and Wales were also affected significantly by tides. Generally, tidal water is a positive variable in navigation. As the Woodbastwick example shows, incoming and outgoing tides can propel vessels upstream and downstream at very little cost. However, the reality of water transportation was more complex. The scale of high and low tides varies month by month (the highest are known as *spring tides* and the lowest



**Map 2: Navigable waterways in 1835 with annual average days of frost in 1960-90.**



are termed *neap tides*). These variations affect the number of days per month that the upper reaches of a river remain navigable. The case of the River Weaver above Frodsham Bridge in Cheshire provides an extreme but instructive example. In the mid seventeenth century, this part of the river could only be passed during ninety-minute periods when spring tides occurred. This caused vessels to be delayed for days on end and, in consequence, goods were generally carried by land to Frodsham bridge and then transhipped onto small vessels for the downstream journey to Liverpool.<sup>21</sup> Likewise, vessels going up the tidal Trent to Lincoln in the summer could only access the entrance lock of the Foss Dyke at Torksey (Lincolnshire) on six days each month - when, that is, the spring tides occurred.<sup>22</sup> In addition, tides created other problems like silt deposition, which necessitated dredging, and storm surges, which occasionally caused major damage to infrastructure and vessels. On the east coast of England, the progressive lowering of the land relative to the sea in the later middle ages made the tidal sections of rivers more likely to silt-up; this accelerated the deterioration of some rivers.

The economic effects of the impediments to water navigation that have been described above have largely been ignored by scholars in Britain. In other countries, economic historians have tried to model these effects through *inventory costs* (i.e. the costs incurred by goods being kept in transit) and there is great potential such analyses to be applied to water transportation in England and Wales.

The limited navigable state of rivers in England and Wales and the growth in aggregate demand caused by urbanisation and rising population made the extension of navigable waterways and the building of canals a top priority in our period. Some areas were ripe for development. Wetlands came into this category. In such areas, the work and cost of making rivers navigable could be shared with land reclamation. Key areas of wetland were the Fens of Lincolnshire and Cambridgeshire, the Yorkshire marshes, the Somerset Levels, the Norfolk Broads, the Lancashire mosslands, Romney Marsh and the Essex marshes. These areas generally had some rivers that were semi-navigable and could be improved by land reclamation projects that straightened rivers and dug new artificial channels for drainage. For example, in 1633 Simon Hill proposed to drain the fens between Boston and Lincoln and create "one new Ryver" (a drainage cut) that was 25 miles long and would straighten the Witham between the two towns.

Turning to canals, one must begin recognising that they are different from rivers because their routes are deliberately chosen. For Turnbull, this distinction is absolute:

*“But canals were very different from natural waterways, with characteristics that transformed water transport. Their technology freed them from the tyranny of natural hydrology that limited the value of rivers. Canals could be constructed to exploit potential opportunities, linking places at will by deliberate, rational, economic calculation. This greatly changed and indeed reversed, the relationship between water transport and the economy: bulk water transport could be brought to favourable manufacturing sites instead of a forced movement in the opposite direction.”*<sup>23</sup>

In practice, geographical factors mean the distinction between river and canal routes is less clear-cut than Turnbull indicates. While a canal route does not require the pre-existence of a potentially navigable river, it is constrained by modest changes in elevation. In the eighteenth century, one pound lock was considered necessary for every 7ft (2.13 metres) of elevation<sup>24</sup> and locks constitute a major capital expense. For example, in the late seventeenth century, two new pound locks were built on the River Weaver at an approximate cost of £7000 each - or about £800,000 each in today's money. Consequently, canals routes only tackled significant changes in elevation when the economic case was compelling or investors were unwise.

Locks also reduced travel speeds and limited haulage capacity. The effect of locks on travel speed can be established by comparing road and water carriage, which, if unimpeded, proceeded at similar speeds. For example, in 1825 a non-stop journey by fly-boat from Birmingham to the Bridgwater canal (via the Birmingham and Fazeley Canal and the Trent and Mersey Canal) took 44 hours. This route was 93 miles in length, traversed 96 locks and went under four tunnels. A fly-van could travel double that distance by road in the same time.<sup>25</sup> If the necessity for barges to slowdown in tunnels is ignored, this example suggests that each lock took around 13 minutes to pass. Data on travel speeds is plentiful for scheduled waterway and road transportation services between towns - although it has only recently been gathered and analysed systematically. After this data has been combined with information on locks and other

impediments, it will be possible to model and compare travel speeds by waterways and roads much more scientifically.<sup>26</sup>

Pound locks required enormous amounts of water to function properly, so many reservoirs had to be purpose-built, which increased capital costs further.<sup>27</sup> The most spectacular example here relates to the building of ‘*lock flights*’ - sets of locks up a hillside which resemble a staircase – see Figure 1. In practice, lock flights were a major impediment to efficient travel and by the late 19th century moves were occasionally made to replace them with inclined planes. Hence, the flight of ten locks at Foxton on the Grand Junction Canal were replaced by a steam-powered inclined plane in 1900 to recapture the Derbyshire coal trade. In this case, travel by inclined plane was four times faster than travel by lock flight.

**Figure 1: Caen Hill Lock Flight on the Kennet and Avon Canal**



In summary, geographical and associated cost factors determined that most canals followed river valleys, only crossed watersheds when necessary and made minimal elevation changes. Indeed, for much of the eighteenth century, canals tried to follow a specific contour to minimize changes in elevation and keep costs down. These constructions are termed ‘*contour canals*’ by historians and they are characterised by gentle curves and meandering

routes. One such example is the Brecon and Abergavenny Canal; this is 33 miles long - although the straight-line distance between its start and end-points is only 23 miles and its first 14 miles is lock free.<sup>28</sup> Thus, the reality of canal building is far from Turnbull's abstract view, with the choice of routes being conditioned by a potent combination of geography and competing interests.

## **5. Changes in the Navigable Waterways Network from 1600 to 1835**

This section is in four parts. The first describes the decline that occurred to the navigable waterways of England and Wales prior to 1600. The second presents the improvements and extensions to the waterways network that occurred between 1601 and 1680, which were mainly of regional or local importance. The third discusses the river expansions that happened from 1681 to 1756, which had national significance. The last explores the canal-led expansion from 1757 to 1835, which had strategic effects on the British economy and society.

### **5.1 The decline to 1600.**

By 1600, the English and Welsh network of navigable rivers had declined in both extent and quality from its peak in the thirteenth century.<sup>29</sup> This affected some of the most important rivers in the country. For example, whereas the Great Ouse had previously been navigable to Bedford, by 1600 vessels could only reach St Ives. Similarly, the Thames had been navigable from the sea to Radcot (near the Gloucestershire border) in the 13th century but, by 1600, upstream vessels were restricted to a short section from Oxford to Eynsham and, below Oxford, the river only became navigable again at Burcot (see Map 3).

In addition, the size of vessel that many rivers could bear had declined markedly as well as the reliability of passage. For instance, in the first half of the fourteenth century, the Witham had been navigable from the port of Boston to Lincoln by vessels carrying up to 12 tons of cargo. Both towns were important places and the Witham was a key waterway; it transported coastal and international cargoes landed at Boston to Lincoln, which was itself connected to the Trent, Humber and Yorkshire Ouse by the Foss Dyke. The decline of the Witham in the latter middle ages is mirrored by the fading fortunes of Lincoln and Boston; by 1635 it was said that

the port of Boston had only seven or eight small vessels and was virtually "landed [silted] up".<sup>30</sup>  
The scale of this problem is apparent in a survey of 1733, which shows the river to be virtually

**Map 3: English and Welsh navigable rivers in 1600**



un-navigable between Boston and Lincoln – only the smallest of vessels could travel in the very shallow water.<sup>31</sup>

Human interference in the river system was a central cause of the contraction in navigable rivers. Two aspects of this are particularly important: mill weirs and bridges; these will be discussed in turn.

**5.1.1 Mill weirs (see Figure 2).** On many rivers, the gradient was steep enough to make water mills viable and their proliferation acted as a major hindrance to navigation. While boats could travel through a weir via a special type of sluice called a '*flash*' or '*flashlock*', there was a tension between millers and navigators. The former wished to conserve water in the mill dam, while the latter wanted the water to flow through the flash. Travel up or down stream used extremely large amounts of water and many weirs extended right across the river.

Another factor was the height difference above and below weirs. This could be considerable: weirs on the River Medway were said to be six to eight feet high in 1600, whilst Monmouth Weir on the River Wye was said to be eleven feet high around 1700.<sup>32</sup> Higher weirs required a miller to let out more water so boats could move upstream and this might happen only twice a week in the summer months as millers tried to conserve water. Therefore, boats would proceed slowly from flash to flash and run aground for days until the next flash came. Thus, on the Aire and Calder Navigation, a journey from Stock Reach to Leeds that should have taken 15 hours took over a week in 1771.<sup>33</sup> In summary, the building of mills, dams and flash locks slowed down river transportation a great deal, especially in the summer when river levels were low.

Nevertheless, one must not be excessively negative about the impact of mill weirs on waterways. On one hand mill, flashlocks did delay travel



and limit the tonnage of a laden vessels. On the other hand, when mill-weirs with flash-locks occurred in succession, they made some marginal sections of rivers *more* navigable by dividing them into a series of deeper, slower flowing pools.<sup>34</sup> Also, in a few instances, co-operation between millers and boatmen became well-established – as on some sections of the river Thames.<sup>35</sup> Lastly, many rivers were not constrained by mills at all.

**Figure 2: Bypassing an obstacle: Ham Mill, River Tone (Somerset).**



*Coal Harbour is the former navigable limit and transit point for goods from water to land carriage c. 1600. The mill weir shown on the map would have blocked the navigation but was bypassed by a new channel or cut - the lowest of the three courses - after 1638. Water to power the mill would go down the mill leat - the central channel*

**5.1.2 Bridges.** Besides mills, bridges also made water transportation more difficult. The ubiquity of vessels without masts and sails on some waterways is partly due to the height of bridges. This was especially the case for canals because landowners usually insisted on a connecting bridge being built at the canal company's expense whenever a canal dissected a pre-existing road. Normally, it was too expensive to build bridges high enough to accommodate masted vessels.

On rivers, the situation was different. Removing or lowering masts to pass under bridges was normal practise on some rivers. For example, on the Severn below Shrewsbury trows and barges routinely lowered their masts to pass under the seven



bridges downstream of the town. Also, the rebuilding of bridges to create sufficient headroom for sails occurred commonly when the navigability of a river was being improved. In 1727, for example, an Act of Parliament relating to the Don navigation specified that three wooden bridges with drawbridges should be replaced, "For the more easy passage of boats lighters and other vessels with masts through the same without taking down or lowering their masts".<sup>36</sup> In some instances, however, the density of pre-existing bridges presented a substantial obstacle to river navigation and restricted a river to small, narrow-beamed vessels or blocked navigation completely. To illustrate, the Warwickshire Avon had 9 bridges within 43 miles.

Bridges with many piers was another issue because they caused dangerously fast currents and restricted the width of vessels. For example, the 19 piers of London Bridge were too narrow for the larger barges that carried goods upriver. Consequently, coal and other goods had to be loaded on narrow lighters to pass under the bridge and then transhipped into the larger barges for passage upstream. Also, the piers of London Bridge increased the flow of the river considerably so that passage under it during tides could be very dangerous. This problem was partially fixed in 1756, when the central pier of the bridge was removed to allow barges to pass through,<sup>37</sup> and completely fixed in 1831 - when the bridge was rebuilt.

Despite the reduction in the English and Welsh waterways to 1600, they remained economically significant and facilitated London's exceptionally fast growth. By 1600, London had about 200,000 inhabitants who consumed some 150,000 tons of coal per annum. The coal was sourced exclusively from the North-East coalfield; it was barged down the River Tyne, shipped along the coast and then sent up the River Thames to London. The total trade represented something like 1500 voyages each year. Although the Thames was unnavigable beyond Abingdon, it was a major conduit for the transportation of barley, malt and other goods into London - as were two of its tributaries: the rivers Lea and Wey.<sup>38</sup> The River Lea had been extended and improved under an Act of 1571 and, in 1588, it had a fleet of forty-four small barges with a total carrying capacity of 7000 tons per annum.<sup>39</sup> London's growth also influenced river traffic further afield. Substantial movements of grain on most of the navigable rivers of eastern England is apparent from the port books of Lynn (served by the Great Ouse

and its tributaries), Yarmouth (the Deben, Alde, Glaven, Yare and tributaries), and Ipswich (the Orwell and Stour).

## **5.2 Waterways restorations and extensions from 1601 to 1680**

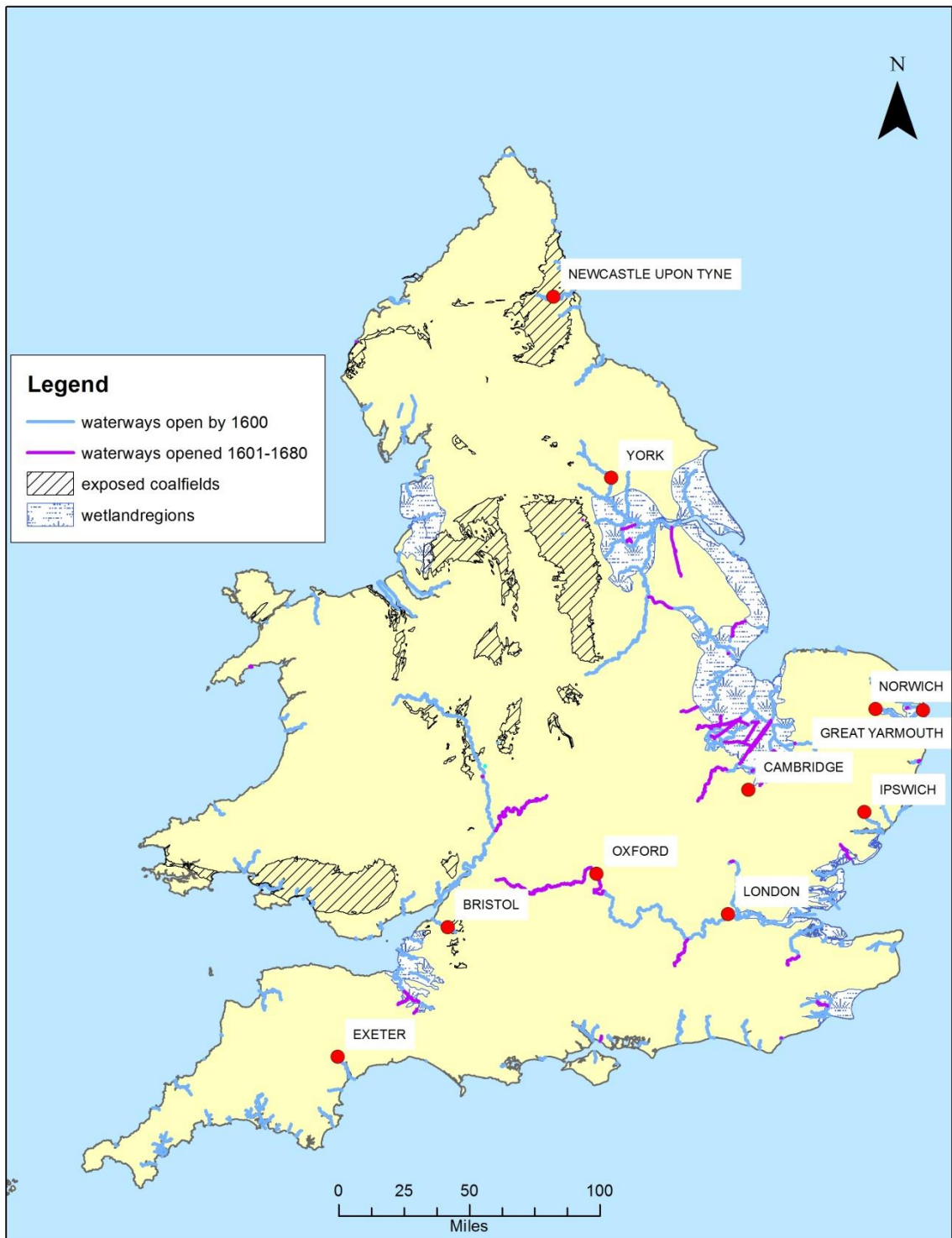
From 1601 to 1680 the network of navigable rivers in England and Wales expanded and, for the first time, there was a growth in coal transportation via river beyond the North-East coalfield. London continued to be the major driver of river traffic and development; by 1700 its population had reached 500,000 and they consumed some 375,000 tons of coal each year. The capacity of the coastal vessels carrying coal to London had trebled, and they had become too big to dock and unload directly onto the quay. This led to a huge growth in the number of *lighters* - small craft that carried coal to and from coastal vessels on the Tyne and Thames respectively.

Despite considerable legislation, the level of river improvement achieved by 1680 was relatively modest and mostly of regional or local significance. Furthermore, it was geographically concentrated in the south and east of England. No extension of navigable waterways occurred to the north and west of a line drawn from the mouth of the Severn to that of the Humber - see Map 4.

The most significant development was the restoration of the lower Thames in 1635, which made it navigable to Oxford once again and increased the number of inland places that could supply London with grain. Later, in 1641, the Thames was restored and extended upstream of Eynsham to the small market towns of Lechlade in Gloucestershire and Cricklade in Wiltshire. The economic effects of these changes were complex and widespread. Besides downstream trade on the Thames, upstream trade was also enhanced as coal supplanted firewood and peat in many places. Writing in the early eighteenth century, Cox commented, "Since the Wey hath been navigable coal for firing is become of general use and coal yards are kept in many towns standing upon it, for the supply of the towns and villages about them".<sup>40</sup>

Other navigation schemes of major importance were initiated on four tributaries of the Severn: the Avon (1635), Dick Brook (c.1651), the Salwarpe and the Stour (1662). This concentration of effort in the Severn Valley partly reflects a new awareness of the profitability

**Map 4: Waterways opened from 1601 to 1680**



of transporting of coal by river. The mining of rich, easily accessed coal seams near Broseley, which is close to the Severn and 140 miles upstream, led to a massive increase in river traffic and the adoption of coal across a huge marketing region that encompasses the Severn Valley, the Bristol Channel and the north Devon coast. The length of the Severn (it is the longest navigable river in England and Wales) and its strong flow meant it was largely unencumbered by weirs, locks and bridges for most of its length.<sup>41</sup> Also, it was toll-free in this period and tidal for much of its length. Consequently, the Severn could be navigated by trows with sails that were probably cheaper and more efficient than smaller lighters or horse-drawn barges.<sup>42</sup> These factors may help to explain the phenomenal growth in output of the Shropshire coalfield: from an estimated 12,000 tons in 1600 to 200,000 tons in 1680. The latter figure, if correct, represents 8.7% of national output, and most of this coal was transported by river.<sup>43</sup>

The developments to the Severn were not all plain sailing. After the Warwickshire Avon had been made navigable to Stratford in 1639, it was wrecked by the English Civil War and remained unnavigable until 1672. In 1667, a substantial part of the Stour navigation had been opened between Kidderminster and Stourbridge in Worcestershire but the canal remained unconnected to the Severn. If opened as planned, the new connection would have made coal from the landlocked Staffordshire coalfield readily accessible. But this did not occur; the scheme ran out of money and the works were wrecked by flooding five years later.<sup>44</sup> Lastly, by 1668 work to make the Salwarpe navigable was at advanced stage with five out of six pound locks built; however, these were found to be defective and the scheme was scrapped.

In the east of England, after 1642, river navigation benefitted from a major project to reclaim the Fens that was directed by the Dutch engineer, Cornelius Vermuyden. This scheme enabled vessels to pass up an artificially straight drainage cut that had been added to the Bedford River; the journey was more direct than the former route, which had used the Great Ouse. Other drainage cuts were also navigable and benefitted communities like Chatteris, which could now access the navigation network via the artificial Forty Foot River. It may be that the region's improved economic fortune is attributable to the reclamation scheme's major extension in arable farming and its impact on water transportation.

Besides an extension of the waterways network, this period saw an improvement in *capacity* due to an increase in both the size of vessels and the tonnage of goods they could carry. In part, this was due to the adoption of the *pound lock*; this has of two pairs of mitred gates at either end of the pound - the level stretch of water between the gates. A vessel enters the lock through one set of open gates while the other gates are shut. The open gates are then closed and the water level within the pound is equalised to that of the canal in the intended direction of travel. The exit gates are then opened to allow the vessel to continue its journey. Pound locks were used in parts of continental Europe before 1400 and were first used in England in 1564-6; this innovation occurred on a minute stretch of the River Exe (from Countess Wear to Exeter in Devon).<sup>45</sup> Bigger navigations adopted pound locks soon after - including the Thames in 1624-1635, the Wey in 1651-3, and some of the Fenland rivers from 1642.<sup>46</sup> Compared to the flashlock, pound locks were less wasteful of water and could, if big enough, be used by very large vessels. The innovation meant that rivers which had been used intermittently by small craft could now be made accessible to much larger vessels.

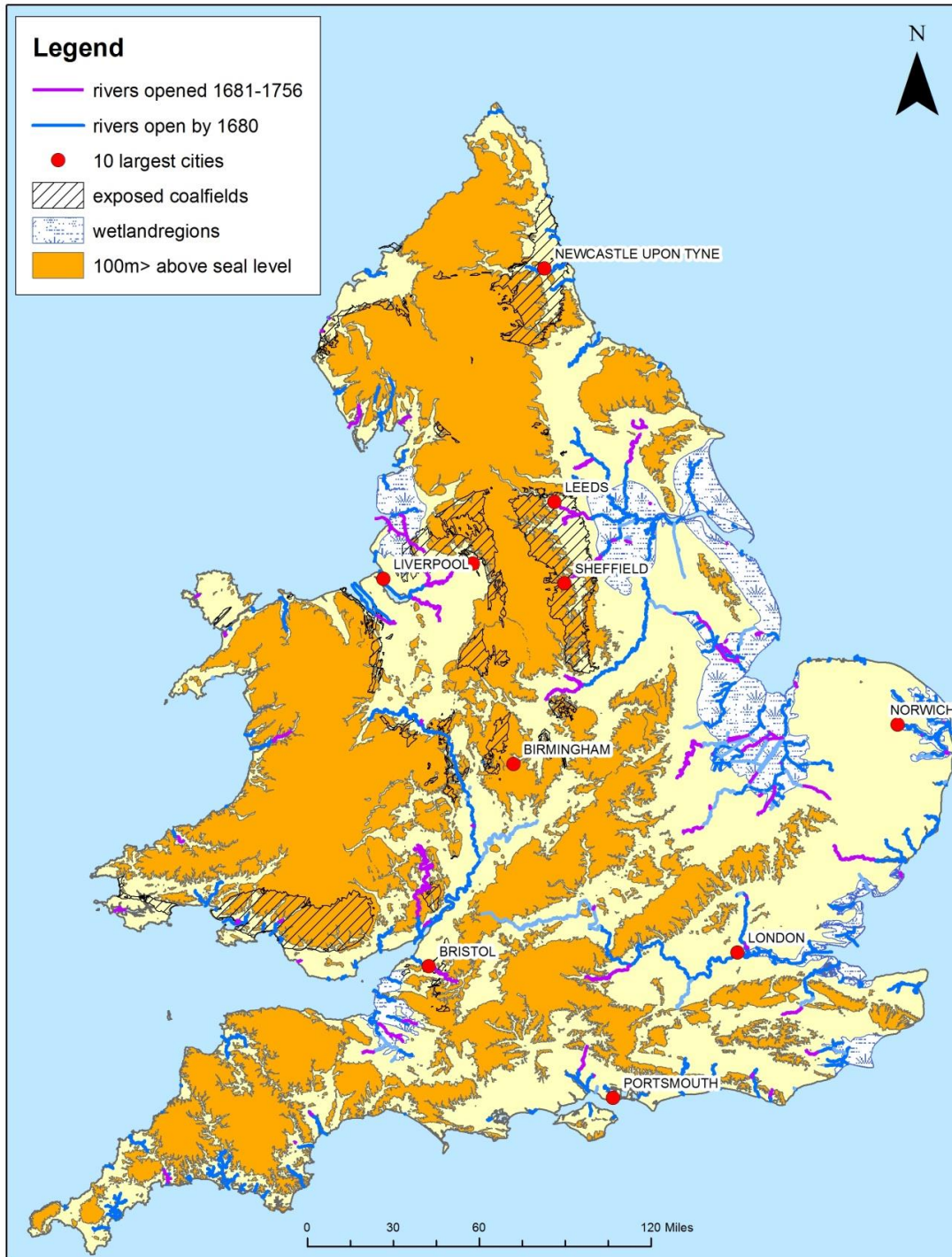
### **5.3 To the limits of nature: the extension of the river network from 1681 to 1756**

Map 5 shows the extension of the river network from 1681 to 1756, the year before the first proper canal - the Sankey Brook Navigation - opened in 1757. Unlike the previous period, river navigations were now extended across England and Wales. Several schemes linked long-established county towns and other regional centres in agricultural hinterlands to the waterways network. Some of these restored rivers to their medieval heights, such as the restoration of the Great Ouse to Bedford in 1689, the Lugg to Monmouth and Hereford in 1695-6, the Itchen to Winchester (Hampshire) in 1695-6, the Suffolk Stour to Sudbury in 1709, the Kennet to Newbury (Berkshire) in 1723 and the Lark to Bury St Edmunds (Suffolk) by 1724. In the main, these improvements were local in significance.

More significant were the new navigations that connected burgeoning industrial towns to coastal and international shipping networks. Of major importance was the extension of the Aire and its tributary the Calder to Leeds and Wakefield in the West Riding of Yorkshire in 1700. Leeds and Wakefield were both situated on the Yorkshire coalfield and the former was a major textile centre. Further south, on the same coalfield, the River Don was made navigable

to Rotherham in 1731 and to within three miles of Sheffield by 1751. The Don, Aire and Calder were also linked via the Humber to the port of Hull, which had an enormous shipping network.

**Map 5: The extension of navigable rivers from 1681 to 1756**



These developments had their corollary in Lancashire on the other side of the Pennines; landlocked Manchester was connected to the markets of the Irish Sea and the North Atlantic via the Mersey and Irwell navigation in 1734, and an extension of the Douglas to Wigan in 1740 made the riches of the hitherto landlocked Lancashire coalfield accessible.

Fenland developments continued in this period. New navigable drainage channels were cut and old water courses, such as the Cam, were upgraded. Moderate extensions or improvements also occurred in the Somerset Levels, Romney Marsh and other wetlands. Map 4 shows the major areas of wetland development plus the extension of navigable rivers that occurred between 1680 and 1756.

In summary, by 1750, the stock of economically significant rivers that could be made navigable was dwindling. Map 5 shows the major accessible coalfields, navigable rivers and land above 100 metres in England and Wales; it demonstrates that the easiest linkages had been achieved by 1756.

#### ***5.4 The Canal Age: 1757 to 1835***

In England and Wales the first proper canal opened partially in 1757; it ran 8 miles inland from the navigable Sankey Brook, a tidal tributary of the Mersey, to the Haydock and Parr collieries and incorporated eight single pound locks and one double pound lock. It provided Liverpool with direct access by water to the rich seams of the Lancashire coalfield.<sup>47</sup> Access to cheap coal partly explains the meteoric growth of Liverpool and, over the next fifty years, many towns followed the precedent for canal building that had been set. The literature assumes that the opening of the canal and Liverpool's growth are causally related. We are working actively to test this assumption.

Canals differed from river navigations both organisationally and financially. The primary vehicle for funding canals was the joint stock company. Each venture was empowered to raise a stated sum by the issue of shares and could borrow a fixed capital sum by mortgaging future toll incomes. Unlike some European countries, notably France, the public sector played a minimal role in planning and financing navigable rivers and canals. Only the Liverpool

Corporation played a significant role in commissioning a canal - the Sankey Brook Navigation between 1754 and 1757.

Maps 6-8 shows the expansion of the network over three periods: 1757-70, 1771-90 and 1791-1835. Nationally, the network did not change radically from 1756 to 1770 although there were some very important developments (see Map 6). In addition to the Sankey Canal, other canals linked coal mines to established regional centres – such as the canal joining Coventry to the Warwickshire coalfield at Bedworth in 1769, and the canal linking Birmingham to the Warwickshire coalfield at Wednesbury in 1757.

Only in the early nineteenth century were canals built to enable the movement of goods and raw materials between the two northern industrial centres of Lancashire and the West Riding of Yorkshire. This occurred through the completion of three trans-Pennine routes: (i) the Rochdale in 1805, which ran from the Bridgewater Canal in Manchester to the Calder and Hebble Navigation at Sowerby Bridge in the West Riding; (ii) the Huddersfield in 1811, which ran from Sir John Ramsden's Canal in Huddersfield (Yorkshire, West Riding) to the Ashton Canal, Ashton-under-Lyne (Lancashire) and; (iii) the Leeds-Liverpool in 1816, which ran from Liverpool and joined the Aire and Calder Navigation at Leeds.

The Rochdale and the Leeds and Liverpool were both very successful. In 1839, just prior to the arrival of the railways, the former carried 875,436 tons of cargo and generated £62,712 of toll revenue. In 1833, the latter transported 270,753 tons of coal to Liverpool (46% of the total coal consumed in and exported from Liverpool). Raw materials for the rapidly expanding textile industries came from Liverpool, Hull and West Yorkshire, while stone flags, limestone and coal were carried to and from wharves all along the canals. As usual, coal mines expanded production after the canals opened. Grain was another important cargo.

The Huddersfield falls into the category of heroic engineering as it encompassed 76 locks and 2-mile tunnel under the Pennines. Being a narrow canal, it had less capacity than the Rochdale and the Leeds and Liverpool and it was less successful because goods had to be transhipped at Huddersfield onto the Yorkshire river navigations.<sup>48</sup>



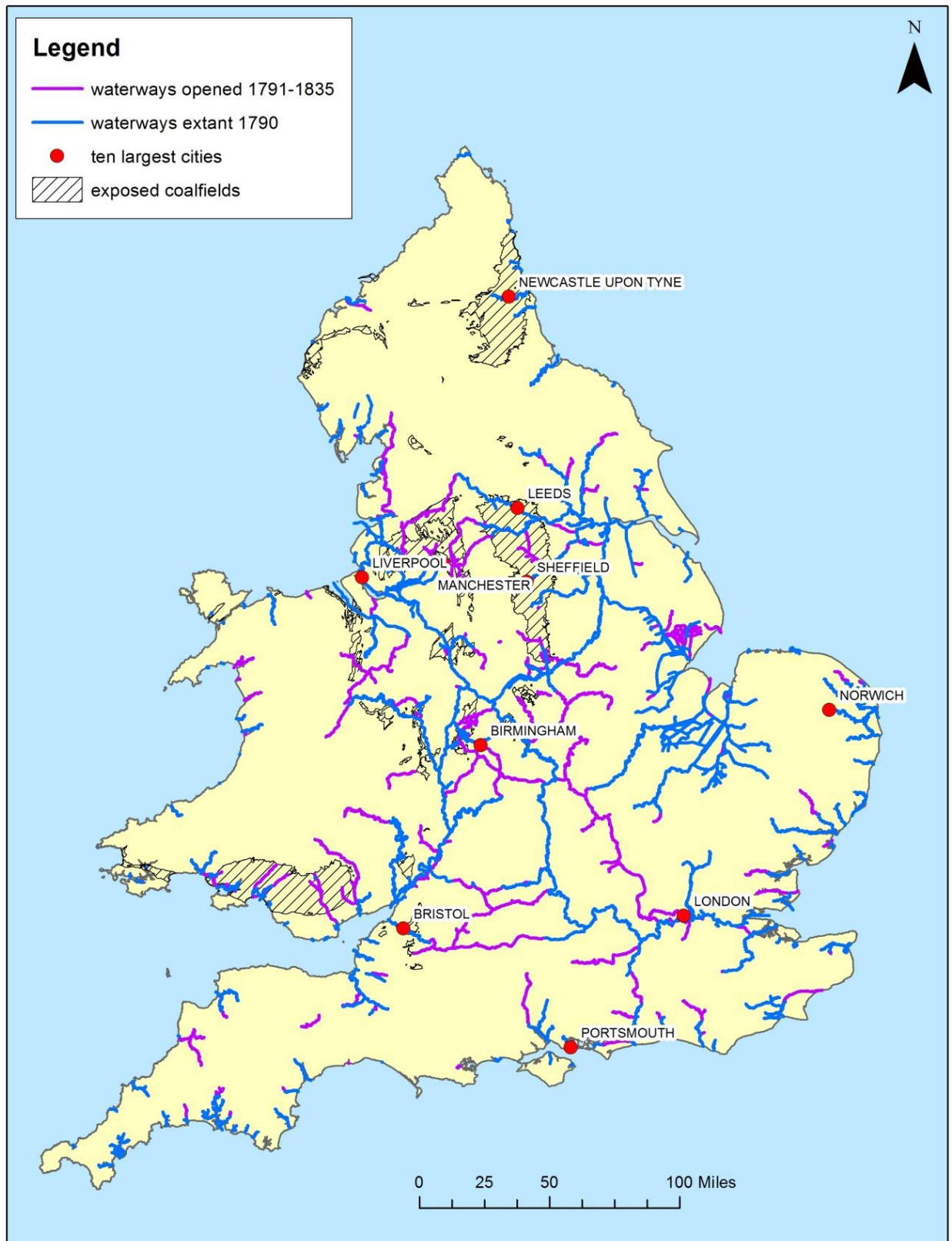
**Map 6: the extension of the network from 1757 to 1770**



**Map 7: the extension of the network from 1771 to 1790**



**Map 8: the extension of the network from 1790 to 1835**



The first north-south route, which connected the west Midlands to London and to the southern network was opened even later in 1790. It ran via the Oxford, the Coventry and Birmingham and the Fazeley canals to Fradley Junction on the Trent and Mersey Canal, which is near Lichfield in Staffordshire. Getting to London required a journey of 177 miles and the passage of 150 locks. The completion of the Grand Junction Canal in 1805 shortened the distance between London and Birmingham by 60 miles but the capacity problem had not been completely eradicated. The onward connections of the Grand Junction to Birmingham - the Napton & Warwick and the Warwick & Birmingham canals - had narrow locks, which limited them to vessels of 30 tons.

In the past, canal historians emphasised that these developments were important because they completed the national network. However, this view has been overturned by Turnbull who argues convincingly that such canals were primarily of local or regional importance. The promotion of long distance routes or connections as a concept is apparent in the earliest navigation schemes of the seventeenth century and it persisted into the nineteenth century.<sup>49</sup> Hence, the prospectus of the Grand Union Canal Company, described this development as "the greatest line of canals which extended from the Thames to the Humber".<sup>50</sup> The tonnage data available for many companies shows that short journeys represented about 80% of the total. However, this does not mean that long journeys were unimportant. From the perspective of the canal company, fewer, longer journeys were as, if not more, important than many shorter journeys; this was because toll revenues increased as journeys became longer. It should also be remembered that in 1848 long distance journeys on the Leeds & Liverpool and the Grand Junction Canal were ranked second and sixth in terms of tonnage.

## **6. The economic significance of navigable waterways**

Historically, scholars have linked navigable waterways to urban growth, coal production and industrialisation. This section presents and analyses those views. We begin with urban growth and then consider coal and industrialisation.

## 6.1. Waterways and urban growth

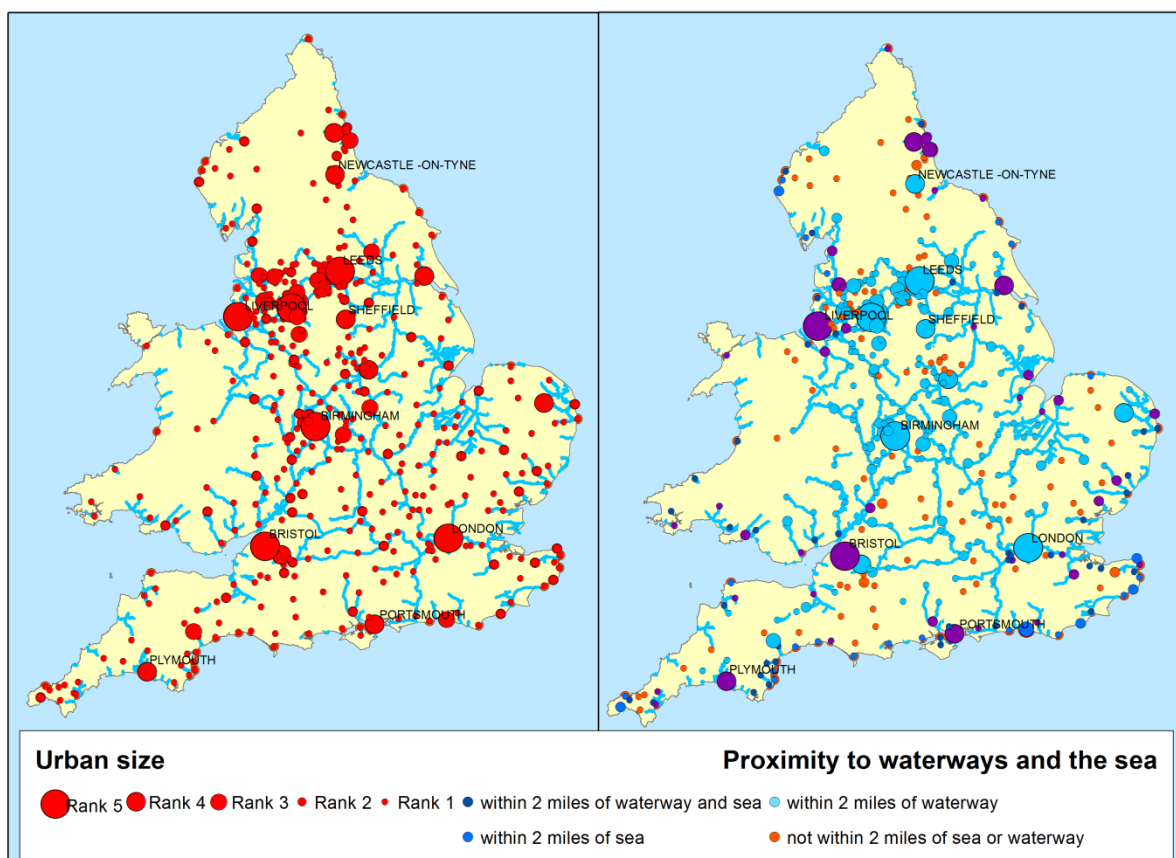
Researchers have long argued that access to navigable water stimulated the capacity of urbanisations to grow. For example, in 1819 one commentator said, "General arguments in favour of canals are superseded by the rapidly improving and thriving state of the several cities, towns, and villages, and of the agriculture also near to most of the canals of the kingdom".<sup>51</sup>

Birmingham, perhaps, is the most spectacular case study. It was connected by canal to the Warwickshire coalfield at Wednesbury in 1769 and the price of coal immediately fell by 46% from 13 to 7 shillings a ton. Before this development, Birmingham either used domestic coal that had been transported 8-12 miles by road or it used imported coal that had travelled up the Severn to Bewdley and had then been carried overland to the city.

In addition, historians have claimed that canals profoundly altered the geography of industrial and urban growth in the eighteenth century. They enabled, it is argued, towns located on or near the coalfields to attract coal-dependent industries as well as the labour they needed. According to this view, the uneven distribution of the coalfields determined that the towns which benefitted most were in the Midlands and the north of England so that the benefits of canals were concentrated here.<sup>52</sup>

Until recently, these theories have never been tested systematically. GIS methodology now makes this possible. Map 9 shows the waterways of England and Wales in 1831, when the network was virtually complete, in relation to the 433 towns and cities of England and Wales that had at least 2000 inhabitants. The map on the left shows the distribution of towns after they have been allocated into five categories based on population size (Rank 1: 2000-10,000; Rank 2: > 10,000-25,000; Rank 3: > 25,000-50,000; Rank 4 >50,000-100,000; Rank 5: > 100,000). The map on the right classifies towns in the same way and highlights those that have a navigable waterway within two miles or are near the coast. The degree to which the towns and cities of England and Wales benefitted from access to navigable waterways is immediately apparent and is tabulated below (see Table 4).

### Map 9: Urban size and proximity to waterways and the sea in 1831



**Table 4: England & Wales 1831: towns & cities 2 miles from a navigable waterway or the coast**

Rank	Population	Near waterways	Near coast	Near both	Not near either	Total
1	2,000-10,000	162	20	64	99	345
2	10,001-25,000	33	5	14	41	56
3	25,001-50,000	13	1	2	-	16
4	50,001-100,000	6	-	4	-	10
5	>100,000	4	2	-	-	6
	<b>Total</b>	<b>218</b>	<b>28</b>	<b>84</b>	<b>103</b>	<b>433</b>



The data suggest that towns need to have access to navigable waterways, the sea or both if they are to grow beyond a population of 25,000. Even towns that had less than 10,000 inhabitants appear to have been constrained by poor access to cheap water transportation: those within two miles of a navigable waterway were, on the average, 8% larger; those within two miles of the coast were 14% larger and; those within two miles of the coast and a navigable waterway were 26% larger.

Furthermore, the relationship does not simply work in one direction. Larger more established towns were more able to promote and realise river navigations or canal developments. Future work should concentrate on exploring the reciprocal relationship between urbanisation and water transportation.

## **6.2. Navigable Waterways, Coal and the Industrial Revolution**

The relationship between raw material extraction and navigable waterways, especially canals, was easy to see. Writing in 1803, Phillips claimed that 90 of the 165 canal acts passed after 1758 had collieries nearby and a further 47 were close to iron, lead and copper mines.<sup>53</sup> With some important exceptions, the key raw material was normally coal. Coal demand increased tremendously as households used it for domestic heating instead of wood and industry used it to produce metals like iron, glass, salt, pottery and bricks. The invention and widespread use of the steam engine in agriculture, industry and transportation boosted coal demand still further.

Hence, as Wrigley<sup>54</sup> has discussed, an energy revolution occurred in Britain during our period; mineral fuels replaced organic and the potential for sustained economic development soared. From 1680 to 1835, English and Welsh coal production increased 13-fold (from around 2 to 27 million tons per annum). Moreover, a significant regional shift occurred in coal production. In 1680, the North-East coalfield produced 45% of the nation's coal but by 1835 this share had fallen to 25% as the South Wales, Lancashire, Yorkshire, and Staffordshire coalfields expanded production rapidly. By 1835, each of these new coalfields was producing more than England and Wales had done in 1680. None of the new coalfields, except for South Wales, was near a navigable river in 1680 - so their riches remained largely unexploited at that date. Within three decades, river improvements and canal building had transformed the picture.

The Yorkshire coalfield was made accessible by the Aire and Calder Navigation in 1700 and the Don Navigation in 1731, whilst the Lancashire coalfield was linked to the River Weaver from 1720 and the River Douglas from 1740.

Contemporaries clearly perceived the relationship between navigable waterways and coal production. For example, when the great pioneering geologist William Smith placed canals on his famous map of 1815, which depicted the geology of England and Wales, he stated:

*“The canals are added to this map, for the purpose of showing how the heavy articles of subterraneous produce may be best conveyed from their native sites in the strata to the places of consumption. It may thus be seen what parts of the kingdom have benefitted the most by canals, and where they are still wanting and from whence heavy articles of tonnage (which alone can render them profitable) may be the most readily maintained... It is by the establishment of the great works [canals] and the minerals they have distributed that England owes half her present consequence in the scale of nations.”*<sup>55</sup>

The table accompanying Smith's map shows that 53 out of 62 canals were transporting coal as their primary mineral.<sup>56</sup>

As waterways expanded the demand for coal rose; once again, a reciprocal relationship is apparent, which had significant implications for mining sector employment, regional development, consumer demand and wealth creation. It is unsurprising, therefore, that some transport historians see the relationship between canals, cheap coal and the Industrial Revolution as absolute. Hence, Crompton argues, "Coal attracted all the manufacturing activities that needed heat or power, with the result that the Industrial Revolution in Britain could largely be defined geographically as the map of the coalfields. Cheap coal and good transport were the most fundamental of the characteristics shared by the industrialising areas". Except for the North-east coalfield, Crompton thought, "The contribution of canals" was either "particularly large and obvious" or else "important".<sup>57</sup> This view sees the Industrial Revolution as a post 1750 phenomena. However, starting with Crafts<sup>58</sup>, this chronology has been overturned by a more gradualist view of the Industrial Revolution. Modern research indicates



that Britain's structural shift from agriculture into industry and its acceleration in GDP per capita growth were well under way by 1700. Hence, the work of Shaw-Taylor and colleagues has found that by 1710 nearly 40% of working men and women were employed in the secondary sector.

## 7. Conclusions

Were navigable waterways a success or failure? Historians appear split. Mokyr claims the completion of the national waterways network led to, "Gains in economic integration that accrued to the whole country" and, for him, Britain's canals went, "From triumph to triumph... until the trains came."<sup>59</sup> Other historians regard the waterways system as a failure due to its in-built network flaws and its inferiority when compared to railways. This perspective draws on the dramatic decline in navigable waterways that occurred as Britain's railways developed and the anti-canal propaganda campaign of the rail lobby.

Other historians have analysed the profitability of individual waterways by using dividend data. According to this research, some rural canals were never profitable whilst some mineral canals made immense returns. For example, the profitability of the ten most lucrative canal companies in 1825 was 27 per cent above the average. This approach has several limitations. To begin with, the focus on joint stock companies means one cannot judge the success of the numerous waterways that did not use this funding model. For example, many tidal rivers had a major economic impact and did not require significant up-front investment. Also, none of the major navigable rivers, and only a few of the minor ones, were managed as joint stock companies. In addition, dividend data before 1820 is patchy. Furthermore, as Deane has argued, it may be, "Inappropriate to judge the contributions of canals to British economic growth in terms of the returns they yielded to their shareholders." A more significant, national impact, it can be argued, was the impact of cheap coal on households and industrial enterprises and, "In these terms the Canal Age made a massive contribution to the first industrial revolution and was a worthy forerunner of the railway age".<sup>60</sup>

Another approach to evaluating the success of canals is social savings analysis. This was developed by Robert Fogel<sup>61</sup> in the 1960s and it uses quantitative methods to see what the

economy in question would have been like if an innovation like canals was absent. Apart from the short "conjectural, non-factual" exercise conducted by Hawke and Higgins in 1981,<sup>62</sup> this type of analysis has never been applied to the navigable waterways of England and Wales. However, Shaw-Taylor and colleagues are actively trying to fill this gap.

Alternatively, a holistic approach can be adopted, which focuses on the utility of the network. To what extent were waterways able to sustain the long-term movement of goods to market and how did this change over time? Each waterway had capacity characteristics (like the width and depth of locks) and maintenance characteristics. The former characteristics were based on the initial design and investment funding while the latter depended on the money made available for maintenance. The overall capacity of the English and Welsh navigable waterways can be explored through the prevalence of narrow canals. In 1906, narrow canals accounted for two-thirds of the network's total canal mileage, which constituted a major capacity limitation - see Table 5.

**Table 5**  
**England & Wales in 1906: Mileage of broad and narrow waterways**

<b>Capacity</b>	<b>Canals</b>	<b>River Navigations</b>	<b>Open Rivers</b>	<b>Total</b>
<b>Narrow</b>	1165	478	0	1643
<b>Broad</b>	762	843	812	2417
<b>Total</b>	1927	1321	812	4060

Source: BPP, Fourth Report on Inland waterways, 23

We do not understand systematically the impact that capacity limitations had on economic growth. Defoe, in 1727, discussed the high cost of coal in inland settlements along the Thames valley and fact that six transhipments were required to move coal from the Northeast coalfield to these settlements. Transhipments could certainly inflate costs. One document shows that the transport of 21 chaldrons of coal in 1703 from a ship moored in Thames to Westminster Abbey added 14% to the total cost.<sup>63</sup> Such sources are rare but

extremely important and, if systematically collected, they will enrich our understanding of the network's cost structure.

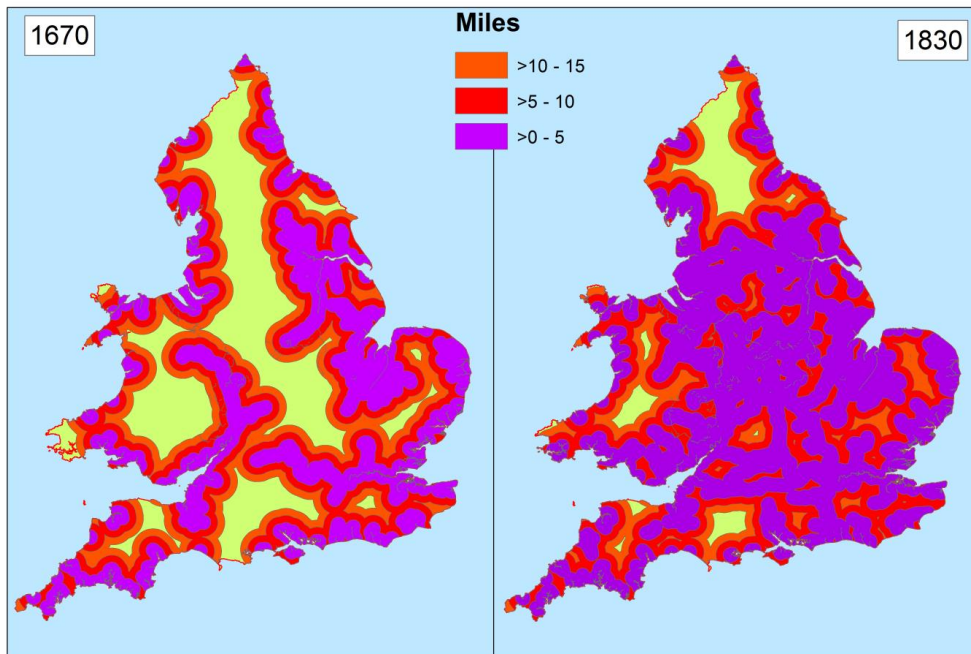
Nevertheless, we must bear in mind that access to a capacity-limited waterway network was better than to no access at all. It may be better, therefore, to explore the zone of influence of each waterway. Transport historians have tried to quantify the "economic zone of influence" by defining an overland distance extending from waterways. Sometimes this is termed a '*buffer*' or '*corridor*'. The preferred distance is open to debate. Fogel, for instance, uses a 40-mile buffer to study the development of transportation in the USA, whilst Willan uses a 15-mile buffer to study seventeenth century England.<sup>64</sup> Others think the zone of influence is much smaller; hence Turnbull argues the, "Stimulus of cheap water transport ...weakened steeply as distance from the canal increased and was perhaps completely exhausted in no more than a few miles."<sup>65</sup> Historical sources veer towards a smaller zone of influence. Consequently, GIS maps of the UK use three smaller buffers: five miles, ten miles; and fifteen miles (see Map 10).

Even the smallest, five-mile buffer shows that during our period there was an enormous expansion in England, and to a lesser extent in Wales, of habitations within 5 miles of a navigable waterway. By 1835, only upland communities in Wales, Northern England, the South-West and some other rural areas lay five miles beyond of a navigable waterway. From 1680 to 1835, the area of England and Wales within 5 miles of a navigable waterway increased by 87% (from 1,149,167 acres to 2,153,351 acres). Selecting those censuses parishes whose centres lay within the five-mile buffer reveals another powerful statistic. By 1841, 80% of the English and Welsh population lived in census parishes lying within five miles of a navigable river or canal. We do not have comparable data for the seventeenth century; however, we can estimate that only 45% of the population that lived within 5 miles of a river in 1841 would have done in 1680. These estimates suggest that navigable waterways gave England and Wales a major comparative advantage over more landlocked industrialising nations.

In conclusion, various methodologies exist to assess the impact of navigable waterways development in England and Wales. Whichever method is used, there seems little doubt that navigable waterways had a significant, positive impact on most of the population, especially when the network was at its peak in the 1830's. Although the network was imperfect and had

inbuilt weaknesses it had, most probably, a major beneficial effect on the British economy and it provided the nation with a comparative advantage over countries that were close to its level of economic development.

**Map 10: Navigable waterways of England and Wales with 5, 10 and 15 mile buffers**



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- <sup>1</sup> My thanks to Leigh Shaw-Taylor and Dan Bogart for commenting on earlier drafts of this paper.
- <sup>2</sup> anon, 'Canals', *The cyclopaedia*, (London, 1819), unpaginated
- <sup>3</sup> D. Gerhold, *Road transport before the railways* (Cambridge, 1993), p. 26. R. Parkinson, *General view of the agriculture of the county of Huntingdon* (London, 1811), p. 279
- <sup>4</sup> J. Hatcher, *The history of the British coal industry, 1* (Oxford, 1993); J. Langton, *Geographical Change*, 45
- <sup>5</sup> W. Marshall, *The rural economy of Norfolk*, 2 (London, 1796), 99, 363-5
- <sup>6</sup> The toll free nature of this section of the Bure is mentioned explicitly in an advertisement for a mill at Horstead further upstream "situate ...upon the Navigable river running to the Port of Great Yarmouth between which and the Mill there is no toll payable": *Norfolk Chronicle* 8th April 1797
- <sup>7</sup> Geo. III c. 51
- <sup>8</sup> Journal of the House of Commons, 1702-1704, 470
- <sup>9</sup> Szostak, for example, used a reproduction of Thomas Kitchen's 1:575000 'New Map of England and Wales', (London, 1794): R. Szostak, *The Role of Transportation in the Industrial Revolution* (1991), 55. This map purports to show canals up to 1792 but some of those shown were never built.
- <sup>10</sup> Initially the aim was to produce GIS snapshots of rivers and canal network at four dates c. 1820, 1851, 1861 and 1881 which was achieved thanks to generous funding from the ESRC from 2006 and 2009: ESRC Grant RES-000-23-157. Generous funding from the Leverhulme Trust in 2009-2012 enabled the dataset to extended back in time to c. 1600 and made time dynamic i.e. the GIS captures episodes where a waterway was navigable or not for each year from 1600 to 1948: Leverhulme Trust Grant F/09674/G. From 2014-2016 further upgrades and making the waterways GIS suitable for network analysis were made possible by the Leverhulme funded project 'Transport, urbanisation and economic development in England, c.1670-1911'.
- <sup>11</sup> The great majority of some 70 proposals for navigable waterways presented to the Crown or Parliament between 1606-1688 were not implemented in these years: D. Bogart, 'Did the Glorious Revolution contribute to the transport revolution? Evidence for investment in roads and rivers', *Economic H*
- <sup>12</sup> J. Langton, 'The efficiency of inland water transport in Medieval England' in *Waterways and Canal Building in Medieval England*, ed. J. Blair, (Oxford, 2007), 110-32.
- <sup>13</sup> The "main stem" of a river refers to its primary downstream segment as opposed to its tributaries.
- <sup>14</sup> J. Plymley, *General view of the agriculture of Shropshire* (London, 1813), 317-33
- <sup>15</sup> M.G. Freeman, 'Road transport in the English Industrial Revolution: An interim re-assessment', *Journal of Historical Geography*, 6 (1980), 17-28: 22-6
- <sup>16</sup> BPP, 1893-4 [Cd. 395] 'Report from the Joint Committee of the House of Lords and the House of Commons. On the Canal Rates, Tolls, and Charges', 41. An ice breaker for the Bridgwater Canal invented by the engineer James Brindley is reported as early as 1766: T. S. Willan, *The navigation of the River Weaver in the Eighteenth Century* (1951), 93. Ice-breaking appears as a regular category of expenditure in the annual accounts of some waterways, such as the Birmingham Canal Navigations and the Wiltshire and Berkshire Canal.
- <sup>17</sup> Inland Navigation Commission Working Group 23, *Technical and economic problems of channel icing* (Brussels, 2004)
- <sup>18</sup> Instances of canal closure due to frost are mentioned in passing in some secondary sources. There is valuable un-used material concerning canal closures in private business records. See for example J. Lindsay, 'The Butterfly Coal and Iron Works, 1792-1816', *Derbyshire Archaeological Journal*, 85 (1965), 25-43: 42
- <sup>19</sup> Freeman, 'Road transport in the English Industrial Revolution', 23; J. Parkes, *A statement of the claim of the subscribers to the Birmingham and Liverpool Railroad* (London, 1825), 50-1
- <sup>20</sup> D.E. Parker, T.P., Legg, C.K, Folland, 'A new daily Central England temperature series, 1772-1991', *International Journal of Climatology*, 12 (1992), 317-42
- <sup>21</sup> J. Brindley, *A history of inland navigations*, II (London, 1766), 78; J. Phillips, *A general history of inland navigation* (London, edn 1793) 182-3
- <sup>22</sup> BPP, 1909 [Cd. 4840] Royal Commission on canals and waterways. Volume V, 167
- <sup>23</sup> G. Turnbull, 'Canals, coal and regional growth during the Industrial Revolution', *Economic History Review*, 40 (1987), 537-60: 539-40
- <sup>24</sup> J. Priestly, *Historical account of the navigable rivers, canals, and railways of Great Britain* (London, edn 1831), 190
- <sup>25</sup> C. Hadfield, *The Canal Age* (1981), 73; Freeman, 'Road transport in the Industrial Revolution', 20-21

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<sup>26</sup> D. Bogart, M. Lefors, and M. Satchell, 'Intermodal Competition and Innovation in Britain's Canal Age', forthcoming

<sup>27</sup> The locks of the Lea Navigation measured approximately 100ft x13ft x 6ft required 50,000 gallons of water: The locks of the Grand Junction Canal had an average capacity of 56,000 gallons while those of the Birmingham Canal Navigations had a capacity of 25,000 gallons: anon, 'Second report of the Commissioners appointed to inquire into the best means of preventing the pollution of rivers (River Lee)', BPP, 1867 (3835), 87; H. de Salis, *Bradshaw's canals and navigable rivers of England and Wales* (London, 1904), 10-11

<sup>28</sup> anon, 'Canals', *The cyclopaedia*, (London, 1819), unpaginated

<sup>29</sup> J. Blair, 'Transport and canal building in the upper Thames', in *Waterways and canal building in Medieval England*, ed. J. Blair, (Oxford, 2007)

<sup>30</sup> Langdon, 'The efficiency of inland water transport in medieval England'; Rigby, 'Sore decay" and "fair dwellings": Boston and urban decline in the later middle ages', *Midland History*, 14 (1985), 47-61; *Calendar of state papers domestic 1635-6*, 8.

<sup>31</sup> Wheeler, 143-4

<sup>32</sup> T.S. Willan, *River Navigation in England 1600-1750* (London, 1936), 16-17, 86-7. Strype in an addition to Stow's survey of London of 1720 stated "That they were in times past want to unlade some of their lading beneath the lock and when they were to come up, and take in again above": J. Stow, *A survey of the cities of London and Westminster*, 1 (London, 1720), 40. Journal of the House of Commons

<sup>33</sup> J. Smeaton, *Report on the state of the Aire and Calder Navigation*

<sup>34</sup> J. Blair, 'Transport and canal building in the upper Thames'

<sup>35</sup> In 1770 only three of the locks on the river were pound locks. The rest were flash locks which were only replaced piecemeal: C.R. Hadfield, 'The Thames Navigation and the canals, 1770-1830', *Economic History Review*, 14 (1944), 172-9: 172. A regular twice weekly flash for the whole river was only introduced in 1771: *ibid*, 173

<sup>36</sup> 13 George I, c. 20

<sup>37</sup> In 1796 the Port of London reported 2,596 barges with a tonnage 85,103 of which it was said 80% were used for unloading coal from coasters: Report from the Committee appointed to enquire into the Port of London, BPP (1796), p. x, xix, 165 appendix (S s) These figures give a plausible mean tonnage of just over 32 tons per barge: Given the enormous quantity of coal annually consumed in London by this date of > 700,000 tons (based on Wrigley's estimates of 0.75 tons of coal per person and a population of 960,000) the real number of barge trips must have been far larger: E.A. Wrigley, *The Path to Sustained Growth* (Cambridge, 2016), 49, 61

<sup>38</sup> J. Chartres, *Internal Trade 1500-1700* (, 1977), 18

<sup>39</sup> J.G.L. Burnby and M. Parker, *The navigation of the River Lea 1190-1799*, Edmonton Hundred Historical Society Occasional Paper New Series No. 36 (1978); G. Willmore and F. Wollaston, *Reports of cases argued and determined in the Court of Queen's Bench*, 1 (London, 1839), 446

<sup>40</sup> T. Cox, *Magna Britannia*, 5 (1738), 443

<sup>41</sup> The Severn has a mean annual discharge of 62.7 m<sup>3</sup>/s (cubic metres per second). Navigable rivers with greater discharges are the Trent, 82.21, Wye 71.41, and Thames 67.4 : R.C. Ward, 'River systems and river regimes' in *British rivers*, ed. J. Lewin (London, 1981), 1-33, table 1.1

<sup>42</sup> Some scholars claim navigation on the Severn was cheaper than most other rivers: J. Nef, *The rise of the British coal industry*, 1 (London, 1932), 98, 393; W.H.B. Court, *The Rise of Midland industries* (Oxford, 1938), 7-9. Others, such as Willan, are more sceptical.

<sup>43</sup> Hatcher, *The history of the British coal industry*, 1, 68; M. Flinn and Stoker, *The history of the British coal industry*, 2, 26, 27 gives a higher output and a greater share of a greater national output. Hussey on the basis of extensive port book data argues that little of the Shropshire coal was marketed downstream of Gloucester in 1699: D. Hussey, *Coastal and River Trade in Pre-Industrial England* (Exeter, 2000), 34. This would suggest a lower output.

<sup>44</sup> It is an open question whether the straightening of rivers to make them navigable by increasing flow velocity also made them more vulnerable to greater flooding as occurred in some of the canalised Yorkshire rivers in 2016.

<sup>45</sup> Skempton, 'Canals and river navigations before 1750'. The cut was only 1.75 miles (2.8km) long but is known in the literature by the rather grandiose title of "the Exeter Canal".

<sup>46</sup> M. Chisholm, 'Locks, sluice, and staunches: confusing terminology', *Transactions of the Newcomen Society*, 75 (2005), 289-304

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- <sup>47</sup> There is a degree of confusion concerning the first canal. The Sankey Brook Navigation was originally planned to be a river navigation. In the event the plan was changed and an artificial cut complete with locks and physically independent of the Sankey Brook was made. This waterway is thus referred to in the literature variably as the Sankey Brook Navigation, the Sankey Canal and the St Helens Canal.. The Bridgwater Canal by way of contrast was from the beginning conceived as such.
- <sup>48</sup> P. Maw, *Transport and the Industrial City. Manchester and the Canal Age, 1750-1850* (Manchester, 2013), 57
- <sup>49</sup> In 1905-6 the average haul of fourteen major canals was 17.5 miles with a range of 3.5 to 25 miles: J. Armstrong, *The Vital Spark: The British Coastal Trade 1700-1930* (Newfoundland, 2009), 245
- <sup>50</sup> *VCH Leicestershire*, 3, 102
- <sup>51</sup> anon, 'Canals', unpaginated
- <sup>52</sup> Turnbull, 'Canals, coal and regional growth during the Industrial Revolution', 557-8
- <sup>53</sup> J. Phillips, *A General History of Inland Navigation* (London, edn 1803), 598
- <sup>54</sup> J. Phillips, *A General History of Inland Navigation* (London, edn 1803), 598
- <sup>55</sup> W. Smith, *A Memoir to the Map and Delineation of the Strata of England and Wales and Part of Scotland* (London, 1815), 10
- <sup>56</sup> W. Smith, *A New Geological Map of England and Wales with the Inland Navigations Exhibiting the Districts of Coal and Other Sites of Mineral Tonnage* (1820)
- <sup>57</sup> G. Crompton, 'The tortoise and the economy. Inland waterway navigation in international economic history', *Journal of Transport History*, 25 (2) (2004), 1-22: 3
- <sup>58</sup> G. Crompton, 'The tortoise and the economy. Inland waterway navigation in international economic history', *Journal of Transport History*, 25 (2) (2004), 1-22: 3
- <sup>59</sup> J. Mokyr, *The Enlightened Economy. An Economic History of Britain 1700-1850* (New Haven & London, 2009), 210
- <sup>60</sup> P. Deane, *The First Industrial Revolution* (Cambridge, edn 1979), 81
- <sup>61</sup> G.R. Hawke and J.P.P. Higgins, 'Transport and social overhead capital' in *The Economic History of Britain since 1700. I 1700-1860*, ed. R. Floud and D. McCloskey (Cambridge, 1981). 227-253: 248-9. Hawke, however, did model an expanded network of canals and roads in the absence of railways for England and Wales.
- <sup>62</sup> G.R. Hawke and J.P.P. Higgins, 'Transport and social overhead capital' in *The Economic History of Britain since 1700. I 1700-1860*, ed. R. Floud and D. McCloskey (Cambridge, 1981). 227-253: 248-9. Hawke, however, did model an expanded network of canals and roads in the absence of railways for England and Wales.
- <sup>63</sup> Westminster Abbey Archives, Voucher no. 45043. My thanks to Judy Stephenson for this reference. A chaldron was a measure of coal of about 1.25 tons. The distance depends on whether the collier was moored in the Upper Pool of the Thames as occurred later or given the earlier date it could moor at a wharf further upstream
- <sup>64</sup> T.S. Willan, *River Navigation in England 1600-1750*, p. 133 n. 2; C. H. Firth and R. S. Rait, eds., *Acts and Ordinances of the Interregnum, 1642-1660*, 3 vols., 191 I, vol.2, p. 168. December 10, 1741; Issue 2197
- <sup>65</sup> Turnbull, 'Canals, coal and regional growth during the Industrial Revolution', 544