Part 2 The Physical Usability of Rivers

Chapter 2.1 Introduction

2.1.1   Historic change

The principal question considered in Part 2 is 'Which sections of the rivers could be used physically by boats or barges in the period 1189–1600?' It will be shown that the limit between usable and unusable sections of the rivers moved from day to day and year to year and was in a different place for each type of boat or barge and that some rivers could be used to their source. It is also shown that usability has been reduced on most rivers which have not been canalised.

Some historians have tended to think that rivers have not changed their usability since medieval times, except for the construction of weirs and fish traps and rivers 'silting up'.[1] Thus Brent assumed that in 1540-1640 the navigable limit of the Ouse was at Barcombe Mills, the present tidal limit.[2] Other historians have made generalised comments about changes to rivers such as 'during the Roman era springs were more plentiful and nearer the surface, while the rivers were more rapid and larger in volume, and, running in shallower beds'.[3] Brown, a physical geographer, wrote that 'The majority of *lowland* floodplains in Britain show remarkably little *channel* change during the Roman and Medieval periods.'[4] It would be a mistake to think that there have been few changes since then, for recently it has been appreciated that 'many smaller streams were navigable in the early middle ages'.[5] Indeed Macklin and Lewin suggest that rivers 'adjust their size and shape more frequently, and more rapidly, than is generally appreciated'.[6]

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[1] eg. The Thames. Mary Prior, *Fisher Row*. Oxford: Clarendon Press. 1982.
[2] Colin Brent, 'Employment, Land Tenure and Population in East Sussex, 1540-1640.' Unpub. PhD thesis, Univ. of Sussex, 1973, 162.
[3] Urquhart A. Forbes and W.H.R. Ashford, *Our Waterways.* London: John Murray. 1906, 18.
[4] A.G. Brown, 'Floodplain Palaeoenvironments.' In Malcolm G. Anderson, Des E. Walling and Paul D. Bates, Eds. *Floodplain Processes.* Chichester: John Wiley & Sons. 1996, 125.
[5] James Bond, 'Canal Construction in the Early Middle Ages: An Introductory Review.' In Blair, 2007, 182.
[6] Mark G. Macklin and John Lewin, 'Channel, Floodplain and Drainage Basin Response to Environmental Change.' In Colin R. Thorne, Richard D. Hey and Malcolm D Newson, Eds. *Applied Fluvial Geomorphology for River Engineering and Management.* Chichester: John Wiley & Sons. 1997, 39.

According to Money's description of the Second Battle of Newbury some soldiers were drowned crossing the Lambourn.[7] Money did not state his sources. The river now has a depth of about 0.5 m and so this seems to indicate that in 1644 the river was deeper than it is now. But whether this was for only a short period of time or all the year is at present unknown. A detailed examination of the historical physical usability of rivers is now justified both for variation within the period 1189-1600 and between 1600 and the present. Passable rivers may have been used. Impassable rivers were not.

It is only since the flooding of 1947 and 1953 that priority has been given to keeping rivers within their banks. Writing in 1937 Bates described a river of his childhood.

> In winter, occasionally in summer, … It was as though the Nene had been turned into the Rhine. Water would be pouring down, everywhere, throughout the whole width of the valley, three feet deep, rising, perhaps to five feet deep, submerging hedges, lapping up against the roadways, beating and flopping in sudden wind-caught waves above the arches of bridges. It was a great wild wateriness.[8]

It is anachronistic to think of rivers flowing exclusively within their channels but difficult to measure the effect of out-of-channel flow or its historic extent.[9]

Modern cartographers, at large scales, portray rivers as a line. Lawyers define a river as 'a running stream pent in on either side with walls and banks'.[10] Yet during the medieval period rivers were shown on maps as bands. This may be a difference of convention, perception or represent an actual difference between medieval rivers and

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[7] Walter Money, *A History of Newbury.* (1st Edition 1905.) Newbury: Newbury Bookshop and Maidenhead: Thames Valley Press. 1972, 54.
[8] H.E. Bates, *Down the River.* (1st Edition 1937.) London: Victor Gollancz Ltd. 1987, 50-51
[9] G.E. Petts, 'Sustaining the Ecological integrity of large floodplain rivers.' In Malcolm G. Anderson, Des E. Walling and Paul D. Bates, Eds. *Floodplain Processes.* Chichester: John Wiley & Sons. 1996, 544.
[10] William Howarth, *Wisdom's Law of Watercourses.* 5th Edition. Crayford: Shaw & Sons Limited. 1992, 3.

those of today. The source of the Thames is now shown on Ordnance Survey maps as being half a mile from the nearest river.[11]

It is not only the changes to the present rivers which need to be studied. Some lost rivers were also used for transport. The lost rivers of London have been well studied[12] and Appendix A includes records of the use of these. There has been no similar study of the lost rivers of the remainder of the country. The river Sherbourne now flows under Coventry but is of a size which could have been used by small boats.[13]

Some factors which change, like precipitation, are cyclic. Others, like channel shortening, are unidirectional. Some factors, again like precipitation, have varied throughout the period 1189-2010. Others, like reservoir construction, have occurred during specific periods.

Establishing which rivers were usable at a given time requires knowledge as to which boats were using the rivers at that time. It seems likely that the first boats which were used were small. The average size of the load carrying vessels increased with time and the rivers were modified to accommodate them. Now rivers are often used by small recreational vessels as well as barges.[14] Unless otherwise qualified, 'usable' in this Part refers to usable by boats as defined in Section 1.2.3 'Usable by barges' is a difficult concept to measure for if a barge carrying 20 tonnes is just unable to use a river at a certain point then part of its load may be unloaded so that it can pass.

No description of the form of rivers during the period 1189-1600 nor any statement about their usability has been found. Geomorphologists have studied the channels. Pursglove described historic rivers but his study only started at 1600.[15] Russell and Burton entitled their books *Rivers*[16] and *The Changing River*.[17] But they wrote not about the rivers but their valleys, the towns, villages, architecture, bridges and mills. Many similar books have been written about individual rivers.

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[11] Grid Reference 3980 1995.
[12] Nicholas Barton, *The Lost Rivers of London.* London: Phoenix House Ltd. 1962.
[13] http://www.lightingthedarkness.co.uk/Sherbourne.htm. Accessed 02/12/2006.
[14] Peter W. Downs, Kenneth J. Gregory, *River Channel Management.* London: Arnold. 2004, 26
[15] Jeremy Purseglove, *Taming the Flood.* Oxford: Oxford University Press. 1988.
[16] Ronald Russell, *Rivers*. London: Book Club Associates. 1979.
[17] Anthony Burton, *The Changing River*. London: Victor Gollancz Ltd. 1982.

Some authors have treated the words ‘river’ and ‘channel’ as being synonymous. Here the word ‘river’ is used exclusively to refer to the water. The study of river channels has been hindered by the failure to agree on definitions of the factors being measured, for example the key concept of bankfull discharge has been defined in at least fourteen different ways.[18]

Some of the causes of change in usability are shown in Table 1.

Table 1 Causes of change in usability

Allogenic		**Secondary Effects**
Climate.	Precipitation total.	Change discharge.
	Precipitation distribution.	Change seasonality of discharge.
	Temperature.	Change sediment supply.
		Change sediment calibre.
Anthropogenic		Change channel width.
Land Use.	Woodland - Pasture - Arable.	Change channel depth.
	Urbanization.	Change channel shape.
Mining.	Sediment injection.	Change bed material.
Field drainage.		Change roughness/vegetation.
Arterial drainage.		Change sinuosity.
Floodplain drainage.		Change gradient.
Channel modification.		Change pattern .
Vegetation/In-channel wood removal.		Change floodplain level.
Weirs.		
Reservoirs.		
Abstraction/inter-basin transfers.		
Autogenic		**Assumed constant**
Adjustment of inherited characteristics.		Valley slope.
Response to short/medium term changes.		Bank material.
Cyclic. eg. Incision, widening, aggradation.		
Effect of tributaries.		

[18] See Artur Radecki-Pawlik, ‘Bankfull discharge in mountain streams: Theory and Practice.’ *Earth Surface Processes and Landforms.* Vol. 27, (2002), 115.

2.1.2 Qualities required for a river to be physically usable

For a canal or a canalised river, the depth of the water determines whether a vessel of a certain size may pass. However when considering rivers from 1189-1600 no measurements of depth have been found which are relevant for usability. In naturally flowing rivers depth often varies along the length of a river and usability depends on other factors, like bed material. There are two approaches to establishing which rivers were usable: experimental and variational.

First some other approaches are shown to be inappropriate. Because many of the largest rivers were modified between 1600 and 1830 under powers given in 'Navigation Acts' and most other rivers have been modified to provide protection from floods and for faster drainage, retrodiction from present form is not possible.

While empirical equations are available for establishing the likely form of straight, smooth, wide, canals with steady flow and sediment supply in sandy beds[19] the many site-specific studies of changes in river form have produced few general models or theories valid for river form[20] and none for historic forms of rivers.[21] Even estimates of past discharge from geomorphic evidence have an unacceptable chance of error[22] and would provide evidence of flood discharges, not mean discharge.[23]

It has been shown that modelling river behaviour over a time span of 10 to 10,000 years is at present not possible due to chaotic behaviour in the self-organisation of the

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[19] T. Blench, *Regime Behaviour of Canals and Rivers.* London: Butterworths Scientific Publications. 1957, 16, 24.
[20] L. Allan James, W. Andrew Marcus, 'Preface, The 2006 Binghamton Geomorphology Symposium on The Human Role in Changing Fluvial Systems.' *Geomorphology.* Vol. 79, (2006), 144.
[21] S.A. Schumm, 'Geomorphic Thresholds and Complex Response of Drainage Systems.' In Marie Morisawa, *Fluvial Geomorphology.* London: George Allen & Unwin. 1981.
George A. Griffiths, 'Extremal Hypothesis for River Regime: An Illusion of Progress.' *Water Resources Research.* Vol. 20, (1984) 113-118.
A.G. Brown and T.A. Quine, 'Fluvial Processes and Environmental Change: An Overview.' In A.G. Brown and T.A. Quine, *Fluvial Processes and Environmental Change*. Chichester: John Wiley & Sons. 1999, 20.
Stuart N. Lane and Keith S. Richards, 'Linking River Channel Form and Process: Time, Space and Causality Revisited.' *Earth Surface Processes and Landforms.* Vol. 22, (1997), 249-260.
[22] Robert B. Jacobson, James E. O'Connor and Takashi Oguchi, 'Surficial Geologic Tools in Fluvial Geomorphology'. In G. Mathias Kondolf and Herve Piegay, Eds. *Tools in Fluvial Geomorphology.* Chichester: Wiley. 2003, 29.
[23] Geraldene Wharton, 'The Channel-geometry Method: Guidelines and Applications.' *Earth Surface Processes and Landforms.* Vol. 20, (1995), 649-660.

river and the complex response to external forcing.[24] Thus in studies of the Trent it has been shown that 'the same degree of morphological and sedimentary response is not necessarily associated with floods of similar magnitude, i.e. there is no constant relationship between event magnitude and landform change.'[25]

Palaeochannels seldom establish the usability of historic rivers. If the section was static there is no palaeochannel. If movement was by migration no distinct palaeochannel remains. Where avulsion has occurred in a multi-channel river that channel does not define the usability of the river. In a single-channel river it is likely that the palaeochannel will have been reworked since 1600.[26] Thus normally the only palaeochannels which can be examined usefully are those caused by an anthropogenic realignment of the course of the river. Most physical evidence from quays, wharves and jetties has been either washed away or buried.[27]

Even if all climatic and other factors affecting a river were constant the river would still be changing because it is recovering from the most recent glacial phase[28] and because of the nature of dynamic equilibrium.[29]

While alluvial records can give some information about the form of channels, they provide little information about rivers. Floodbasin coring gives little information even about the style of channels.[30] Floodplain surface sediments vary with the frequency, magnitude and sediment loading of overbank events. They are disturbed by renewed scour and bioturbation. While increased alluviation indicates the

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[24] A.P. Nicholas, T.A. Quine, 'Crossing the divide: Representation of channels and processes in reduced-complexity river models at reach and landscape scales.' *Geomorphology.* Vol. 90, (2007), 335.

[25] A.G. Brown *et al.* 'Late Holocene channel changes of the Middle Trent: channel response to a thousand-year flood record.' *Geomorphology.* Vol. 39, (2001), 69 – 82.

[26] A.G. Brown, 'Time, space and causality in floodplain palaeoecology.' In Andy J. Howard, M.G. Macklin and D.G. Passmore, Eds. *Alluvial Archaeology in Europe.* Lisse: Swets & Zeitlinger B.V. 2003, 15-24.

[27] T.W. Potter, 'Valleys and Settlement: Some New Evidence.' *World Archaeology.* Vol. 8, (1976), 207-219.

[28] K.J. Gregory, 'An introduction to the fluvial geomorphology of Britain.' In K.J. Gregory, Ed. *Fluvial Geomorphology of Great Britain.* Joint Nature Conservation Committee. London: Chapman & Hall. 1997, 8.

[29] David Knighton, *Fluvial Forms and Processes.* London: Edward Arnold (Publishers) Ltd. 1984, 139.

[30] J. Lewin, M.G. Macklin and E. Johnstone, 'Interpreting alluvial archives: sedimentological factors in the British Holocene fluvial record.' *Quaternary Science Reviews*, Vol. 24, (2005), 1874.

occurrence of overbank events it does not show whether the flooding was due to high discharge or low capacity of the channel. Absence of an alluvial record should not be taken as evidence of the absence of overbank events, as there may have been little sediment in the flood waters or the sediment may have been reworked. Channel enlargement and flood protection have caused the decline in the number of alluvial units since 1200.[31] Rivers, in general, are now impounded and excluded from their floodplains.[32] Relationships between fluvial deposits and channel form for present channels may not apply to palaeochannels since the amount of armouring and the pattern of sediment accumulation may have been different.[33]

Throughout this Part of the thesis where consideration is given to a change due to one external factor it is assumed that other independent external factors remained constant. The question as to which variables are independent and which dependent depends on the timescale and possibly the magnitude of the change being considered.[34] In all calculations change in valley slope is ignored as it is considered that there was no significant change in the period 1189-1600. Also, except when otherwise stated, it is assumed that the bed and banks are not formed of bedrock which would control the channel morphology.[35] While the exact forms of historic rivers can not be established, it is possible to study the factors which have modified the rivers and to consider how these may have caused changes to the limits of usability.[36]

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[31] John Lewin and Mark G. Macklin, 'Preservation potential for Late Quaternary river alluvium.' *Journal of Quaternary Science.* Vol. 18, (2003), 117.
[32] Brown *et al.* in preparation. Cited in A.G. Brown, 'Geoarchaeology, the four dimensional (4D) fluvial matrix and climatic causality.' *Geomorphology.* Vol. 101, (2008), 279.
[33] K.J. Gregory, 'Introduction.' In K.J. Gregory, Ed. *Background to Palaeohydrology.* Chichester: John Wiley & Sons. 1983, 18-19.
[34] John Lewin, 'Available and appropriate timescales in geomorphology.' In R.A. Cullingford, D.A. Davidson and J. Lewin, Eds. *Timescales in Geomorphology.* Chichester: John Wiley & Sons. 1980, 3-12.
[35] Stanley A. Schumm, *The Fluvial System.* London: John Wiley & Sons. 1977, 153.
[36] L. Allen James, W. Andrew Marcus, 'The human role in changing fluvial systems: Retrospect, inventory and prospect.' *Geomorphology.* Vol. 79, (2006), 160.
Stanley A. Schumm, *To Interpret the Earth. Ten ways to be wrong.* Cambridge: Cambridge University Press. 1991, 78.

Chapter 2.2 Conditions for present use

An initial question is which sections of a natural river are now usable by a canvas and lathe canoe at mean discharge in winter? It is considered that historic logboats and other wooden boats would have been usable on similar rivers. The furthest place upstream at which a boat can be used is called the Recent Limit of Usability (RLU) and, for the purposes of this study, these have been taken from the *BCU Guide.* Rivers which were found on inspection to have obviously been modified are not considered because their usability depends on the nature of the modification and not on the natural state of the river. It is not claimed that the other rivers are in their 'natural' state. It is thought that they are closer to it.

In a divided river usability depends on the form of the largest channel. No natural river has been found where present use is limited because it is divided. The Middlesex Colne which is divided for much of its length is not considered as it has been greatly modified. There are at present no rivers which are braided and usable.

Experience shows that for a given section of a natural river in England it is always the stage of the river which controls whether it is usable or not.[37] On all natural rivers the width is always sufficient where the depth is adequate. For many rivers, and in particular for pool and riffle rivers, depth is variable along the river. A short shallow obstruction may not make a river unusable while a long shallow section of the same depth may well be unusable because the flow of water provides a cushion over the short obstruction. At present no mathematical relationship has been found between depth and usability although on rivers with a gravel, silt, sand or clay bed-material a depth of 0.5 m or greater is normally adequate.

As discharge increases in a given channel at some stage the river becomes usable. Thus it is the form of the channel at the RLU which has been investigated here. Gradient adequately describes the longitudinal aspect of a channel. When inspecting the rivers it became clear that the bed material is also relevant when considering the depth required for usability.

[37] Personal experience of author.

When all other factors are constant, if the width of a river is increased the depth will be reduced so it seems likely that greater discharge is required for usability on a wide river compared with a narrow one.

Discharge, gradient and bed material at the RLU were recorded and have been plotted on a Graph 1 (page 21A) which shows that:

1. The discharge required for usability increases with gradient.
2. The discharge required for usability increases with the size of the bed material.

It is known that the location of RLUs are only approximate because the *BCU Guide* dates from 1936, the discharge data refer to 1996-2000; the *BCU Guide* only refers to places which were accessible by public transport; the *BCU Guide* does not state accurately the stage of the river when the report was written; the reports are not complete as sections which were considered private, uninteresting or which did not provide a satisfactory day's paddling were omitted; weirs may make a river usable which would not be usable in their absence; abstraction has increased since 1936; some rivers which were described as usable in 1936 are not usable now, like the Rhee at Guilden Morden.

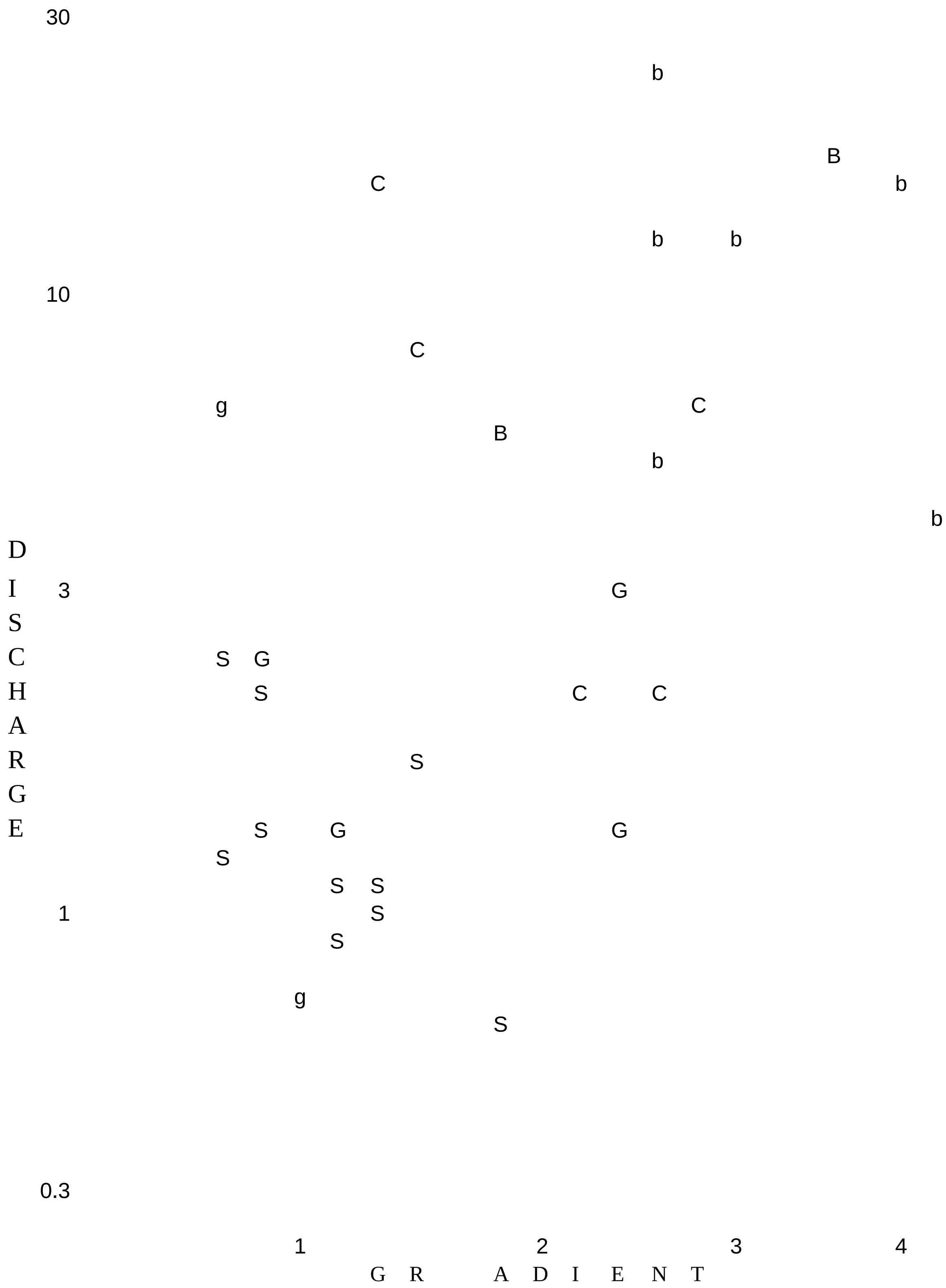
It is considered that the gradient and bed material are likely to vary by only an insignificant amount between the assumed RLU and the actual RLU.

In Table 2 the following abbreviations are used:

P&R = Pool and riffle.
B = Boulder
C = Cobble
G = Gravel
S = Silt, Sand and/or Clay.

Table 2. RLUs ordered by bed material

			Discharge $m^3\ s^{-1}$	Gradient $m\ km^{-1}$	Form	Material	Symbol
NW 6	Lune	Sedburgh	17	3.6	P&R	B	B
Se 13	Monnow	Pontrilas	6	1.9	P&R	B	B
NE 4	Wear	Wolsingham	4	4.3	P&R	B&C	b
NE 5	Tees	Whorlton Falls	14	4	P&R	B&C	b
Y 11	Wharfe	Bolton Abbey	14	2.5	P&R	B&C	b
Y 14	Nidd	Ripley	5.0	2.5	P&R	B&C	b
Y 15	Swale	Catterick	13	3	P&R	B&C	b
NW12	Cumberland Derwent	Cockermouth	22	2.5	P&R	B&C	b
Y 7	Aire	Coniston Cold	2.1	2.1	P&R	C	C
Y 10	Rye	Helmsley	2.2	2.5	P&R	C	C
Y 16	Ure	Wensley	15	1.4	P&R	C	C
Tr 9	Derbyshire Derwent	Hathersage Bridge	5	2.7	P&R	C	C
NW 5	Ribble	Settle	7	1.7	P&R	C	C
Tr 14	Penk	Penkridge	2.3	0.9	Uniform	G	G
E 17	Pant / Blackwater	Kelvedon	1.2	1.2	Uniform	G	G
SE 22	Salisbury Avon	Scales Bridge	1.5	1.2	Uniform	G	G
SW 2	Dorset Frome	Dorchester	3.0	2.4	Uniform	G	G
Th 15	Wey	Farnham	0.7	1	Uniform	G&S	g
Se 2	Warwichshire Avon	Ashow	5.6	0.6	Uniform	G&S	g
F 1	Welland	Duddington	2.0	0.9	Uniform	S	S
F 4	Great Ouse	Buckingham	2.5	0.8	Uniform	S	S
F 11	Cam	Audley End	0.6	1.9	Uniform	S	S
F 16	Tove	Towcester	1	1.3	Uniform	S	S
E 15	Suffolk Stour	Stoke by Clare	1.2	1.1	Uniform	S	S
E 18	Chelmer	Little Waltham	0.9	1.1	Uniform	S	S
Th 14	Mole	Horley	1.3	0.8	Uniform	S	S
SE 6	Eastern Rother	Etchingham	1.5	1.6	Uniform	S	S
Se 9	Tern	Stoke upon Tern	1.3	0.6	Uniform	S	S
Se 10	Perry	Wykey	1.2	1.4	Uniform	S	S



Graph 1

B	Boulders	b	Boulders and cobbles	C	Cobbles
G	Gravel	S	Silt, Sand and/or Clay		

Chapter 2.3 Discharge and Usability

2.3.1 Introduction

Details of discharge alone do not allow the calculation of the amount of water in a river. One may know the variable inflow to, and the variable outflow from, a tank but this does not provide information about the volume of water in the tank. Similarly the fact that a river used to be wider does not mean that it used to be shallower.

Discharge increases and decreases due to variation in precipitation on annual and multi-annual scales and changes in abstraction. For any river channel, if all other factors are fixed, an increase in discharge increases the depth which, in turn, improves usability. There are two relevant elements of discharge: the volume and the distribution through the year. Discharge is composed of two elements, runoff and baseflow. In the short term changes in groundwater storage can be ignored and baseflow considered to be constant. But in the medium and long term, changes in groundwater storage can have a significant effect on discharge.[38] The calculated annual naturalised discharge is found by eliminating the effect of ground and surface water abstraction.[39]

For those wishing to use a river for transport on a regular basis, variability of discharge is a disadvantage. For those wishing to use a river only on an irregular basis, variability may be an advantage in that there will be more days when the river is deep. Deep fast flowing water is normally an advantage when travelling downstream. It may be a disadvantage when travelling upstream. One wet year is unlikely to persuade people to build a boat. However it might extend their use to a previously unusable section of a river.

There are relatively few historic records of the usability of rivers being affected by drought. In 1632 Taylor reported that there were five barges aground downstream of

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[38] R.C. Ward, *Principles of Hydrology*. London: McGraw-Hill Publishing Company Limited. 1967, 264-271.
[39] *Hydrological Data UK*, 8.

Staines.[40] In 1641 he excused his slow progress from London to Goring between 20th and 22nd July by stating that due to the great drought he was forced to 'wade, and leade or hale the boate divers times'.[41] In that month in London it was recorded that 26th May to 8th June was a 'hot spell' and 14th July to 1st August a 'dry spell'.[42]

The only record of the number of days a year that a river could be used which has been found is contained in Green's summary of Telford's 'Survey of the Severn' which relates to the end of the 18th century at Coalport where during a ten year period there was insufficient water for navigation by 20 ton barges on average for 146 days a year. In the worst year, 1796, the river was unusable for 234 days.[43]

While there are many comments by contemporaries that rivers were small or large, swift flowing or slow, only one report has been found which indicates that the discharge of a river has changed. Camden recorded that the Trin, a river downstream of Bristol, 'is now dwindled into a little brook.'[44] He gives no reason for the change.

2.3.2 Records of variation in discharge

Few discharge gauges have been in use for more than 40 years so while their records can be used to estimate the recent ratio of winter-summer discharge and the inter-annual variation there are no records for the period 1189-1600.

The average variability of discharge within a year may be assessed by the ratio of the 10 percentile discharge (the discharge which was exceeded for 10 per cent of the period of measurement) and the 95 percentile discharge (the discharge which was exceeded for 95 per cent of the period of measurement). The calculated ratio is

[40] John Taylor, 'Taylor on Thame Isis.' In John Taylor, *Works of John Taylor Water Poet not included in the Folio Volume of 1630.* Spenser Society. Vol. 7, 1870. Reprint New York: Burt Franklin. 1967. 25.
[41] John Taylor, *John Taylor's last Voyage.* London: John Taylor. 1641. Contained in *Works of John Taylor. Second Collection.* The Spencer Society Vol. 14, 1873. Reprint New York: Burt Franklin. 1967, 11-12.
[42] Sir Humphrey Mildmay, 'Diary of Sir Humphrey Mildmay. 1633-1651.' B.L. Harleian, MS 954. Cited in P.D. Jones, A.E.G. Ogilvie, and T.M.L. Wigley, *Riverflow Data for the United Kingdon: Reconstructed Data Back to 1844 and Historical Data Back to 1556.* Norwich: Climatic Research Unit, University of East Anglia. 1984, 135.
[43] Colin Green, *Severn Trader.* Lydney: Black Dwarf Publications. 1999, 17.
[44] William Camden, *Camden's Britannia.* Trans. and Ed. Edmund Gibson. London: F. Collins. 1695, 248.

referred to as the winter-summer variation. The inter-annual variation may be assessed by the ratio of the maximum annual runoff to the minimum annual runoff. This ratio depends on the period used for the records. This is referred to as the year-year ratio.

Table 3 shows the effect of selecting different periods for measuring discharge. It shows that, as expected, the year-to-year ratio increases with the period of measurement. It is by no means clear why the winter-summer ratio is so much greater on the Tyne, Great Ouse and Bristol Avon for the longer period of measurement. Possibly, as shown by the naturalised figures for the Thames, the difference is due to the effect of abstraction rather than varying precipitation.

Table 4 shows the ratios for the downstream gauges on usable rivers in Kent, Sussex and Hampshire. The winter-summer ratio can be highly variable for rivers within one region. The ratio depends on the geology of the catchment. It also shows that rivers with a high winter-summer ratio have an above average year-year ratio. Table 5 shows the ratios for a selection of other rivers.

Table 3 Variable average discharge over different periods

Column 3 is the catchment area in sq. km. and column 4 the period of record. ‘n’ means that the records have been naturalised. All the data are taken from *Hydrological Data UK 1996-2000.*

		km^2		10 percntl / 95 percntl	Max. runoff / Min. runoff
Tyne	Bywell	2175	1956-2000	17	2.6
	Riding Mill	2174	1989-2000	10	1.7
Great Ouse	Bedford	1460	1933-2000	27	7.8
	Roxton	1660	1972-2000	14	4.5
Thames	Eynsham	1616	1951-2000n	17	6.0
	Farmoor	1608	1992-2000	55	3.6
Thames	Days Weir	3444	1938-2000n	20	5.0
	Sutton Courtenay	3414	1973-2000n	20	2.5
Bristol Avon	Bath St James	1595	1939-2000	19	2.7
	Bath untrasonic	3414	1976-2000	11	1.3

Table 4 Discharge Ratios of South East Region Rivers

		10 percentile / 95 percentile	Maximum runoff / Minimum runoff
Medway	Teston	20	4
Kentish Stour	Horton	6	3
Eastern Rother	Udiam	30	7
Combe Haven	Crowhurst	30	6
Nunningham Stream	Tiley Bridge	40	9
Ash Bourne	Hammer Wood Bridge	10	7
Cuckmere	Sherman Bridge	50	10
Ouse	Barcombe Mills	30	5
Arun	Pallingham Quay	30	6
Western Rother	Hardham	6	3
Itchen	Riverside Park	3	2
Test	Broadlands	3	2

Table 5 River Discharge Ratios

		10 percentile / 95 percentile	Maximum runoff / Minimum runoff
Wear	Chester le Street	10	3
Tees	Low Moor	10	3
Yorkshire Ouse	Skelton	20	3
Tame	Lea Marston	3	2
Trent	Shardlow	7	3
Nene	Orton	20	6
Cam	Bottisham	8	8
Little Ouse	Abbey Heath	7	3
Suffolk Stour	Stratford St Mary	10	7
Thames	Kingston	10	4
Dart	Austins Bridge	20	2
Torridge	Torrington	40	2
Perry	Yeaton	9	3
Warwickshire Avon	Bredon	10	3
Severn	Haw Bridge	10	2
Dee	Chester Weir	20	2
Ribble	Samlesbury	20	2
Lune	Halton	30	2
Cumberland Derwent	Camerton	20	3
Eden	Sheepmount	10	3

2.3.3 The relationship between Precipitation and Discharge

In the short term river discharge depends on the difference between precipitation and evapotranspiration, assuming that there is no change in groundwater storage and thereby baseflow.[45] Mean annual precipitation varies between 550 mm in parts of eastern England to 2,500 mm in the Lake District.

Mean potential annual evapotranspiration varies from over 550 mm in the Thames valley and some South Coast areas to between 400 and 450 mm on the Pennines. Actual evapotranspiration varies from over 500 mm in a belt reaching from Bristol to Norwich with a branch to Brighton, to under 400 mm in East Yorkshire, the North East and South Lancashire.[46] Studies of the relationship between climate and discharge have shown that the change in the rate of evapotranspiration has not been significant during the last millennium.[47]

In the period 1750-1990 the decadal average winter precipitation in England and Wales varied from 160 mm to 300 mm. The mean winter precipitation was about 230 mm.[48] Thus in 'wet' decades the rainfall was 30% greater than the average. In a period when accurate records are available it is known that 'over most of the UK average annual runoff in the period 1979-1988 was over 20% higher than in the period 1969-1978.'[49] So it seems reasonable to assume long term variations of annual precipitation of 30% above and below the mean.

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[45] As in D.B. Burgess and E.J. Smith, 'The effects of groundwater development: the case of the Southern Lincolnshire Limestone Aquifer.' In G.E. Hollis, Ed. *Man's Impact on the Hydrological Cycle of the United Kingdom.* Norwich: Geo Abstracts Ltd. 1979, 47.
[46] R.C. Ward, 'River systems and river regimes.' In John Lewin, Ed. *British Rivers.* London: George Allen & Unwin. 1981, 17.
[47] Jurg Luterbacher *et al* 'European Seasonal and Annual Temperature Variability, Trends and Extremes Since 1500.' *Science,* Vol. 303, 5 March 2004, 1499-1503.
N.W. Arnell, R.P.C. Brown and N.S. Reynard, 'Impact of Climatic Variability and Change on River Flow Regimes in the UK.' Wallingford: Institute of Hydrology. Report No. 107. 1990, 32.
R.S. Bradley, *et al.* 'The Climate of the Last Millennium.' In Keith Alverson, Raymond S. Bradley and Thomas S. Pederson, Eds. *Paleoclimate, global change, and the future.* London: Springer. 2003, 118.
C. Pfister, *et al.* 'Winter Air temperature variations in western Europe during the Early and High Middle Ages (AD 750-1300).' *The Holocene.* Vol. 8.5. (1998), 535-552.
[48] Mike Hulme and Elaine Barrow, *Climates of the British Isles.* London: Routledge. 1997, 186, 206.
[49] N.W. Arnell, R.P.C.Brown and N.S. Reynold, 'Impact of Climatic Variability and Change on River Flow Regimes in the UK.' Institute of Hydrology. Report No. 107. 1990, 61.

If evapotranspiration is considered to be constant and the change in ground storage and inter-basin percolation are ignored, the relationship between the change in precipitation and change in runoff can be expressed as follows.

If at a given time a: R_a is the runoff, P_a precipitation, E evapotranspiration,

$$R_a = P_a - E$$

At a later time b: $R_b = P_b - E$

If x is the fractional increase in precipitation $P_b = (1 + x) P_a$

and $E = y \,.\, P_a$

where y is the original fractional evopotransporation

$$R_b / R_a = (1 - y + x) / (1 - y) \qquad \text{(Eq. 1)}$$

Thus for $x = -0.3$, $y = 0.5$, $R_b / R_a = 0.4$

$x = -0.3$, $y = 0.7$, $R_b / R_a = 0$

The 1988-92 drought, the most severe of the 20th century, confirms this calculation. The period was the warmest five year period in the 332 year Central England Temperature series and evaporation rates were above average. The effects of the drought varied across the country. In the area east of the line joining Maidstone - Oxford - Hull the discharge in the period September 1990 to August 1992 was less than 50% of the long-term average. On the Heachem (Norfolk) and Waithe Beck (Lincolnshire) average discharges were 20-30% of long term values. In eastern and southern England in late-1990 there were lengthy stretches of dried-up river bed. In Cumbria for the same period the discharge was in excess of the long term average.[50] No report was prepared to show how the drought affected river usability.

Variation in annual discharge due to snowmelt has had an effect on channel form and the distribution of discharge through the year.[51] No records have been found where this effect has been measured nor has any discussion been found as to how this would have affected the usability of rivers.[52]

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[50] T.J. Marsh *et al*, *The 1988-92 Drought.* Wallingford: Institute of Hydrology. 1994, 3, 35-41.
[51] David Archer, *Land of Singing Waters.* Stocksfield: The Spredden Press. 1992, 6.
[52] Leszek Starkel, 'The Role of Extreme (Catastrophic) Meteorological events in Contemporary Evolution of Slopes.' In Edward Derbyshire, Ed. *Geomorphology and Climate.* London: John Wiley & Sons. 1976, 228.

2.3.4 Discharge and Usability

When considering the difference between the summer and winter limit of use a convenient example is provided by Langdon who considered that the Thames was used by barges to Oxford in the period 1294-1348 at all times of year and during all years.[53] He was interested in the economic movement of goods, not the geomorphology of the rivers, so his limit point was an urban area rather than the physical limit of navigation. However this does not materially affect the following calculations.

The notation used is Q = discharge, D = depth, W = width, V = velocity, upper case for Oxford, lower case for the winter limit point, subscript s for summer, w for winter, m for mean.

If the river channel was rectangular then

$$W_w = W_s \quad \text{and} \quad w_w = w_s$$

The standard discharge equation is:

$$q_w = w_w \times d_w \times v_w$$

Since the width of a river increases in the downstream direction:

$$w_w < W_w$$

Since the velocity of a river increases in a downstream direction:

$$v_w < V_w = V_s \times V_w/V_s$$

Since the same barges could reach to the winter limit point as could reach Oxford in summer

$$d_w = D_s$$

Hence: $$q_w < W_s \times D_s \times V_s \times V_w/V_s = Q_s \times V_w/V_s$$

There is no exact relationship between velocity, discharge, and depth in a rectangular channel but the widely accepted Manning formula assumes that v varies as $r^{2/3}$, where

[53] John Langdon, ‘The Efficiency of Inland Water Transport in Medieval England.’ In Blair, 2007, 113.

r is the hydraulic radius of the river.[54] (Note:- r = Area/wetted perimeter, for a rectangular cross-section r = w . d / w + 2d)

If the width of a river is much greater than the depth then r is approximately proportional to d and so v varies as $d^{2/3}$.

Thus $V_w/V_s = (D_w/D_s)^{2/3}$

since $\dfrac{Q_w}{Q_s} = \dfrac{W_w \times D_w \times V_w}{W_s \times D_s \times V_s}$

and W is a constant

$$Q_w/Q_s = D_w/D_s \times (D_w/D_s)^{2/3} = (D_w/D_s)^{5/3}$$

hence $D_w/D_s = (Q_w/Q_s)^{3/5}$

thus $V_w/V_s = (D_w/D_s)^{2/3} = \{(Q_w/Q_s)^{3/5}\}^{2/3} = (Q_w/Q_s)^{2/5}$

but $q_w < Q_s \times V_w/V_s = Q_s \times (Q_w/Q_s)^{2/5} = Q_w^{2/5} \times Q_s^{3/5}$

If it is assumed that the ratio of the mean discharge to winter discharge at the limit point is the same as the ratio of the mean discharge to winter discharge at Oxford

$$q_m/q_w = Q_m/Q_w \qquad \text{or} \qquad q_m = q_w \times Q_m/Q_w$$

Thus $q_m < Q_w^{2/5} \times Q_s^{3/5} \times Q_m / Q_w = Q_m \times Q_s^{3/5} / Q_w^{3/5} = Q_m \times (Q_s/Q_w)^{0.6}$

From the data in *Hydrological Data UK 1996-2000* the mean discharge at Oxford is about 28 $m^3\,s^{-1}$, the 10 percentile is about 63 $m^3\,s^{-1}$ and the 95 percentile 3 $m^3\,s^{-1}$.[55]

[54] Ven Te Chow, *Open-channel Hydraulics.* London: McGraw-Hill Book Company. 1973, 99.
[55] Taking the figures for the Thames at S. Courtenay minus the Ock at Abingdon gives the approximate flow immediately downstream of Oxford.

Thus $q_m < 28 \times (3/63)^{0.6} = 28 \times 0.047^{0.6} = 28 \times 0.16 = 4.5$

The mean discharge at Buscot is 9.17 $m^3 s^{-1}$. So the barges which used to go to Oxford in summer could, in the absence of weirs and flashlocks, have passed to well above Buscot, possibly as far as Lechlade in winter. Lechlade is about 33 miles upstream of Oxford.

However the width at Lechlade would have been expected to have been less than at Oxford. One could therefore use the downstream hydraulic equation

$$w = a\ Q^{1/2}$$

to revise the estimate of the winter limit point.[56] The revision would show that barges could have gone even further upstream than Lechlade. It also risks the accusation that the calculation implies greater accuracy in the conclusion than the data permits.

A similar calculation shows that if the wet-dry summer precipitation ratio was about 2.5[57] in wet summers the barges could have worked to about Eynsham which is eight miles upstream of Oxford.

This method can not be applied to all rivers. The Itchen is physically usable to New Alresford but its winter-summer discharge ratio is much less than that of the Thames and there is a confluence of three tributaries at New Alresford. It may well be that none of the tributaries would be usable even at high rates of discharge.

If it assumed that there is, and was, a limit point for the use of each river for each type of boat, even when the form of the channel remained constant the limit point moved from day to day, year to year and decade to decade purely due to the fact that the precipitation in England does not fall at a constant rate.

[56] Nancy D. Gordon, *et al*, *Stream Hydrology. An Introduction for Ecologists.* 2nd Edition. Chichester: John Wiley & Sons. 2004, 181.
[57] The naturalised value at Sutton Courtenay.

2.3.5 Abstraction

It is extremely difficult to estimate the effect of abstraction either from groundwater or surface water on the usability of rivers. The effect of abstracting water from near the tidal limit of a river is much less than abstracting water from near a river's source. Surface abstraction in times of flood may have little effect. In time of drought it may cause a river to stop flowing. Abstraction can only be considered in connection with the return of the water to a river. Water abstracted for cooling may have little effect except on a very short reach of a river. Water abstracted for overhead irrigation is effectively lost.[58] In addition the mechanisms of groundwater-river exchange are poorly understood.[59] These uncertainties make it difficult to relate the change in usability of a river to the timing and amount of abstraction. Abstraction has local effect, normally on a single catchment area, so national averages do not show the effect of abstraction on the usability of rivers.

The estimated abstraction as a % of runoff in the period 1961-90 was:[60]

Region	%
North West	9
North East	13
Midland	21
Anglian	18
Thames	55
Southern	31
South West	14

As different percentages were taken from each river it seems that abstraction would have significantly reduced the usability of some rivers.

58 Prashant Vaze, Ed. *UK Environmental Accounts 1998.* London: The Stationery Office for Office for National Statistics. 1998, 86.
59 T.R. Grapes, *et al.*, 'Dynamics of river-aquifer interactions along a chalk stream: the River Lambourn, UK.' *Hydrological Processes*. Vol. 19, (2005), 2036.
60 Terry Marsh *et al.* 'River Flows.' In Mike Acreman, Ed. *The Hydrology of the UK.* London: Routledge. 2000, 110.

Since regional averages do not show the effect of abstraction on individual rivers one may consider rivers which are known to have been significantly affected.

1. Abstraction from the river Glen has caused a reduction in the dry weather discharge of 80%.[61]
2. In the past the river Wilbraham was used by boats. It is now unusable due to abstraction of the local ground water.[62]
3. The 2006 Ordnance Survey 1:50,000 map of Cambridgeshire shows a river 10 km long upstream of Fowlmere which drained an area of about 34 km^2. There is now a Cambridge Water Company works at Fowlmere and after a month of heavy rain there was no flow of water in the channel. It seems that this was due to abstraction by the Cambridge Water Company.[63]
4. On the Waveney the depth of water was reduced by a metre in the 1960s due to abstraction making it unusable.[64]
5. Taunt observed that at the end of the 19th century in summer the source of the Thames moved a mile downstream due to abstraction of water but in winter the water was not needed and the original springs flowed again flooding the valley.[65]
6. The river Wye, a tributary of the Thames, once supported 29 water mills along its length, but a model simulation indicates that dry weather discharge has been reduced by approximately 80% as a result of abstractions and peak discharges are reduced by about 40 to 70%.[66]
7. The river Wylye in Wiltshire dried up for the first time in living memory in 1996.[67] In the same catchment area the Environment Agency are concerned about over-abstraction from the Piddle and Malmesbury Avon.[68]

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[61] D.B. Burgess and E.J. Smith, 'The effects of groundwater development: the case of the Southern Lincolnshire Limestone aquifer.' In G.E. Hollis, *Man's Impact on the Hydrological Cycle of the United Kingdom.* Norwich: Geo Abstracts. 1979, 39 – 53, 49.
[62] T.D. Hawkins, *The drainage of Wilbraham Fulbourn and Teversham Fens.* Little Wilbraham: Dr T. D. Hawkins. 1990, 8, 22.
[63] Personal observation by the present author. 15 December 2008.
[64] Sarah Fowler, 'Actions start to flow on water?' *ECOS* Vol. 18 (2). 1997, 20-26, 23.
[65] Henry W. Taunt, *A New Map of the River Thames.* 3rd Edition. Oxford: Henry W. Taunt & Co. c. 1878, 7.
[66] C.P. Mainstone, *Chalk Rivers nature conservation and management.* Produced on behalf of English Nature and the Environment Agency. (English Nature contract number FIN/8.16/97-8)
[67] Sarah Fowler, 'Actions start to flow on water?' *ECOS* Vol. 18 (2). 1997, 23.
[68] http://www.swenvo.org.uk/environment/water_resources.asp. Accessed 30/03/2006.

One locally important form of water abstraction is mining. Younger wrote that during the 18th and 19th centuries in the Wear catchment area the water-table of the Durham Coalfield was lowered by more than one hundred metres beneath an area in excess of 2,000 km^2 by combined pumping of 1.2 $m^3 s^{-1}$ from nine pumping stations. Some of the adits still operate as drainage channels and as some are several tens of kilometres long, it is difficult to establish the extent to which they reduce the natural baseflow.[69] It seems likely that discharge through old adits also affects other rivers.

Inter-basin transfers are a form of abstraction or enhancement. The first major anthropogenic inter-basin transfer involved the transfer of water from Wales to Liverpool in 1892. Since then more schemes have been developed. Invariably the delivery point is a city or town.[70] The effect of each scheme on river transport can only be determined on an individual basis. Thus on the Witham at Colsterworth summer flows were very heavily augmented by transfers from Rutland Water until June 1985, when the direct Rutland/Saltersford pipeline opened.[71]

Both drought and abstraction reduce the usability of rivers but it is not possible to measure their combined effect without a measure of usability. It would seem likely that their combined effect would be greater than the sum of the parts.

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[69] P.L. Younger, 'Possible environmental impact of the closure of two collieries in County Durham.' *Journal of the Institute of Water Environmental Management.* Vol. 7, 1993, 521-531. Cited in Brian Adams *et al*, 'Groundwater.' In Mike Acreman, Ed. *The Hydrology of the UK.* London: Routledge. 2000, 165.

[70] Angela Gurnell and Geoff Petts, 'Causes of catchment scale hydrological changes.' In Mike Acreman, Ed. *The Hydrology of the UK.* London: Routledge. 2000, 93.

[71] *Hydrological data UK.1996-2000.* p. 76.

2.3.6 **Land use change**

The amount of moisture lost due to evapotranspiration varies according to the nature of the ground cover. Several studies have shown that in general the change in the rate of evapotranspiration has not been significant during the last millennium.[72] Thus the difference between the runoff of the largely forested Severn catchment and the runoff of the predominantly grassland of the Wye catchment is approximately 15%[73] to 22%.[74] This is not significant. However for relatively small areas afforestation has the potential to significantly reduce discharge in the areas where evapotranspiration is high compared with precipitation. At Thetford in East Anglia groundwater recharge has been reduced by 50%, a potentially significant proportion.[75] It seems that medieval woods were relatively small and that medieval woodland, in general, did not have a closed canopy.[76] No catchment has been identified where forestry has caused a change to the usability of a river.

Urbanization is the land use change which has most affected the hydrology of an area[77] and is also the best documented.[78] The impermeable surface in cities varies from 10% to 80% and the factors affecting the hydrological balance have varying

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[72] Jurg Luterbacher *et al* 'European Seasonal and Annual Temperature Variability, Trends and Extremes Since 1500.' *Science*, Vol. 303, 5 March 2004, 1499-1503.
N.W. Arnell *et al.* 'Impact of Climatic Variability and Change on River Flow Regimes in the UK.' Wallingford: Institute of Hydrology. Report No. 107. 1990, 32.
R.S. Bradley, *et al.* 'The Climate of the Last Millennium.' In Keith Alverson, *et al.*, Eds. *Paleoclimate, global change, and the future.* London: Springer. 2003, 118.
C. Pfister, *et al.* 'Winter Air temperature variations in western Europe during the Early and High Middle Ages (AD 750-1300).' *The Holocene.* Vol. 8.5, (1998), 535-552.
[73] Mark Robinson *et al*, 'Land Use Change.' In Mike Acreman, Ed. *The Hydrology of the UK.* London: Routledge. 2000, 38.
[74] Ian R. Calder, 'Hydrologic effects of land-use change.' In David R. Maidment, *Handbook of Hydrology.* New York: McGraw-Hill. 1992, 13.20.
[75] Mark Robinson *et al*, 'Land Use Change.' In Mike Acreman, Ed. *The Hydrology of the UK.* London: Routledge. 2000, 41.
D.J. Mitchell, A.J. Gerrard, 'Morphological Responses and Sediment Patterns.' In K.J. Gregory, *et al.*, Eds. *Palaeohydrology in Practice.* Chichester: John Wiley & Sons Ltd. 1987, 188.
[76] Oliver Rackham, *The History of the Countryside.* (1st Edition 1986.) London: Phoenix Press. 2000, 130.
[77] J.B. Leopold, 'Hydrology for urban land planning-a guidebook on the hydrologic effects of urban land use. U.S. Geol. Surv. Circ. 554. Cited in F.A. Branson *et al. Rangeland Hydrology.* Toronto: Kendall/Hunt Publishing Company. 1981, 244.
[78] C.C. Park, 'Man-induced Changes in Stream Channel Capacity.' In K.J. Gregory, *River Channel Changes.* Chichester: John Wiley & Sons. 1977, 124.

significance between cities and within cities.[79] The Bollin is now in places 50% wider, and so approximately 34% shallower, due to urbanization in Macclesfield.[80] Urban growth has also increased the speed of runoff making the flow more peaky.[81] However no place has been identified where the change in discharge due to urbanization has significantly changed the usability of a river in England.[82]

2.3.7 Groundwater Flow and Drainage

It is said that 'The unwritten rule of basic drainage, is to pass as much of one's own water to one's neighbour as possible and to reject any in return'[83] The technique of drainage is to provide an outlet for water lower than the previous outlet and a quicker route for the water to the outlet. In the west of England the principal upland areas are composed of impermeable rocks which promote a rapid river flow response to rainfall.[84] It would seem that the main change to drainage in these areas is that many of the marshes have been drained causing a faster runoff and shorter, higher discharge peaks compared with the 'natural' flow. The second major change has been the building of reservoirs. No study has been found which considered the combined effect of these two changes.

In southern and eastern England there are extensive areas where porous and fractured rocks are interleaved between beds of impermeable clays. In these areas groundwater is a major supply source and is a component in the discharge of many lowland rivers.[85] The speed of groundwater movement through permeable strata range from a few thousandths of an inch per day in some fine-grained pervious rocks to 18,000 feet

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[79] D.N. Lerner, 'Too much or too little – recharge in urban areas.' In J. Chilton, Ed. *Groundwater in the Urban Environment, Volume 1; Problems, Processes and Management.* Rotterdam: Balkema. 1997, 41-47.

[80] M.P. Mosley, 'Channel Changes on the River Bollin, Cheshire, 1872-1973.' *East Midlands Geographer.* (1975), 185-199.

[81] Peter W. Downs, Kenneth J. Gregory, *River Channel Management.* London: Arnold. 2004, 239.
D.E. Walling, 'The hydrological impact of building activity: a study near Exeter.' In G.E. Hollis, Ed. *Man's Impact on the Hydrological Cycle in the United Kingdom.* Norwich: Geo Abstracts. 1979, 135.
K.J. Gregory, 'Changing Drainage Basins.' *The Geographical Journal.* Vol. 142, (1976), 237-247.

[82] R.I. Ferguson, 'Channel form and channel changes.' In John Lewin, Ed. *British Rivers.* London: George Allen & Unwin. 1981, 124.

[83] K.S.G. Hinde, 'Meres and Mills in Willingham and Stretham.' *Proceedings of the Cambridge Antiquarian Society.* Vol. LXVI. (1977), 165.

[84] R.C. Ward, 'River Systems and river regimes.' In John Lewin, Ed. *British Rivers.* London: George Allen & Unwin. 1981, 2.

[85] T.J. Marsh *et al*, *The 1988-92 Drought.* Wallingford: Institute of Hydrology. 1994, 5.

per day through fissured chalk in Hertfordshire.[86] This causes wide variation in the effect of precipitation in different areas on spring discharge and ephemeral streams.

There are no records of the water-table levels in the period 1189-1600 but there are indications that it was, in general, higher than now. Floodplains used to be flooded more often and for longer periods of time. There used to be artesian wells at Barrington in the valley of the Rhee in 1892 which no longer flow.[87] In 1586 it was reported that the Hans in Staffordshire was 'being swallowed up under the ground, breaketh up againe three miles off.'[88] It seems that now the upper section does not flow. No survey has been found of present or historic ephemeral streams. Where a river flows over clay it seems likely that the groundflow will be negligible. However where it flows through gravel, fractured limestone or chalk or unconsolidated course material the lowering of the watertable will reduce the river discharge.

When drainage is considered at a more local scale the connection between field drainage and flooding has been a subject of debate for centuries.[89] It would appear that an Institute of Hydrology study has resolved the problem:

> It was found that, … the drainage of heavy clay soils (prone to prolonged surface saturation in their undrained state) generally results in a lowering of large and medium flow peaks. This is because their natural response is 'flashy' with limited soil water storage available, whereas when drained, surface saturation is largely eliminated.
> On more permeable soils, less prone to surface saturation, the more usual effect of drainage is to improve the speed of subsurface discharges, tending to increase peak flows.[90]

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[86] R.C. Ward, *Principles of Hydrology*. London: McGraw-Hill Publishing Company Limited. 1967, 271.
[87] C.L. Forbes, 'Landforms and water in the Cam Valley above Barrington.' In Elsie M. Widdowson, Ed. *Cam or Rhee*. Barrington Local History and Conservation Society. c1973, 8.
[88] William Camden, *Britain.*Trans. Philemon Holland. London: Joyce Norton, and Richard Whitaker. 1637, 587.
[89] H.H. Nicholson, *The Principles of Field Drainage*. Cambridge: Cambridge University Press. 1946, 143.
[90] M. Robinson, *Impact of improved land drainage on river flows.* Institute of Hydrology Report 113. 1990, Unnumbered.

The earlier delivery of water to some rivers may have shortened the period of time for which the rivers are usable. It seems unlikely however that field and arterial drainage have significantly affected the usability of the rivers. Certainly the effect has not been quantified. However the drainage of marshes, ponds and lakes before discharge gauging was introduced could have had a material effect on the discharge of rivers.[91]

Of particular interest are the wetlands which it has been claimed used to occupy 20% to 30% of the land area of England.[92] This included not only the coastal marshes but also many inland valleys like the Humberhead marshes, the valley at Chippenham (Wiltshire) where a causeway 7 km long was built across wetlands[93] and the Sussex Ouse upstream of Ardingly Reservoir where the river used to vary in width from 6 feet to 200 yards.[94] The name Cuckmere refers to a lake or mere either 'of running water' or 'belonging to Cuca'.[95]

The amount of floodplain which existed in 1189 is unknown. In the Domesday Book the areas of marsh and meadow were recorded in such a way that it is impossible to calculate their total area.[96] In the 17th century a poet wrote:

> They'll sow both beans and oats, where never man yet thought it,
> Where men did row in boats, ere undertakers bought it.[97]

Ecologists have noted the disappearance of the wildfowl and other flora and fauna,[98] archaeologists have noted the change in the preservation of artefacts buried in the

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[91] Nancy D. Gordon, *et al*, *Stream Hydrology. An Introduction for Ecologists.* 2nd Edition. Chichester: John Wiley & Sons. 2004, 67.
[92] A.G. Brown and C. Bradley, 'Past and Present Alluvial Wetland and the Eco-archaeological Resource: Implications from Research in East Midland Valleys, UK.' In Margaret Cox *et al.*, Eds. *Wetlands Archaeology and Nature Conservation.* London: HMSO. 1995, 190.
[93] Paul Hindle, *Medieval Roads and Tracks.* Princes Risborough: Shire Publications Ltd. 2002, 45.
[94] Edna & 'Mac' McCarthy, *Sussex River. Upstream, from Lewes to the Sources.* Seaford: Lindel Organisation Limited. 1979, 70.
[95] Victor Watts, Ed. *The Cambridge Dictionary of English Place-Names.* Cambridge: Cambridge University Press. 2004, 174.
[96] H.C. Darby, *Domesday England.* Cambridge: Cambridge University Press. 1986, 137, 142, 144.
[97] Cited in William Dugdale, *The History of the Imbanking and Draining of Divers Fens and Marshes.* 2nd Edition. London: Richard Geast. 1772, 391.
[98] Eg. A.G. Brown, *Alluvial geoarchaeology. Floodplain archaeology and environmental change*. Cambridge: Cambridge University Press. 1997.

wetlands,[99] but little notice seems to have been taken by historical geographers of the disappearance of boats.

When a river reaches bank-full stage, the excess water flows onto the floodplain and remains there until the water level falls when it returns to the river. For any given floodplain, understanding of drainage requires knowledge of the distribution and permeability of the alluvial sediments as well as their connectivity.[100] When the groundwater level falls some of the channels become dry.[101]

The effect of floodplain drainage is clear from the records of historic use. In East Sussex alone there has been the loss of the use of the Brede from Sedlescombe to Winchelsea, and on the Reading Sewer, Combe Haven, Ashbourne Stream, Nunningham Stream, Pevensey Haven, Middle Sewer, parts of the Cuckmere and Sussex Ouse. In the Fens, Lincolnshire Marshes and other areas boats were from 1189-1600 the normal or only mode of transport. This is no longer true.

In Bedfordshire in 1279 a man was drowned having fallen from a boat on the Ouzel at Eaton, Bedfordshire.[102] At the start of the 17th century Speed showed this section of river as being well established.[103] Now the marsh has been drained and there is only a ditch with the water normally less than six inches deep. In the Hull valley because of artificial drainage the water table is now in many places several metres lower than the depth at which it would naturally occur.[104]

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[99] Eg. Bryony Coles, ‘Paradox and Protection: The Significance, Vulnerability and Preservation of Wetland Archaeology.’ In Margaret Cox, *et al.*, Eds. *Wetlands Archaeology and Nature Conservation.* London: HMSO. 1994, 144-155.
[100] T.P. Burt and N.E. Haycock, ‘Linking Hillslopes to Floodplains.’ In Malcolm G. Anderson, *et al.* Eds. *Floodplain Processes.* Chichester: John Wiley & Sons. 1996, 470.
[101] A.G. Brown and T.A. Quine, ‘Fluvial Processes and Environmental Change: An Overview.’ In A.G. Brown and T.A. Quine, Eds. *Fluvial Processes and Environmental Change.* Chichester: John Wiley & Sons. 1999, 1-28, 15
[102] *Select Cases from the Coroners’ Rolls, 1265-1413.* Editor Charles Gross. Selden Society, Vol. 9. (1895), 16.
[103] John Speed, *Theatre of the Empire of Great Britaine, Part II.* (1st Edition 1611.) Facsimile London: Phoenix House Limited. 1953-4.
[104] Robert Van de Noort and Jon Etté, ‘Introducing the survey of the Hull valley.’ In Robert Van de Noort and Stephen Ellis, Eds. *Wetland Heritage of the Hull valley. An Archaeological Survey.* Hull: Humber Wetlands Project. Commissioned by English Heritage. 2000, 11.

2.3.8. <u>Minimum discharge at mills.</u>

One possible source of information about how the discharge of rivers has changed is the location of historic water-mills. Aubrey wrote in about 1670 that weaving moved from Castle Combe and that 'The local tradition is that the dryness of the brook enforced this migration.'[105] The only list of sites of 14th century mills, which has been found, is for the Middle Wye catchment area. It appears that there is now no water supply at six of the thirty eight sites.[106] King wrote of the Sussex mills listed in Domesday Book 'many of the mills seem to have been on the small tributary streams that discharge northward from the Chalk escarpment to join the major rivers.'[107] Now possibly only the stream at Plumpton has discharge adequate to operate a mill.

In Cambridgeshire there is adequate discharge for mills on the Cam, Rhee and Granta. In Domesday Book there are records of fourteen manors not located on these rivers which had mills. Of these there appears now to be no suitable river for a mill in Lolworth or Burwell. At Bottisham where there used to be four mills there is now no stream on which a mill could operate. On inspection of the parish it appeared that the water-table has been lowered by land drainage.[108] At Fowlmere there used to be one mill. Now even after heavy rain no water flows in the bed of the river.

Hawkins wrote of the former Great Wilbraham River and the extant Little Wilbraham River:

> Not only did they provide power for watermills but also bathing and boating excursions, shoals of fish and abundant wildlife … all occurred within living memory. Over the last 35 years or so discharge in Little Wilbraham River was first diminished then became intermittent due to licensed water abstraction and seepage through its bed and banks where it runs above the natural drainage

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105 M.W. Beresford & J.K.S. St Joseph, *Medieval England.* 2nd Edition. Cambridge: Cambridge University Press. 1979, 269.
106 See Appendix J. Watermills of the Middle Wye Valley and East Sussex.
107 S.H. King, 'Sussex.' In H.C. Darby, Ed. *The Domesday Geography of South-East England.* Cambridge: Cambridge University Press. 1962, 461.
108 By the present author November 2008.

> level. For several years discharge ceased altogether when winter rainfall was low.'[109]

The discharge at Hawk Mill is now not sufficient to operate the mill.

While the closure of mills is a very crude measure of discharge it appears that they indicate that there has been a significant reduction in discharge in some rivers.

2.3.9 Summary

At the start of this chapter it was stated that there are two elements of discharge which should be considered, the volume of water and its distribution through the year. It has been shown that the variation in discharge due to variation in precipitation had a significant effect on the length of river which was usable at both annual and longer timescales. There has been a significant local reduction in the usability of rivers due to abstraction and probably also due to increased groundwater flow.

The distribution of the discharge through the year has certainly changed. Reservoirs delay the movement of water downstream[110] and change the channel downstream in complex ways.[111] In some soils field drainage and in all soils arterial drainage accelerate the movement of water to the rivers. However, no way has been found of quantifying these effects. For a thousand years farmers, and for a not much shorter time drainage authorities, have sought to remove water from the land and direct it to the sea more quickly. If the process was not a continuous one from field to sea then someone in between was likely to find their land flooded. In general rivers now transport precipitation to the sea more quickly. This results in a more peaky flow and a lower volume of water in the rivers between high flows. This means, in general, that the rivers are usable for a shorter part of the year than previously.

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[109] T.D. Hawkins, *The drainage of Wilbraham Fulbourn and Teversham Fens.* 2nd Edition. Little Wilbraham: T.D. Hawkins. 2000, 52.
[110] Barbara Rumsby, Mark Macklin, 'Channel and Floodplain response to recent abrupt climate change: the Tyne Basin, Northern England.' *Earth Surface Processes and Landforms.* Vol. 14, (1989), 233-246.
[111] G.E. Petts & J.D. Pratts, 'Channel changes following reservoir construction on a lowland river.' *Catena.* Vol. 10, (1983), 77-85.

Chapter 2.4 Anthropogenic Modifications of River Form and Usability

2.4.1 Introduction

The following notation is used in this chapter:-

w = width	A = area of cross-section of a channel
d = depth	S = slope of the channel
v = velocity	Q = discharge

l = length of section

h = height difference

p = wetted perimeter of the channel

r = hydraulic radius (cross-section area divided by wetted perimeter)

n = the Manning resistance factor

It is to be noted that all empirical hydrological equations are approximations. 'Depth' varies along a section of a river and may even vary at a fixed point with time under conditions of constant discharge.[112] 'Bankfull' is not a well defined term.[113] The ratio of the width to depth depends partly on 'bank strength' and vegetation. Huang and Nanson found that bank strength can produce a three-fold change in channel width, two-fold in depth and 1.6 in cross-section area.[114] Klein showed that rivers at first get deeper and later become wider than the above equations would imply.[115] Pickup and Rieger have shown that the channel form is a product of the whole series of discharges experienced by the channel rather than only the bankfull discharge.[116]

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[112] Mary Ann Madej, 'Temporal and spatial variability in Thalweg Profiles of a Gravel-bed River.' *Earth Surface Processes and Landforms.* Vol. 24, (1999), 1153-1169.
[113] Artur Radecki-Pawlik, 'Bankfull discharge in mountain streams: Theory and Practice.' *Earth Surface Processes and Landforms.* Vol. 27, (2002), 115-123.
[114] He Quing Huang and Gerald C. Nanson, 'The influence of bank strength on channel geometry: an integrated analysis of some observations.' *Earth Surface Processes and Landforms.* Vol. 23, (1998), 865-876.
[115] M. Klein, 'Drainage Area and the Variation of Channel Geometry Downstream.' *Earth Surface Processes and Landforms.* Vol. 6, (1981), 589-593.
[116] G. Pickup and W.A. Rieger, 'A conceptual model of the relationship between channel characteristics and discharge.' *Earth Surface Processes.* Vol. 4, (1979), 37-42.

During the period 1600 to 1830 more than 67 rivers were canalized under powers granted by parliament.[117] This involved straightening the channels, widening, dredging and the building of weirs and locks. There were three ways in which this was done. The canal could be built adjacent to the river and water from the river used to supply the canal as on the Trent and Mersey Canal. The river itself might be used as the route for the barges, the weirs being built across the river to maintain the depth, as on the Thames, Medway and Sussex Ouse. Otherwise the route of the barges might be along a combination of new cuts and the river channel as on the Wey and Arun canal. Where the river channel was used by the barges, if there was sediment in the water flowing into the canalized section, then normally the river would need dredging periodically. Many of the canalized rivers are no longer maintained for use by barges. The modifications have destroyed much of the evidence of the pre-existing channels and even where pre-canalization channels exist it is normally not possible to know if these sections were modified when canalization work was being carried out.

Other river channels have been dredged and widened for drainage purposes and vegetation has been cut. Changes in sediment supply to the rivers have caused aggradation and degradation. It seems that anthropogenic modification of river channels is the determinant factor in their present form.[118]

2.4.2 Shortening a channel

In 1586 Harrison wrote of the Thames:

> For the more that this river is put by of hir right course, the more the water must of necessitie swell with the white waters which run downe from the land: because the passage cannot be so swift and readie in the winding as in the streight course.[119]

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[117] See Appendix D. A list of rivers made navigable by Act of Parliament.
[118] L.B. Leopold, 'Land use and sediment yield.' In W.L. Thomas Junior, Ed. *Man's Role in Changing the Face of the Earth.* Chigago: University of Chicago Press. 1956, 646.
[119] Raphaell Holinshed, William Harrison, and others, *Holinshed's Chronicles.* (1st Edition 1586.) London: J. Johnson; F.C. and J. Rivington, *et al.* 1807, 81.

The effect of shortening a channel may be expressed more prosaically: steeper slope; higher velocity; potential increase in sediment transport; degradation and possible headcutting; degradation in tributaries.[120]

If the effect of friction is ignored the effect of channel shortening on the depth of a river may be calculated approximately using the Chezy formula which is normally used for comparing the velocities of two rivers with similar characteristics.[121]

$$v = A \times S / p$$

In this calculation.

$$\frac{v_1}{v_2} = \frac{A_1 S_1 p_2}{A_2 S_2 p_1}$$

If a loop of a river is shortened, the length of the loop being ‘l’ and the height difference between the two ends of the loop being ‘h’, the new channel being cut to the same width as the original, then, if the width is considerably greater than the depth,

$$v = Q/wd, \quad S = h/l, \quad p = \text{approximately } w$$

Hence $\frac{Q/wd_1}{Q/wd_2} = \frac{wd_1}{wd_2} \cdot \frac{h/l_1}{h/l_2} \cdot \frac{w}{w}$

Which simplifies to $d_2 / d_1 = (l_2 / l_1)^{1/2}$

Similarly since $Q = w.d.v$

$$v_2/v_1 = (l_1/l_2)^{1/2}$$

Hence the depth of the river is reduced by the square root of the ratio of the original length of the section and the velocity is increased in the same ratio.[122]

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[120] Andrew Brookes, *Channelized Rivers.* Chichester: John Wiley & Sons. 1988, 86. After Simons D.B. & Senturk, F. *Sediment Transport Technology*. Water Resources Publication, Fort Collins. CO. (1977)

[121] Hsieh Wen Shen, *River Mechanics Volume 1.* Fort Collins, The Author. 1971, 1-8.

The shortening of the river will result in a nick-point at the top of the new section. This nick-point may migrate upstream and the resulting surplus sediment deposited downstream of the section, possibly below a scour pool. The resulting channel form cannot be forecast exactly because the behaviour of a straightened stream depends on the erodibility of its bed and bank.[123] Degradation will be reduced where there is an outcrop of bedrock or where a coarse segregated or armoured bed develops. When the river reaches a stable state the gradient over the whole of the altered section will be greater than the original, the velocity of the river will be greater and the depth will be less.

After a survey of 46 sites where channelization works had been carried out Brookes concluded that there had been erosive adjustment downstream at most high stream power sites but not at the low stream power sites. The maximum increase in channel size was 153 per cent.[124] Estimates of the time taken for these changes range from a half life of ‘the order of one to seven years’[125] to ‘less than one hundred to a thousand years.’[126]

The above quotation from Harrison is the only reference which has been found to the shortening of the Thames and its tributaries in the middle of the 16th century. It may be no coincidence that the first reference to barges being grounded in the Thames occurred shortly after in 1641.[127]

The greatest change was the shortening of the Great Ouse from 30 miles to 21 miles by means of the Bedford Cut in 1637.[128] However there are few records of rivers

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[122] Ryckborst has obtained the same result by consideration of Enthalpy and Entropy. H. Ryckborst, ‘Geomorphological changes after river-meander surgery.’ *Geologie en Munbouw.* Vol. 59(2), 1980, 121-128.
[123] Andrew Brookes, *Channelized Rivers.* Chichester: John Wiley & Sons. 1988, 95.
[124] Andrew Brookes, ‘River channel adjustments downstream from channelization works in England and Wales.’ *Earth Surface Processes and Landforms*, Vol. 12, (1987), 344.
[125] Martin W. Doyle and Jon M. Horbor, ‘Modelling the effect of Form and Profile Adjustments on Channel Equilibrium Timescales.’ *Earth Surface Processes and Landforms*. Vol. 28, 2003, 1271-1287.
[126] H. Ryckborst, ‘Geomorphological changes after river-meander surgery.’ Geologie en Mijnbouw, Vol. 59(2), (1980), 127.
[127] John Taylor, *John Taylor’s last Voyage.* London: John Taylor. 1641. Contained in *Works of John Taylor. Second Collection.* The Spencer Society 14. 1873. New York: Burt Franklin. 1967, 12.
[128] R.A. Butlin, ‘The Role of the State in the initiation and development of land drainage schemes in England in the seventeenth century.’ In Paola Sereno and Maria Luisa Sturani, Eds. *Rural Landscape between State and Local Communities in Europe Past and Present.* Proceedings of the 16th Session of

becoming less usable due to channel shortening. Normally the change was one of scale, not an absolute loss of use. Thus if a boat of 3 tons could use a river at a discharge of 3 $m^3 s^{-1}$ before shortening and required a discharge of 4 $m^3 s^{-1}$ after shortening the reduction in usability is unlikely to have been recorded. This is the type of change which might be expected to have occurred as a result of the channel shortening on the Thame near Shabbington[129] where the mean discharge now is 2.74 $m^3 s^{-1}$. In c.1050 the Thames at Abingdon became usable for a longer period of the year when the channel was lengthened.[130]

In England the main effect of channel shortening was to increase the speed at which water was conveyed to the sea. This shortening has significantly reduced the volume of water in the rivers and it would seem their usability.

2.4.3 <u>Widening a channel</u>

When a river channel is widened, if the velocity remains constant, the river will become less deep. If the channel is then overfit, this may result in sediment being deposited causing a greater reduction in the depth. The overall effect of deepening and widening a channel depends on the variability of the discharge, the nature of the bed and banks and on the sediment supply. Thus Brookes observed that on the River Usk in Brecon after a comprehensive flood alleviation scheme between 5,000 and 8,000 tonnes of gravel are removed at least once per year from a section of a river channel 500 metres long.[131]

Nixon reported that the River Tame near Birmingham was enlarged to enable it to carry a greater flood discharge. Within 30 years in the absence of any maintenance the enlarged channel had been reduced to its original capacity. The enlarged channel would have been in equilibrium at the designed flood discharge. At normal discharge

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the Standing European Conference for the Study of the Rural Landscape. Torino: Edizioni dell'Orso. 1998, 125.

[129] Ed Rhodes, 'Identifying Human Modification of River Channels.' In Blair, 2007, 147.

[130] *Chronicon Monasterii de Abingdon,* Rolls Series 2, I, 480-1. Cited in R.H.C. Davis, 'The Ford, The River and The City.' *Oxoniensis.* Vol. 38. (1973), 263.

[131] Andrew Brookes, *Channelized Rivers.* Chichester: John Wiley & Sons. 1988, 110.

it was out of equilibrium and sediment was deposited which reduced the channel to its original capacity.[132]

It seems likely that channel widening may have affected the usability of some rivers in the medieval period. Where a river was used for the upstream transport of a considerable amount of goods, eg. stone, the bank would have been used for towing. This may well have resulted in the erosion of the bank, the material being deposited in the river. The resulting river would have been wider and so shallower.

Much has been written about the canalization of the Itchin.[133] Rather than the river being canalised it is considered here to be more likely that in the 11th and 12th centuries, during the construction of Winchester Cathedral and Castle, stone was transported up the river in boats towed from the bank. The transport of wine on the river continued at least until the middle of the 14th century. These would have caused erosion of the banks and destruction of the bank vegetation. The river would have become wider and shallower, so that the size of the boats which could be used would have been reduced. The bank material would have included silt and cobbles. The silt would have been removed by the flow of the water and the cobbles would have armoured the bed. This could have prevented the normal cycle of incision of the bed which might otherwise have occurred. In time the river would have become unusable by barges.

It is known that in the Kentish Stour the bed has been at different levels.[134] It is not known if other chalk streams have become wider and shallower due to the collapse of the banks as a result of erosion. However this is certainly a possibility with the Nadder. It would seem that widening a river channel will always result in a reduction in depth and so of usability.

In some towns channels have been made narrower, as at Lincoln, where Jones and Jones observed that land had reclaimed so that the medieval wharf is now 50 m from

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[132] Nixon, M. (1966). Flood regulation and river training. In *River Engineering and Water Conservation Works* (ed. R.B. Thorn). Butterworth, London, pp. 293-297. Cited in Andrew Brookes, *Channelized Rivers.* Chichester: John Wiley & Sons. 1988, 101.

[133] See Appendix A. Records of Historic Use.

[134] Frank Jenkins, 'Archaeological Notebook, Canterbury 1949-51.' *Archaeologia Cantiana,* Vol. 64, (1951), 68.

the river.[135] At Cambridge one bank is recorded as having moved 3.5 m.[136] These sections are too short to affect the overall usability of the rivers.

2.4.4 Dredging

It is commonly thought that dredging makes a river deeper. In general this assumption is true for tidal rivers but false for non-tidal rivers in the absence of weirs. On a tidal river the surface level is at sea level. When the bed of the river is dredged the depth is increased.

Where a non-tidal river is not controlled by weirs dredging will, on average, reduce the depth of the river. The normal effect of dredging is to remove material from the bed of the river where it is most shallow, which is at the riffles. The water in the pools is then not held back by the riffle so the depth of the whole section of the river is reduced to little more than the depth of the original riffles. This is obvious in an ornamental garden where there is a series of pools and falls from one pool to the next. If the weirs are lowered the water in every pool is lowered and the pools become shallower. In addition in the reaches with pool and riffle sequences the water moves more slowly than in the uniform reaches.[137] In 1431 the Commons asked Henry VI to appoint commissioners with authority to remove the 'shelps' which had formed in the river Lea.[138] It is likely that after the work was carried out usability deteriorated. This fact has long been known[139] but also forgotten.

Where the level of the water in a section of a non-tidal river is set by the level of a down-stream weir, dredging a river will make the river deeper. Flow will also be slower. This may result in sediment being deposited upstream of the weir. Thus at Cambridge in 1630 blame was put on 'the miller of y[e] King's Mill for not scowring y[e]

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[135] M.J. Jones and R.H. Jones, 'Lincoln.' In Gustav Milne and Brian Hobley, Eds. *Waterfront Archaeology in Britain and Northern Europe.* CBA Research Report No. 41. 1981, 138.
[136] Paul Fairman and Joyce Pullinger, 'Excavation at Riverside, Thompsons Lane, Cambridge.' *Proceedings of the Cambridge Antiquarian Society.* Vol. LXXVI, (1987), 83.
[137] Malcolm Newson, *Hydrology and the River Environment.* Oxford: Clarendon Press. 1994, 55.
[138] Parliamentary Rolls of Medieval England. (CD version. 2005) Henry VI, 1431, para 43, iv – 381.
[139] Sir Clement Edmonds, 'Report of 1618.' In Samuel Wells, *The History of the Drainage of the Great Level of the Fens, called Bedford Level. Volume II.* London: The Author. 1830, 62-63.
Mr Atkyn, 'Report of 1618.' In Samuel Wells, *The History of the Drainage of the Great Level of the Fens, called Bedford Level. Volume II.* London: The Author. 1830, 87.

river against his little holt on y^e side of shippe grene' which was upstream of his mill on the Cam.[140]

Channel changes may be only local. Thus the gravel-bedded River Swale at Catterick experienced valley–floor incision during the late Holocene with major phases of incision occurring during the cooler and wetter phase of the Little Ice Age whereas in the lower reaches of the river at Myton there has been relative stability and vertical aggradation.[141]

The change in the velocity of the water downstream of the weirs and bridges, both in speed and direction of flow will, for most bed materials, alter the shape of the river bed. This may result in shallower areas which vessels have difficulty in passing.

2.4.5 Cutting in-stream vegetation

The historic records from the Fens contain many references to land owners and tenants being responsible for the scouring of rivers. It is often not possible to distinguish cases where the scouring was to avoid flooding, to improve navigation or both.[142] Nor is it possible to know if scouring involved the removal of vegetation or sediment. DeWindt in his study of the manuscript rolls of the manorial court rolls of Ramsey records many cases of failures to properly clear the waterways, ditches, gutters and weirs which resulted in the inundation of the adjacent land and also prevented their use by boats. 'Between 1268 and 1591, there were nearly a thousand instances in the rolls dealing with the blockage, narrowing or otherwise impeding of the several watercourses of the town, and from the fifteenth century the matter was made the subject of byelaws.'[143]

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[140] Rev. Dr. Stokes, 'The Old Mills of Cambridge.' *Proceedings of the Cambridge Antiquarian Society.* Vol. XIV, (New Series VIII), 1909-1910, 201.
[141] M.P. Taylor *et al*. 'River sedimentation and fluvial response to Holocene environmental change in the Yorkshire Ouse Basin, northern England.' *The Holocene.* Vol. 10.2, (2000), 200.
[142] David Hall and John Coles, *Fenland Survey.* London: English Heritage. Archaeological Report 1. 1994, 137.
[143] *The Court Rolls of Ramsey, Hepmangrove and Bury, 1268-1600.* Editor Edwin Brezette DeWindt. Toronto: Pontifical Institute of Mediaeval Studies. 1990, 48-49.

Normally Manning's equation is used for the calculation of discharge.[144] Here it is used for the totally different purpose of establishing by how much the depth of a river is reduced when vegetation is removed from a river. As always care needs to be taken in assessing the conclusions reached from using an empirical equation in the reverse form to that for which it has been validated.

The Manning equation is[145]

$$Q = \frac{A\, r^{2/3}\, S^{1/2}}{n}$$

Assuming the channel cross-section is rectangular and the width considerably greater than the depth, approximately,

$$r = d$$

When the vegetation is cleared on a section of a river the discharge does not change

$$Q = \frac{A_1\, r_1^{2/3}\, S^{1/2}}{n^1} = \frac{A_2\, r_2^{2/3}\, S^{1/2}}{n^2}$$

substituting: $$\frac{wd_1\ (d_1)^{2/3}}{n_1} = \frac{wd_2^2\ (d_2)^{2/3}}{n_2}$$

giving: $$d_2 / d_1 = (n_2 / n_1)^{3/5}$$

The value of 'n' is taken to be 0.04 for a clean winding stream with some pools and shoals and 0.07 when there is considerable vegetation[146] although higher values have been found by other authors.[147]

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144 Nancy D. Gordon *et al. Stream Hydrology.* Chichester: John Wiley & Sons Ltd. 2004, 101.

145 Malcolm Newson, *Hydrology and the River Environment.* Oxford: Clarendon Press. 1994, 21.

146 *Ibid.* page 23.
K. J. Gregory and D.E. Walling, *Drainage Basin Form and Process.* London: Edward Arnold. 1973, 129.
Nancy D. Gordon *et al. Stream Hydrology.* Chichester: John Wiley & Sons Ltd. 2004, 103.
Harry H. Barnes, *Roughness Characteristics of Natural Channels.* Geological Survey Water-Supply Paper 1849. Washington: United States Government Printing Office. 1967.

147 D. Watson, 'Hydraulic Effects of Aquatic Weeds in U.K. Rivers.' *Regulated Rivers Research and Management.* Vol. 1, Issue No. 3. (1987), 222.
Keith Richards, *Rivers. Form and process in alluvial channels.* London: Methuen. 1982, 174-5.

Substituting: $d_2 / d_1 = (0.04 / 0.07)^{0.66} = 0.57$

Thus is would seem that the effect of cutting the vegetation may reduce the depth of the river by about 50%. This theoretical calculation is in line with observations of the removal of all plant material from the Kennet where it was observed that clearing vegetation clearly resulted in greatly reduced depth[148] and on the Itchin near Winchester by the present author with Environment Agency staff in 2005 where it was agreed that the cutting of the vegetation in summer normally about halved the depth of the river.

The above calculation depends critically on the value of the Manning resistance factors used. It may be wiser to accept Thornes' conclusion that 'the role of vegetation in affecting bank erosion and stability is complex. At this stage it is not possible to quantify the effects of vegetation in any general fashion.'[149] However it does seem clear that removing vegetation has the effect of reducing the depth of the river.

Camden observed that at the end of the 16th century the River Ouse in Huntingdonshire was bedecked with flowers, indicating that the vegetation was uncut.[150] During the period 1189-1600 vegetation was cut in the rivers of the Fens and the Somerset levels but no records have been found of in-stream vegetation being cut elsewhere. In certain areas, particularly in chalk streams, aquatic vegetation is now cut several times a year.[151] It seems that this increase in vegetation control may have significantly reduced the usability of many rivers. However when vegetation

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J.F. Watts and G.D. Watts, 'Seasonal Changes in Aquatic Vegetation and its Effect on River Channel Flow.' In J.B. Thornes, Ed. *Vegetation and Erosion.* Chichester: John Wiley & Sons. 1990, 256-257.

[148] C.P. Mainstone, *Chalk rivers. Nature, conservation and management*. Water Research Centre. English Nature contract number FIN/8.16/97-8. Undated.

[149] C.R. Thornes, 'Effects of Vegetation on Riverbank Erosion and Stability.' In J.B. Thornes, Ed. *Vegetation and Erosion.* Chichester: John Wiley & Sons. 1990, 141.

[150] William Camden, *Britain.* Trans. Philemon Holland. London. 1637, 497B.

[151] Andrew Brookes, *Channelized Rivers. Perspectives for Environmental Management.* Chichester: John Wiley & Sons. 1988, 37

had blocked a river its removal may have improved the usability of the river. There are similar effects from the removal of in-stream wood.[152]

2.4.6 Bank vegetation

The effects of changes in the bank vegetation have been studied.[153] As early as 1978 it was realised that even a single line of trees along a river's bank can result in the tree-lined channel being 30% narrower, and so about 30% deeper, than expected.[154] Other observations have shown that sections of river with grassed banks are up to 30% wider, and so about 30% shallower, than expected.[155] The challenge for future researchers will be to discover the nature of the vegetation on the river banks in the period 1189-1600. At present no suitable data have been found.

2.4.7 Aggradation and Degradation

In addition to direct channel modifications there have been anthropogenic changes to the catchment areas which have affected the river channels. These include the change in sediment supply to the rivers. When the bed material load in stable alluvial rivers that transport small quantities of gravel increases in a river with constant flow the

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[152] K.J. Gregory and R.J. Davis, 'Fluvial geomorphology of central and southern England.' In K.J. Gregory, Ed. *Fluvial Geomorphology of Great Britain.* London: Chapman Hall, Joint Nature Conservation Committee. 1997, 265.
A.M. Gurnell, *et al.* 'Large wood and fluvial processes.' *Freshwater Biology.* Vol. 47, (2002), 601-619.

[153] K.J. Gregory and A.M. Gurnell, 'Vegetation and river channel form and process.' In Heather A. Viles, *Biogeomorphology.* Oxford: Basil Blackwell. 1988, 11-42.

[154] R.I. Ferguson, 'Channel form and channel changes.' In John Lewin, Ed. *British Rivers.* London: George Allen & Unwin. 1981, 119.

[155] A.D. Knighton, 'River Channel Adjustment - the Downsteam Dimension.' In Keith Richards, Ed. *River Channels. Environment and Process.* The Institute of British Geographers Special Publications Series No. 18. Oxford: Basil Blackwell. 1987, 109.

width normally increases and the depth is reduced.[156] However 'the reaction of a [particular] channel to altered discharge and type of load may result in changes of channel dimensions contrary to those indicated by the standard regime equations.'[157]

In the 12th, 13th and the first half of the 14th centuries the amount of arable farming increased and this may have caused an increase in sediment in the rivers. The resulting change in form may have reduced the navigability of some sections of rivers. Brookes wrote that 'During the 14th and 15th centuries extensive silting of rivers is generally thought to have occurred, at least partly as a result of changing land use, and several acts were passed to aid navigation.'[158] In the early 17th century it was the law that boatmen could scour the bed of a stream so that they could pass.[159] If they were regularly using a river this would seem to imply that there was significant sedimentation.

The usability of different sections of a river may vary as a pulse of sediment passes down the river. Empirical evidence has shown that pulsed inputs to alluvial storage may result from climate and erosion system fluctuation. These may be triggered by individual extreme climatic events or by agricultural or forestry activities or the input of mining wastes.[160] For example in south-west Britain the removal of grassland on hill slopes is estimated to have increased soil movement by about 400 times.[161]

The form of many rivers varied during the period 1189-1600 due to changing climate and changing land use. Macklin and Lewin note that 'it is probably true to say that there is no matter of prime significance to the river engineer (and for that matter the geomorphologist) on which ignorance is so profound as that of climate change and

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[156] Stanley A. Schumm, *The Fluvial System.* London: John Wiley & Sons. 1977, 135.
[157] *Ibid.* page 134.
[158] Andrew Brookes, *Channelized Rivers. Perspectives for Environmental Management.* Chichester: John Wiley & Sons. 1988, 12.
[159] 'Repair of Bridges, Highways, &.' [1610] Coke Rep. XIII, 33.
[160] Mark G. Macklin and John Lewin, 'Sediment transfer and transformation of an alluvial valley floor: the river South Tyne, Northumbria, U.K.' *Earth Surface Processes and Landforms.* Vol. 14, (1989), 233 – 246, 233.
[161] M.A. Carson, & M.J. Kirkby, *Hillslope Form and Process*, 217 (Cambridge University Press, 1972). Cited in M.A. Robinson, G.H. Lambrick, 'Holocene alluviation and hydrology in the upper Thames basin.' *Nature.* Vol. 308, (26 April 1984), 811.

how it affects river form and process.'[162] In the short term it will not be possible to establish the reason for each change. There is no record that traffic was transferred from water to land transport due to rivers, other than ponded rivers, becoming less usable.

The extent of out of channel alluviation has varied over time. It raises the level of the flood plain often leaving a deeper channel.[163] No record has been found of the usability of a river being changed in this way, but due to the slow rate of alluviation such change would be unlikely to have been noticed or recorded.

[162] Mark G. Macklin and John Lewin, 'Channel, Floodplain and Drainage basin Response to Environmental Change.' In Colin R. Thorne, *et al*, Eds. *Applied Fluvial Geomorphology for River Engineering and Management.* Chichester: John Wiley & Sons. 1997, 38.
[163] A.G. Brown and M. Keough, 'Holocene floodplain metamorphosis in the Midlands, United Kingdom.' *Geomorphology.* Vol. 4, (1992), 441.

2.4.8 Medieval hydrology

In addition to the above changes there were also deliberate attempts to improve the usability of rivers. One well known example was on the Thames at Abingdon where prior to c.1053 there was a short section of the river which was of higher gradient than the sections above and below and so boats could not pass in the dry season. While the creation of the diversion is well known no one seems to have appreciated the brilliance of the person who conceived the scheme. Nor has any estimate been found of the number of boats which must have been using that section of the river at that time to justify the expenditure of digging the new channel. The channel which was dug was about 2 km in length and wide and deep enough to take the flow of the Thames. It seems that the number of boats using that section of the Thames in the mid 11th century must have been counted in hundreds rather than tens. Nowhere else has an example been found of a section of river being bypassed by a longer and/or narrower channel to provide a passage with deeper water.

There was a good knowledge of hydrology in the 11th to 13th century. A new supply of fresh water for Sandwich was created in 1285. Meyer has commented that 'No writer appears to have appreciated the astounding skill of the engineers who carried out the work.'[164] The same could be said of those who set out the streets of Salisbury in 1220 so that water flowed through them. Blair and Bond have described the many canals which were built at that time.[165] These, and especially the one at Bampton, must have been built by people with understanding. It seems that this understanding would be obtained only by people who were using rivers regularly.

However that does not mean that everyone in the country had a good knowledge of hydrology. There has been much discussion as to whether there was a canal from Winchester to Southampton. But little attention seems to have been paid to the findings of a jury in 1276:

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[164] George M. Meyer, 'Early water-mills in relation to changes in the rainfall of East Kent.' *Quarterly Journal of the Royal Meteorological Society.* Vol. 53, (1927), 412.
[165] John Blair, 'Transport on the Upper Thames.' In Blair, 2007, 254-294.
James Bond, 'Canal Construction in the early Middle Ages: An Introductory Review.' In Blair, 2007, 153-206.

> 'The jurors summoned on an Inquisition *ad quod damnum* (4 Edw. I) said that they did not think the citizens of Winchester would be able to bring the flood and ebb of the sea as far as their city. They might, however, be allowed by the king to bring it to Stoke, distant 4 leagues from Southampton, on the way to Winchester. The jurors also said that this must harm the bishop, because it would be necessary to remove a mill called the Wodemilne, worth £5 a year, and a salmon fishery of the annual value of 10 marks, and … [six other named mills of given value]. Finally, the jury also declared that it would not be necessary to widen the water-course, but rather to make it more narrow and deepen it in various places.[166]

The difficulty of bringing 'the flood and ebb of the sea as far as their city' is seriously under-estimated. Winchester is 30 m above sea level and the tidal range at Springs at Southampton 13ft (4 m).[167] Such an objective is impossible.

However 'the jury also declared that it would not be necessary to widen the water-course, but rather to make it more narrow and deepen it in various places.' This implies either a remarkably good appreciation of hydrology or a memory of a previous state of the river. In view of their ignorance about the tides the second seems more likely. This may imply that previously the river had been used for transport but that the banks had been eroded by those towing the barges so the river became wider, shallower and unusable.

Rhodes has shown that it is not easy to identify where there has been human modification of river channels.[168]

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[166] *VHC Hampshire and the Isle of Wight, Vol. V,* 451-452.
[167] F.H.W. Green, 'Tidal Phenomena With Special reference to Southampton and Poole.' Reprinted from *The Dock & Harbour Authority*. September 1951.
[168] Ed Rhodes, 'Identifying Human Modification of River Channels.' In Blair, 2007,133-152.

2.4.9 Summary

The usability of many rivers has been improved by canalisation, but most other anthropogenic modifications have either lessened the usability of rivers or made no change. At present the frequency of dredging and channel clearance in rivers varies with the environment and the rate of sedimentation. It also varies with the finance available and the perceived pressure for the avoidance of flooding. Some of the clay streams of East Anglia carry much sediment and require dredging every five to ten years[169] but it seems that in general rivers are scoured about every twenty years although there is a wide range of frequencies.[170] No evidence has been found as to the frequency of the scouring of most rivers in the period 1189-1600.

It seems that on those rivers which have not been canalised channel shortening, channel widening, scouring and the cutting of in stream vegetation have reduced the depth and so the usability of the rivers since 1600. It has not been possible to assess the effect of the possible removal of bank vegetation and of aggradation and degradation as a result of land use changes on the usability of rivers. The skills of the medieval hydrologists seem to indicate a familiarity with using the rivers.

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[169] Andrew Brookes, *Channelized Rivers. Perspectives for Environmental Management.* Chichester: John Wiley & Sons. 1988, 37.
[170] Personal comment from a staff member of the Environment Agency. 2004.

Chapter 2.5 Channel Pattern and Usability

2.5.1 Braided rivers

It has been stated that the lowland floodplains show little evidence of change during the Roman and medieval periods.[171] However this may be challenged since the evidence for this stability comes from structures like settlements, quays, bridges and weirs which themselves cause the rivers to be stable.[172] The normal post-glacial, autogenic, sequence of river pattern was braided - multi-channel - single-channel[173] with varying processes causing the changes.[174] The changes occurred at different times in different catchments.[175] 'Braided' refers to rivers with beds of gravel or cobble as bed material and where the flow at low stage is multi-channel.[176] Thus only the large braided rivers would have been usable. There is now no usable braided river in England.[177]

It used to be thought that the distinction between braided and meandering rivers could be established from their discharge and slope.[178] It is now known that there is no sharp threshold between channel patterns and that pattern also depends on sediment supply, bed material, the erodibility of the banks, width/depth ratio and the time variability of flow.[179] This complexity is enhanced in the study of palaeochannels

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[171] A.G. Brown, 'Floodplain Palaeoenvironments.' In Malcolm G. Anderson, Des E. Walling and Paul D. Bates, Eds. *Floodplain Processes.* Chichester: John Wiley & Sons. 1996, 125.
[172] A.G. Brown, *Alluvial geoarchaeology.* Cambridge: Cambridge University Press. 1997, 227.
[173] J. Vandenberghe, 'Timescales, Climate and River Development.' *Quaternary Science Review.* Vol. 14, (1995), 631-638.
[174] John Lewin, 'Changes of channel patterns and floodplains.' In K.J. Gregory, Ed. *Background to Palaeohydrology.* Chichester: John Wiley & Sons. 1983, 303.
[175] M.G. Macklin *et al*., 'The condition of Holocene alluvial archaeology in the UK: progress, constraints and opportunities.' In Andy J. Howard, *et al*., Eds. *Alluvial Archaeology in Europe.* Lisse: A.A. Balkema Publishers. 2003, 10-11.
[176] David S.G. Thomas and Andrew Goudie, Eds. *The Dictionary of Physical Geography.* 3rd Edition. London: Blackwell Publishing. 2000, 62.
[177] R.I. Ferguson, 'Channel form and channel changes.' In John Lewin, Ed. *British Rivers.* London: George Allen & Unwin. 1981, 113.
[178] L.B. Leopold and M.G. Wolman, 'River channel patterns - braided meandering and straight.' *Prof. Pap. U.S. Geol. Surv.* 282-B. 1957. Cited in G.H. Cheetham, 'Palaeohydrological investigations of river terrace gravels.' In D.A. Davidson and M.L. Shackley, Eds. *Geoarchaeology.* London: Duckworth. 1976, 336.
Rob Ferguson, 'Hydraulic and Sedimentary Controls of Channel Pattern.' In Keith Richards, Ed. *River Channels. Environment and Process.* Oxford: Basil Blackwell. 1987, 129.
[179] Colin R. Thorne, 'Channel Types and Morphological Classification.' In Colin Thorne, *et al*., Eds. *Applied Fluvial Geomorphology for River Engineering and Management.* Chichester: John Wiley & Sons. 1997, 206.

where the flood-dependent nature of the channel patterns makes the determination of the channel pattern at mean flow difficult or impossible.[180]

Clear evidence of the existence of braided rivers since the 12th century formed by these processes has only been found for the Tyne and Swale. These are considered first and then the Trent is considered with its braided pattern caused by sediment flow from its tributaries. Finally the existence of braiding on other rivers is considered.

A. River Tyne

Macklin observed that some sections of the Tyne were braided in the late Roman period, the 13th and 14th centuries and also in the late 18th and 19th centuries. This was linked to the increased rate of coarse sediment supply due to increased bank erosion caused by land-use changes, trunk stream incision and metal mining. Hushing, when overburden was washed into streams, was an important source of sediment.[181] However Passmore considered that the timing of recent historic braiding and instability appears to be related to changes in flood frequency and magnitude due to climatic variation.[182] While most of the braiding occurred in the upper river it appears that there was braiding as far downstream as Low Prudhoe in the middle of the 15th century.[183] Macklin and Needham considered that the reduction in the 20th century in the degree of braiding in the South Tyne was partly due to the cessation of metal mining.[184]

The few historic records of use of the middle Tyne are predominantly from the Roman era which may indicate that this section of the river became less usable due to the channel becoming braided.

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[180] Rob Ferguson, 'Hydraulic and Sedimentary Controls of Channel Pattern.' In Keith Richards, Ed. *River Channels. Environment and Process.* Oxford: Basil Blackwell. 1987, 154-155.
[181] M.G. Macklin, 'Fluvial geomorphology of north-east England.' In K.J. Gregory, Ed. *Fluvial Geomorphology of Great Britain.* London: Chapman & Hall for Joint Nature Conservation Committee. 1997, 205.
[182] David G. Passmore *et al.* 'Variability of late Holocene braiding in Britain.' In J.L. Best, C.S. Bristow, Eds. *Braided Rivers.* Geological Society Special Publication Number 75. 1993, 227.
[183] *Ibid.* page 225.
[184] Mark G. Macklin and Stuart Needham, 'Studies in British alluvial archaeology: potential and prospect.' In Stuart Needham and Mark G. Macklin, Eds. *Alluvial Archaeology in Britain.* Oxbow Monograph 27. (1992), 18.

B. River Swale

During part of the medieval period the river at Catterick on the Swale was a braided channel. Taylor and Macklin established that between about 1550-1670 there was a phase of coarse sediment deposition which altered the pattern to an avulsing single-thread channel.[185] The river downstream of Catterick has a mean flow of 13 $m^3 sec^{-1}$ and gradient 3 m km^{-1} and if it had had a single uniform channel it would probably have been usable. Use of the river to Easby Abbey may have depended on the varying state of the braiding of the river. The river is unusual in that its use past Richmond would not have been possible due to steps in the bedrock river bed. Use upstream of Richmond would have been by small boats only.

C. River Trent

Observations made at Hemington,[186] 18 miles upstream, and Colwick,[187] 2 miles downstream of Nottingham, have shown that there was a cyclic phase of channel change from single channel meandering to active braiding to fixed multi-channel state and finally back to a single channel meandering state. This cycle took place over 300-400 years between the 9th and 14th centuries at Hemington and 100-200 years later at Colwick. The cycle was driven by a series of large floods which coincided with the Late Medieval Climatic Deterioration. This channel response is considered to be unique for a large lowland river in England and almost certainly resulted from sediment brought down by the Dove and Derwent.[188]

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185 M.P. Taylor and M.G. Macklin, 'Holocene alluvial sedimentation and valley floor development: the River Swale, Catterick, North Yorkshire, UK.' *Proceedings of the Yorkshire Geological Society.* Vol. 51, Part 4. (1997), 326.

186 Lynden Cooper, *et al.* 'The Hemington Bridges.' *Current Archaeology.* Vol. 140, (November 1994) 316-321.

Patrick Clay, 'Medieval bridges at Hemington Quarry, Lockington-Heminton, Leicestershire.' http://www.eng-h.gov.uk/archcom/projects/summarys/htm196_7/1572anl.htm. Accessed 11/10/2004.

187 Andy Howard, 'The Contribution of Geoarchaeology to Understanding the Environmental History and Archaeological Resources of the Trent Valley, U.K.' *Geoarchaeology.* Vol. 20, (2005), 93-107.

A.G. Brown, 'Human dimensions of Palaeohydrology.' In Bransom J. *et al.* 'Global continental Changes: the Context of Palaeohydrology.' Geological Society Special Publication No 115. (1996), 57-72.

188 A.G. Brown *et al*, 'Late Holocene channel changes of the Middle Trent: channel response to a thousand-year flood record.' *Geomorphology,* Vol. 39, (2001), 79.

A.G. Brown, 'Geoarchaeology, the four dimensional (4D) fluvial matrix and climatic causality.' *Geomorphology.* Vol. 101, (2008), 286.

The gravel extraction sites at Hemington and Colwick appear to be the only sites at which detailed observations have been made. It seems likely that the braiding on the Trent progressed downstream over a period of time. Understanding of the full extent and timing of braiding on the Trent must await further observations.

Charters granted by Henry II (1189) and King John (1200) to the Borough of Nottingham provided for a usable channel two perches wide ‘in the waters of Trent’.[189] In 1265 and 1292 there were complaints that the channel downstream of Nottingham was narrowed by weirs so that boats could not ‘pass so conveniently as they were wont’.[190] A more serious obstruction was created by a weir erected by William of Colewyk which produced four complaints to the King[191] in the years 1299 to 1303. A commission which was appointed in 1383 to investigate an apparently different obstruction at Colwick[192] stated that ‘the waters of Trent … has been used and ought to hold its course from the place where it takes its source to the castle and town of Nottingham’ and from thence to the sea.[193] Edwards gives 38 references to records of the use of the river downstream from Nottingham for the 14th century.

In c.1535 Leland crossed the Trent at Hoveringham, 13 miles downstream of Nottingham, *per cymbam* (a boat used for coffins) and his horse crossed *per vadum* (a ferry).[194] In 1592 there was a ‘great and unlawful assembly’ to pull down a weir at Shelford just downstream of Nottingham[195] presumably because it was obstructing the passage of boats and barges. Despite the braiding of the river it seems that

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[189] *Records of the Borough of Nottingham. Volume I.* Editor W.V. Steveson. Nottingham: Corporation of Nottingham. 1882.

[190] Calendar of Patent Rolls, 1258-66, 480.
Calendar of Inquisitions Miscellaneous, 1219-1307, 442.

[191] Calendar of Patent Rolls, 1292-1301, 476-477, 555.
Calendar of Patent Rolls, 1301-1307, 94, 269.

[192] Bernard Smith, ‘Some Recent Changes in the course of the Trent.’ *The Geograhical Journal.* Vol. 35, (May, 1910), 572.

[193] ‘Royal Commission to inquire into Obstructions of the course of the Trent at Colwick.’ (1383). In *Records of the Borough of Nottingham. Volume I* Editor W.V. Steveson. Nottingham: Corporation of Nottingham. 1882.

[194] *The Itinerary of John Leland in or about the years 1535-1543. Volume Four.* Editor Lucy Toulmin Smith. Carbondale: Southern Illinois University Press. 1964, 18.

[195] *Acts of the Privy Council,* 1592, pp. 16, 148; 1592-3, pp. 201, 243, 440. Cited in A.C. Wood, ‘The History of Trade and Transport on the River Trent.’ *Transactions of the Thoroton Society.* Vol. 54. 1950. 1 – 44, 7.

downstream of Nottingham there was always at least one channel deep enough to be used.

Upstream of Nottingham there are few references to the use of the river.[196] A boat was stolen at Barton six miles up river from Nottingham in 1313[197] and in 1338 a pontage grant was made at Swerkeston for goods coming to the town 'by water as by land'.[198] Possibly Wood described this trade accurately when he wrote 'We possess no clue to the volume of all this early river traffic. No doubt it was comparatively small, and for the most part localized in scope.'[199] It seems that upstream of Nottingham use was restricted to small boats at the confluence with the Derwent and Dove and that the use of these boats was not normally recorded.

D. <u>Other Rivers</u>

While the braiding of the Trent seems to have been unique for a lowland river, the braiding on the Tyne and Swale may be typical of the rivers of the North East and other Highland Regions. Dramatically increased sediment supply due to mining has caused well documented changes in channel form in other countries which involved a change from meandering to braided channel pattern with a period of aggradation being followed by incision and reversion to a single channel in less than a century.[200] Mining was carried out in many northern valleys[201] with over a hundred mines in Weardale alone.[202] The period of time during which the river form would have

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[196] Guy Y. Hemingway, 'History of the navigation of the River Trent.' Typescript held by the University of Nottingham. 197?, 17.
[197] Calendar of Patent Rolls, 1313-1317, 72.
[198] Calendar of Patent Rolls, 1338-1340, 22.
[199] A.C. Wood, 'The History of Trade and Transport on the River Trent.' *Transactions of the Thoroton Society.* Vol. 54, (2007), 7.
[200] Mark G. Macklin and John Lewin, 'Channel, Floodplain and Drainage Basin Response to Environmental Change.' In Colin Thorne, *et al*., Eds. *Applied Fluvial Geomorphology for River Engineering and Management.* Chichester: John Wiley & Sons. 1997, 31-32.
[201] Arthur Raistrick, Bernard Jennings, *A History of Lead Mining in the Pennines.* London: Longmans. 1965.
John Postlethwaite, *Mines and Mining in the English Lake District.* (1st Edition 1877.) Whitehaven: Michael Moon's Bookshop. 1983.
John Adams, *Mines of the Lake District Fells.* 2nd Edition. Skipton: Dalesman Publishing Company. 1995.
[202] R.A. Fairbairn, *Weardale Mines.* British Mining No. 56. Northern Mine Research Society. 1996.

changed due to mining varied.[203] In 1997 Macklin commented on the lack of research into the palaeogeomorphology of these northern rivers[204] and few records of studies carried out since then have been found.[205] Lack of records of historic use of these rivers may be due to the fact that the rivers were impassable due to braiding during certain periods.

In the South-West silt blocked some river channels. Camden recorded that the Dart 'carrieth downe with it certaine grit, and sand out of the Tin-mines, (which by little and little choke up the channel) through the Forrest of Dortmore.' He also stated that 'beyond Totnes bridge' there are whole heaps of sand brought down by the river.[206] On this river it seems that the channel was braided or multi-channel and not passable.

2.5.2 Multi-channel rivers

The word multi-channel is used here rather than anabranching or anastomosing since the origin of the divided channels is often obscure. Many of the islands in rivers have been created by the construction of new channels for mills or fish-weirs.[207] On the other hand many multi-channel rivers have been modified to flow in a single channel because river engineers have followed Tulla's concept that 'As a rule, no stream or river needs more than one bed'.[208] A large multi-channel river is more usable by small boats than a single channel river, especially travelling upstream, but less usable by a barge or boat which is near the size limit for the river. It seems that journeys by large vessels are more likely to be recorded than those of small boats and so a multi-channel river pattern may result in apparent disuse.

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[203] J. Lewin, *et al.*, 'Regime Theory and Environmental Change - Irreconcilable Concepts?' In W.R. White, Ed. *International Conference on River Regime.* Chichester: John Wiley & Sons, on behalf of Hydraulics Research Limited. 1988, 433.
[204] M.G. Macklin, 'Fluvial geomorphology of north-east England.' In K.J. Gregory, Ed. *Fluvial Geomorphology of Great Britain.* London: Joint Nature Conservation Committee, Chapman& Hall. 1997, 203.
[205] Andy J. Howard, *et al.* 'Holocene river development and environmental change in Upper Wharfedale, Yorkshire Dales, England.' *Journal of Quaternary Science.* Vol. 15 (3), (1999), 239-252.
[206] William Camden, *Britain.* Trans. Philemon Holland, London: Joyce Norton, and Richard Whitaker. 1637, 201, 202.
[207] A.G. Brown, *Alluvial Geoarchaeology.* Cambridge: Cambridge University Press. 1997, 259.
[208] Tulla, 1817, Cited in H. Ryckborst, 'Geomorphological changes after river-meander surgery.' *Geologie en Mijnbouw.* Vol. 59, (1980), 121-128.

Geomorphologists have shown that during the Bronze and Iron Ages the Middle Nene floodplain was transformed from a stable, multiple channel system covered by dense woodland, to a cleared agricultural landscape with managed channels.[209] However the river continued to be multi-channel and meandering during the period 1189-1600.[210] Similarly the Lower Welland[211] and Gipping[212] were multi-channel during the medieval period until they were modified by land drainage.

Historians have shown that in the 16th century the Medway was used to just downstream of Tonbridge.[213] It is also known that the river was divided into several channels at Tonbridge.[214] No record has been found of use of the river upstream of Tonbridge.

There is an absence of evidence of the use of the Soar despite a flow at Kegworth of 12.2 $m^3 s^{-1}$ and gradient of 0.6 m km^{-1}. In 1693 a two mile section near Loughborough was described as being as broad as the river at Hackney Marsh but divided into 'many little channels'.[215] It seems likely that if these islands existed for the previous five hundred years they would have obstructed the use of barges.

Few barges seem to have used the Great Ouse to Bedford where the mean flow is 10 $m^3 s^{-1}$ and gradient 0.6 m km^{-1}. In c.1543 Leland wrote 'Ther be many holmes,

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209 A.G. Brown and M.K. Keough, 'Palaeochannels and palaeolandsurfaces: the geoarchaeological potential of some Midland floodplains.' In Stuart Needham and Mark G. Macklin, Eds. *Alluvial Archaeology in Britain.* Oxbow Monograph 27. (1992), 195.

210 Anthony G. Brown, 'Colluvial and alluvial response to land use change in Midland England: An integrated geoarchaeological approach.' *Geomorphology.* (2009). Consulted in draft. Doi:10.1016/j.geomorph.2007.12.021. Accessed 23/9/2009.

211 C.A.I. French, *et al.* 'Archaeology and palaeochannels in the Lower Welland and Nene valleys: alluvial archaeology at the fen-edge, Eastern England.' In Stuart Needham and Mark G. Macklin, Eds. *Alluvial Archaeology in Britain.* Oxbow Monograph 27. 1992, 169-176.
A.G. Brown, *et al.* 'Floodplain Evolution in the East Midlands, United Kingdom: The Late Glacial and Flandrian Alluvial Record from the Soar and Nene Valleys.' *Philosophical Transactions of the Royal Society of London.* A Series. Vol. 348. (1994), 261-293.
Mark Robinson, 'Environment, archaeology and alluvium on the river gravels of the South Midlands.' In Stuart Needham and Mark G. Macklin, Eds. *Alluvial Archaeology In Britain.* Oxbow Monograph 27. 1992, 197-208.

212 C.A.I. French, 'Archaeology and palaeochannels in the Lower Welland and Nene valleys: alluvial archaeology at the fen-edge, Eastern England.' In Stuart Needham and Mark G. Macklin, Eds. *Alluvial Archaeology in Britain.* Oxbow Monograph 27. (1992). 173.

213 Joan Thirsk, Ed. *Hadlow Life Land and People in a Wealden Parish 1460 – 1600.* Kings Lynn: Heritage Marketing & Publications Ltd. 2007, 55.

214 William Camden, *Britain.* Trans. Philemon Holland. London: Ioyce Norton and Richard Whitaker. 1637, 330.

215 John Houghton, 'Leading Article.' *A Collection for Improvement of Husbandry and Trade.* Number 46. 16 June 1693.

otharwyse little isles, in the river betwixt Bedforde and Newham'.[216] Newham is downstream of Bedford. The existence of these little islands seems not to have been previously noted.[217] But the fact that barges could not reach Bedford due to the islands may explain why fords and mill dams were not removed from places further downstream. There transport could be provided by small boats using the river between the dams either with the boats being portaged past the weirs or by transferring the loads to other vessels.[218]

In addition reports have not been found of the use of the Cam by barges upstream of Cambridge. Camden records that the river Cam had 'most pleasantly sprinkled the west side of Cambridge with several little isles'.[219] It is possible that it was the limited size of the channels between these islands which limited the use of barges upstream of Cambridge and so permitted the retention of the mills at Silver Street.

It seems likely that multi-channel sections existed on other rivers which have not been recognised. This is particularly true of the rivers which were used in the 17th century for floating water meadows. This practice was introduced on the Itchen, Test, Salisbury Avon and other river valleys.[220] No work has been found which describes the previous form of these rivers.

On the other hand, the fact that a river was multi-channel does not imply that it was unusable. It is known that the Lea divided into at least six channels in parallel at Stratford and yet it was still usable.[221] Other were usable upstream of the multi-channel section as on the Soar at Leicester.

Many divided rivers result from the cutting of mill streams as on the Eastern Rother upstream of Robertsbridge, the Cam upstream of Cambridge, the Kentish Stour at

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216 *The Itinerary of John Leland in or about the years 1535-1543. Volume Four.* Editor Lucy Toulmin Smith. Carbondale: Southern Illinois University Press. 1964, 33.
Copied by: Raphaell Holinshed, William Harrison *et al. The First and Second Volumes of the Chronicles.* 2nd Edition. London: J. Johnson *et al.* 1807, 173.
217 eg. Dorothy Summers, *The Great Ouse.* Newton Abbot: David & Charles. 1973.
218 *Simpson* v *A-G* [1904] AC 476-515.
219 William Camden, *Camden's Britannia.* Trans. and Ed. Edmund Gibson. London: F. Collins. 1695, 404.
220 Eric Kerridge, *The Farmers of Old England.* London: George Allen & Unwin Ltd. 1973, 110-115
221 Stephen Pewsey, *Stratford A Pictorial History.* Chichester: Phillimore. 1993, Plate 3.

Wye and the Sussex Ouse at Barcombe Mills. In general, where a river has been modified by the creation of a mill stream the main channel has reduced its width and depth due to the reduced flow.[222] However it would seem that normally the change was too small to affect the use of the river. Thus on the Severn there were usable barge-gutters at every mill and fish-weir.[223]

Peberdy has noted 'that many (all?)' of the fish weirs and mills on the Thames were constructed at points where islands occurred.[224] There seems to have been no research as to whether these channels are natural or anthropomorphic modifications to the river channel.

Many towns were built where there was an island, or islands, in usable rivers. Speed in his maps of 1605-10[225] showed the main towns of some counties as inset maps. These show 27 towns built on usable non-tidal rivers at points where there were islands[226] and only 3 where there was no island.[227] Again there seems to have been no study to establish whether these islands were natural or not.

2.5.3 Rivers with pool and riffle form

So far it has been assumed that boats always floated when in use. But this assumption is correct only for certain types of bed material. If the water is not deep enough for a boat to float on a river with a bed of clay or silt there is considerable frictional resistance to the movement of the boat and the river may be considered to be unusable. However if the bed is of gravel, cobbles or boulders a boat may be dragged up the river with the water lubricating the contact points between the river bed and boat. This is particularly true if the section which is shallow is short as on pool and riffle rivers as defined in Section 1.2.3.

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[222] G.H. Dury, 'Magnitude-Frequency Analysis and Channel Morphometry' In Marie Morisawa, Ed. *Fluvial Geomorphology.* London: George Allen & Unwin. 1973, 91 – 121.
[223] Brian Waters, *Severn Stream.* London: J.M. Dent and Sons Ltd. 1949, 68.
[224] Robert Peberdy. Private correspondence. 4 December 2006.
[225] John Speed, *Theatre of the Empire of Great Britaine, Parts I, II, III and IV.* (1st Edition 1611.) Facsimile London: Phoenix House Limited. 1953-4.
[226] Winchester, Newport, Dorchester, Exeter, Bath, Salisbury, Gloucester, Canterbury, Norwich, Hertford, Buckingham, Reading, Cambridge, Bedford, Oxford, Worcester, Warwick, Northampton, Peterborough, Huntingdon, Ely, Stanford, Leicester, Shrewsbury, Lincoln, Nottingham, Derby.
[227] Hereford, Stafford, Durham.

Selkirk records that when he was carrying out archaeological investigations on the Tyne a gentleman walked up the centre of the river across some shallows towing a fairly large rowing boat containing several hundredweight of eels. When he reached a section of the river where the water was deeper he re-entered his boat and continued rowing upstream.[228] Both fishing and load-carrying boats were certainly dragged up the shingle beaches above tide level in medieval times as they are now. Haslam claims that river beds were also used by horse and cart.[229]

Today if a vehicle moves on land it is normally assumed that it has wheels and if it moves on water it is assumed that it floats. However greater use of sledges in the past may have been paralleled by the more frequent dragging of boats up short sections of shallows and round obstructions. It was reported that in the last quarter of the 12th century mares were offered for sale in London for pulling sledges.[230] Parsons wrote that that in the medieval period sledges were used to move stone and slate around quarries and building sites.[231] In 1394 the vicar and churchwardens of Beverley were given permission to transport stones from the Beck to the Minster provided the stones were carried on sleds (*cum sleddis*) and providing that they never requested permission to do so again.[232] The Fabric Rolls show that in c.1395 stone was taken on sledges from the 'Seint Lenard lendyng' to York Minster.[233] Fiennes saw and recorded that in the late 17th century sledges were the only vehicles allowed to be used to carry goods in Southampton and that carts were forbidden.[234] She also recorded that at the same date most goods in Bristol were carried on sledges.[235] In 1853 Dickinson wrote of Cumberland 'Only yeomen and the larger occupiers could boast of carts; the produce of the farms, hay, corn and peat being brought in on railed

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[228] Raymond Selkirk, *Chester-Le-Street & its place in history.* Durham: Casdec Printcentre. 2001, 259.
[229] S.M. Haslam, *The Historic River.* Cambridge: Cobden of Cambridge Press. 1991, 118.
[230] William Fitzstephen, c.1175. Printed in John Stow, *Survey of London.* 1598. Cited in Jeanne Krochalis and Edward Peters, Eds. *The World of Piers Plowman.* Philadelphia: University of Pennsylvania Press. 1975, 30.
[231] David Parsons, 'Stone.' In John Blair and Nigel Ramsey, Eds. *English Medieval Industries.* London: Hambledon. 1991, 6.
[232] *Beverley Town Documents.* Editor Arthur F. Leach. Selden Society. Vol. 14, (1900), 24.
[233] Fabric Rolls of the Minster of York (Surtees Society). p 2. Cited in L.F. Salzman, *Building in England down to 1540.* Oxford: Clarendon Press. 1952, 351.
[234] Celia Fiennes, *Through England on a Side Saddle.* London: Field & Tuer. 1888, 42.
[235] *Ibid.* 199.

sledges and the more portable article on pack horses.'[236] A sledge was used for transporting hay in the Yorkshire Dales in 1952-54.[237] It seems that the use of sledges in England may have been more frequent than the standard texts on transport imply. Equally there has been no investigation into the extent to which the beds of rivers were used as trackways for sledges nor to what extent boats were dragged up riffles.

Archaeological evidence shows that at Skenfrith on the Monnow a wharf and slipway were constructed in c.1190 when stone was being transported for the building of the castle.[238] Stone, from his study of the papers of the Duke of Rutland, wrote that when iron smelting was developed at Rievaulx the processed iron was transported down the Rye by boat.[239] The Rye at Rievaulx now has similar form to the Monnow at Skenfrith. On both rivers at normal flow the boats would have scraped over the stones at the riffles, if the rivers had the same pool and riffle form that they have now.

In 1586 Harrison, the vicar of Radwinter,[240] wrote of the Pant that 'Certes by the report of common fame it hath been a pretty water and of such quantity that boats have come in time past from Beeleigh Abbey beside Maldon unto the moors in Randwinter for corn.' It seems that the boats would not have floated all the way but they could have been dragged. How often, and in how many places, boats were dragged over obstructions, or up riffles, is not known. But it is known that boats were dragged considerable distances on land. Flemming-Yates claimed that in the reign of Mary Tudor a weir was built on the Wye at Monmouth. She wrote that for the next one and a half centuries boats were hauled ashore and then dragged a hundred yards upstream by oxen before being refloated.[241]

Several of the recent limits of use for rivers of pool and riffle form are well upstream of the records of historic use as on the Tees, Wharfe, Swale, Ure, Derbyshire

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[236] William Dickinson, *Essays on the Farming of Cumberland.* (1853). Cited in David Hey, *Packmen, Carriers and Packhorse Roads.* Leicester: Leicester University Press. 1980, 93.
[237] By Mr Porritt, Sparrow Farm, Scugdale, North Yorkshire. Personal comment: Mrs K.E. Caffyn. November 2009.
[238] Phil Evans and Kevin Trott, 'Excavations at Skenfrith Castle, 2003.' Report of a CADW sponsored excavation. Paper unpublished at July 2008.
[239] Lawrence Stone, *Family and Fortune.* Oxford: Clarendon. 1973, 194.
[240] William Harrison, *The Description of England* Editor Georges Edelen,. (1st Edition 1968). Washington: The Folger Shakespeare Library and New York: Dover Publications Inc. 1994, 3.
[241] Joan Fleming-Yates, *The River Running By.* No address: Wedderburn Art Ltd. c.2005, 96.

Derwent, Exe, Torridge, Ribble and Eden. However on the Tyne, Wear, Rye, Nidd, Taw, Teme and Monnow they are at similar places. It has not been possible to establish whether there was a genuine difference in the use of these two sets of rivers or whether the difference lies in the recording of the use.

Similar considerations apply to the records of use of the Tweed, Eden and Esk where frequent periods of fighting may have reduced the use of the rivers and/or may have reduced the recording of their use.

2.5.4 Summary

There have been considerable changes to the form of some rivers which have affected their usability. Braiding of the full width of a river channel would normally have made the channel unusable for much of the year. However at high discharge a braided river may have been suitable for use by flat-bottomed boats or for the floating of timber.

There have been few investigations of the extent of divided channels in the period 1189-1600. However it appears that the reduction in the depth of rivers caused by the existence of a multi-channel form may explain the lack of use of some rivers by barges. The existence of multi-channel forms in smaller rivers remains to be investigated but no section of river has yet been found where the usability was affected.

The historic use of rivers with a pool and riffle form is difficult to determine because it would be expected that they would only have been used by relatively small boats for which there are few records of use. However the recently established record of use of the Monnow at Skinfrith may encourage more investigations, or help the recognition, of other pool and riffle rivers which were used historically.

Chapter 2.6 Ponded Rivers and Meres

2.6.1 Introduction

The Coastal Wetlands have been well studied.[242] The rivers flowing towards them seem only to have been studied as incidental to the exploitation, modification and transformation of the land. The standard regime equations do not apply to these rivers and there seems to have been no attempt to establish why certain rivers became obstructed while others remained usable. There can be no sharp demarcation between marshes, meres, ponds and rivers. In about 4,000BC wetlands may have extended to 20% to 30% of the land area of England.[243]

In this thesis Ponded rivers are those where the gradient is under 0.3 m km^{-1}, water flows out of a section more because water has flowed into it rather than because of the slope. Some pre-estuary rivers flow against the gradient of the land because the land near the sea is higher than the land further from the coast.[244] The ponded rivers include some sections of rivers of the Humberside Estuary, Lincolnshire coastal rivers, the Fens, the Broads area of Norfolk, Romney Marsh, Pevensey Marsh, the Somerset Levels. Much of the land through which the rivers used to flow, or which they used to cover, has now been drained.

The natural state of some non-tidal Ponded rivers was meandering and braided with the channels partly choked with vegetation. The depth and extent of the water on the valley floor varied from the centre to the edge and according to the time of year. Some areas were seasonally flooded and others permanently covered with water. In the upper part of the valley peat would form. In some valleys, like the Hull, the lower boundary was relatively fixed. In others, like the Fens, the boundary moved

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[242] See eg. Stephen Rippon, *The Transformation of Coastal Wetlands.* Oxford: The British Academy by Oxford University Press. 2000.
 See the 'Wetland Heritage Series' commissioned by English Heritage. Somerset Levels, Fenlands, North West wetlands, Humber wetlands.

[243] A.G. Brown and C. Bradley, 'Past and Present Alluvial Wetland and the Eco-archaeological Resource: Implications from Research in East Midland Valleys, UK.' In Margaret Cox *et al.*, Eds. *Wetlands Archaeology and Nature Conservation.* London: HMSO. 1995, 189-206, 190.

[244] Stephen Rippon, *The Transformation of Coastal Wetlands.* Oxford: The British Academy by Oxford University Press. 2000, 15, 22.

according to the relative sea level and the growth of peat. In many of the valleys there were islands rising out of the marsh.[245]

Nine Ponded rivers are considered clockwise around England. All of these were usable at the end of the 12th century except the Hartlake which is an artificial channel created before the middle of the 13th century.[246] It is considered that all the major channels in the Fens had been formed before the end of the 12th century.[247] It is possible that the Hull, Witham and Ant were natural channels in 1189.

There is an increase in the number of records from the start of the 14th century indicating the need for maintenance work required to keep rivers usable.[248] In all these cases the work was to restore the channel to the state 'as it anciently used to be'. Whether this ancient state was natural or anthropologically modified is never stated. The increase in the number of records may have been due to the increase in the number of storms, a change in sea level, the improvement of law enforcement, an increase in the proportion of records which have survived, or a combination of these.

The questions considered here are: 'Did the rivers remain usable?' 'For those that remained usable did they require regular maintenance?' 'What factor(s) determined whether maintenance was needed?'

The factors considered are gradient, discharge and sediment load. These are listed in Table 6. The evidence considered is extracted from the Records of Historic Use (Appendix A) and contemporary reports of the rivers.

[245] Based on June A. Sheppard, *The Draining of the Hull Valley*. East Yorkshire Local History Series: No 8. 1958. Reprinted 1976, 1-3.
[246] Michael Williams, *The Draining of the Somerset Levels.* Cambridge: Cambridge University Press. 1970, 66.
[247] David Hall and John Coles, *Fenland Survey* London: English Heritage Archaeological Report 1. 1994, 137.
[248] *Ibid*, 136.

Table 6 Ponded River Data

	Gradient m km^{-1}	Discharge m^3 s^{-1}	Base Flow Index	Always usable	Maintained
Till/Foss Dyke	0	Low	n/k	No	Yes
Hull	0.31	3.4	0.85	Yes	No
Ancholme	0.125	0.6	0.53	No	Yes
Witham	0.15	17	n/k	No	No
Nene	0.16	9.3	0.51	No	Yes
Glen	0.33	1.18	0.6	Yes	Yes
Cam	0.14	2.86	*	Yes	No
Ant	0.22	0.3	0.87	No	Boats
Hartlake	0.1	1.1	0.67	Yes	Yes

Notes:-

Witham. Estimated. There is no discharge gauge downstream of Lincoln.

Ant. Boats. Maintained by boats passing along the river.

Cam. * See Section 2.6.11, paragraph 4.

Base Flow Index. A measure of the proportion of the river runoff that derives from stored sources.[249]

[249] *Hydrological Data UK 1996-2000.*

2.6.2 **River Till and the Foss Dyke**

It seems likely that the lower section of the river Till was initially a marsh. Through this marsh and continuing to Torksey a channel was dug which formed the Foss Dyke. It is not known when it was constructed nor to what extent the early canal used the channel of the river Till. The channel was regularly obstructed when it was not maintained. Sawyer relying on contemporary reports wrote that a fair was held at Torksey at the west end of the canal in the 8th and 9th centuries when it appears the channel was clear. The lack of coins of the following two centuries and the lack of 10th century Torksey pottery at Lincoln may indicate that the canal was then blocked. On the basis of archaeological finds it seems that the canal may have been open in the early 11th century.[250] It was open in 1066[251] yet was blocked again before it was reopened in 1121 by Henry II.[252] After that date it seems that it was normally usable by small boats in winter but often not usable by large boats in summer. Possibly it was cleared in 1273, 1329, 1365, 1395 and 1518.[253] Dugdale, citing the Patent Rolls of 1366, stated that at times the banks were degraded into the channel by cattle.[254]

No study has been found of the history of the effect of tides on the Foss Dyke. Torksey is below the tidal limit of the Trent. There is some doubt as to whether the tidal range of the Witham reached to Lincoln. No record has been found of there having been gates on the Dyke before 1600 nor any mention of the tides.

2.6.3 River Hull

Sheppard relying on contemporary reports wrote that in the 12th century a creek was deepened from Beverley to the Hull so that sea-going vessels could reach the town.[255] This implies that the Hull was already usable. In 1150 an island in the Hull valley was granted to the Cistercian monks who shortly after dug channels, or enlarged

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[250] Peter Sawyer, *Anglo-Saxon Lincolnshire.* Lincoln: History of Lincolnshire Committee. 1998, 197.
[251] H.C. Darby, *Domesday England.* Cambridge: Cambridge University Press. 1977, 301.
[252] *The Annals of Roger de Hoveden. Volume1. Part 1.* Translator Henry T. Riley. London. 1853, 216. (Copy consulted:- Facsimile reprint, Felenfach, Llanerch Publishers. 1994.)
[253] See Appendix A.
[254] William Dugdale, *The History of the Imbanking and Draining of Divers Fens and Marshes.* 2nd Edition. London: Richard Geast. 1772, 167.
[255] Beverley MS., Minute Book, 1597-1642, 1641-60; BL, Lansdowne MS 896, f. 167. Cited in T.S. Willan, 'Yorkshire River Navigation.' *Geography*, 22 (1937), 189-199, 197.

earlier channels, to enable them to travel by boat to their granges.[256] Later more dykes were constructed to drain the land to make it suitable for agriculture.

In 1361 a commission was appointed to investigate whether 'kiddles or weirs' blocked the channel and if excessive charges were made by masters and mariners of ships and boats passing along the river.[257] Hoskins reported, without stating his sources, that in the 1550s Beverley was still actively in dispute with Kingston-upon-Hull about tolls and harbour facilities.[258] Thus it seems that the river was always usable.

No record has been found of the removal of silt from the Hull. It would be expected that regular cleansing would have been mentioned in the Beverley Town Documents.[259]

2.6.4 River Ancholme

Contemporary records show that the Ancholme was cleared of obstructions in 1290 so that ships and boats might use it 'as they were wont to do'.[260] The Patent Rolls show that it required regular clearance throughout the period 1189-1375[261] when it should have been maintained with a width of forty feet but on at least one occasion was reduced to a width of only three feet.[262] No records have been found relating to the period 1375-1533. In 1533 the abbot of Roche was fined for failing to keep the river clear.[263]

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[256] June A. Sheppard, *The Draining of the Hull Valley.* East Yorkshire Local History Series: No 8. 1958. Reprinted 1976, 3.
[257] Calendar of Patent Rolls, 1358-61, 583.
[258] W.G. Hoskins, *The Age of Plunder: King Henry's England 1500-1547.* London: Longman. 1976, 198.
[259] Arthur A. Leach, Ed. *Beverley Town Documents.* Selden Society, Vol. 14. 1900.
[260] Calendar of Patent Rolls, 1281-1292, 400.
[261] See Appendix A for ten references.
[262] Calendar of Patent Rolls, 1374-77, 145.
Ancient Indictments File 179 m. 105, 106. Cited in *Public Works in Mediaeval Law, Volume I.* Editor C.T. Flower, Selden Society Vol. 32. 1915, 301-302.
[263] Letters and Papers Foreign and Domestic of the Reign of Henry VIII, Volume 6, 315.

2.6.5. River Witham downstream of Lincoln.

No record has been found of the use of the river by the Danes.[264] It is reported that messengers used the river in 1066 to travel from the Wash through Lincoln to Torksey.[265] It has been recorded that at about the end of the 12th century five tributaries of this section of the river were widened or straightened to provide access by water to religious foundations.[266] The 1202-4 table of tax on merchants shows Boston in second place after London and Lincoln fourth after Southampton.[267] In the 1290s the king and his court went from Boston to Lincoln in thirty-seven barges and boats.[268]

Langdon considered that in the period 1294-1348 the average size of boats on the Witham was only exceeded by those on the Lower Thames, Lea and Lower Trent.[269] Hill stated that there was no general complaint about the condition of the river below Lincoln until 1491.[270] Thompson claimed that great ships continued to go to Lincoln in the 14th and 15th centuries.[271] The Staple for Wool was transferred from Lincoln to Boston in 1369.[272] This occurred before the river became totally unusable.

Thompson recorded that from at least as early as 1281 the river frequently flooded the surrounding countryside.[273] In 1500 an attempt was made to construct a sluice at

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[264] Pishey Thompson, *The History and Antiquities of Boston.* Boston: John Noble, Jun. 1856, 28-29. (Reprinted 1997.)
[265] Peter Sawyer, *Anglo-Saxon Lincolnshire.* Lincoln: History of Lincolnshire Committee. 1998, 197. H.C. Darby, *Domesday England.* Cambridge: Cambridge University Press. 1977, 301.
[266] James Bond, 'Canal Construction in the early Middle Ages: An Introductory Review.' In Blair, 2007, 196.
[267] Publications of the Pipe Roll Society. 6 *John*, pp. xliv, 218. Cited in J.W.F. Hill, *Medieval Lincoln.* Cambridge: Cambridge University Press. 1948, 307.
[268] Lib. Cont. Gard., p. 60. Cited in J.F. Willard, 'Inland transportation in England during the Fourteenth Century.' *Speculum*, Vol. 1 (1926), 372.
[269] John Langdon, 'The Efficiency of Inland Water Transport in Medieval England.' In Blair, 2007, 130.
[270] J.W.F. Hill, *Medieval Lincoln.* Cambridge: Cambridge University Press. 1948, 314.
[271] Pishey Thompson, *The History and Antiquities of Boston.* Boston: John Noble, Jun. 1856, 356. (Reprinted 1997.)
[272] M.R. Lambert and R. Walker, *Boston Tattershall & Croyland.* Oxford: Basil Blackwell. 1930, 5.
[273] Pishey Thompson, *The History and Antiquities of Boston.* Boston: John Noble, Jun. 1856, (Reprinted 1997.) 356.

Boston to stop the flooding.[274] This was not successful as Leland stated in c.1535 that the river 'ebbith and flouith withyn a little of Dogdike Fery'.[275] He also wrote that 'the streame wherof is sumtymes as suifte as it were an arow'.[276] In 1586 Camden wrote that the river was 'enclos'd on both sides with artificial banks,' and 'runs with a full stream into the sea'. This seems to imply that the sluice had by then been totally removed.

However in 1662 Dugdale wrote of the contemporary condition of the river:

> the descent of this stream from the said city [Lincoln] to the sea is so little, that the water, having a slow passage, cannot keep it wide and deep enough, either for navigation, or draining of the adjacent marshes, without the frequent helps of digging and clearing the same; the mud and weeds increasing so much therein.[277]

Robinson considered that the change in the form of the channel was due to the rising sea-level in the 13th century which overwhelmed the offshore banks and tidal surges which reshaped the coastline.[278] However Rippon found little evidence for a transgression in the 13th century[279] and it might be expected that a change in the shape of the offshore banks would have had a much quicker effect on the river form.

2.6.6 River Glen

The records of use which have been found are all for the 14th century.[280] However the requirement in the Lynn Law,[281] 1630, that the 'navigable rivers' including the Glen should be preserved seems to indicate that it had for a long time been used by boats.

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274 *Ibid.* 357.
275 *The Itinerary of John Leland in or about the years 1535-1543. Volume Five.* Editor Lucy Toulmin Smith. Carbondale: Southern Illinois University Press. 1964, 36.
276 *Ibid.* page 34.
277 William Dugdale, *The History of the Imbanking and Draining of Divers Fens and Marshes.* 2nd Edition. London: Richard Geast. 1772, 168.
278 David Robinson, 'Drainage and Reclamation.' In Stewart Bennett & Nicholas Bennett, Eds. *An Historical Atlas of Lincolnshire.* Hull: University of Hull Press. 1993, 72.
279 Stephen Rippon, *The Transformation of Coastal Wetlands.* Oxford: The British Academy by Oxford University Press. 2000, 22-34.
280 See Appendix A.
281 Samuel Wells, *The History of the Drainage of the Great Level of the Fens, called Bedford Level. Volume II.* London: The Author. 1830, 105.

Many smaller rivers and channels were drained and became unusable. In 1643 the river 'was of no use for drainage' as the bottom of the channel of the river Glen was for the most part higher than the fenny grounds across which it flowed. The 'defensible' banks had to be strengthened and raised periodically.[282]

2.6.7 River Nene

The history of the Nene is complex but it seems that it always required regular maintenance and was sometimes illegally obstructed by weirs. The course of the main channel often changed and at times was not discernable. In 1334 a commission was appointed because navigation on 'divers lodes' leading from the towns of Peterborough, Yaxley and Spalding were obstructed so that they could not be used even in winter.[283] In 1375 it is recorded that 'the town of Spalding was in danger of being submerged by the flow of the sea and by the flood of water in the winter towards the marsh, because since the first pestilence the lands of the said township have been so divided and alienated that the keepers of the ditches know not by whom they ought to be repaired.'[284]

In about 1546 Leland stated that the Nene divided into three channels downstream of Peterborough which then reunited and that it flowed into the sea near Kings Lynn.[285] In 1587 Harrison wrote that downstream of Peterborough

> it divideth it selfe into sundrie armes, and those into severall branches and draines, among the fennes and medowes, not possible almost to be numbred, before it meet with the sea on the one side of the countie, and fall into the Ouze on the other.[286]

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[282] William Dugdale, *The History of the Imbanking and Draining of Divers Fens and Marshes.* 2nd Edition. London: Richard Geast. 1772, 177.
[283] Calendar of Patent Rolls, 1334-38, 70.
[284] Ancient Indictments File 59 m 13. Cited in *Public Works in Mediaeval Law, Volume 1.* Editor C.T. Flower, Selden Society Vol. 32. 1915, 269.
[285] This reference has not been found in Lucy Toulmin Smith's edition but is quoted from Raphaell Holinshed, William Harrison, and others, *The First and Second Volumes of the Chronicles.* 2nd Edition. London: J. Johnson *et al.* 1807, 172.
[286] Raphaell Holinshed, William Harrison, and others, *The First and Second Volumes of the Chronicles.* 2nd Edition. London: J. Johnson *et al.* 1807, 172.

It would seem that during the second half of the 16th century the channel became blocked so that the water flowed over much of the country. This may have been due to lack of maintenance after the dissolution of the monasteries.

2.6.8 River Cam

Astbury considered that archaeological records indicated that sections of the channel of the Cam were straightened and modified at an early date.[287] Ships came from Ireland to trade at Cambridge in the 10th century[288] and Greenhough considered that the section of the river from Cambridge to the Great Ouse remained usable thereafter.[289] This seems to be an example of absence of evidence of disuse, supported by evidence of periodic use, being considered to be evidence of continuous use. In 1382 when complaints were made that the prior of Barnwell narrowed the river 'to the hurt of the community of Cambridge'[290] it was *navibus et batellis* which were said to be obstructed. Thus large vessels were using the river at that time. Contemporary records indicate that in 1615 James I was told that 'This river Cam … is the life of trafficke to this Towne and Countie'.[291] Similar records indicate that in 1650 the University and Town claimed that if the river traffic were to be interrupted by drainage works it would be 'prejudice to a great part of the whole Nation.'[292]

Those who have studied the history of the city indicate that the first reference to the clearance of the river dates from 1578 when the Cambridge Corporation ordered the removal of some shelves downstream of the city so that boats might pass more easily.[293] Also in 1636 the 'scowring and roading' of the river from Newnham Mills to the Silver Street bridges was ordered.[294]

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287 A.K. Astbury, *The Black Fens.* (1st Edition 1958.) Wakefield: S.R. Publishers Ltd. 1970, 118.
288 *Liber Eliensis* (p.148, ed. Stewart). Cited in Arthur Gray, 'The Ford and Bridge of Cambridge.' *Proceedings of the Cambridge Antiquarian Society.* Vol. XII. (New Series VIII.) (1919.)126-139, 131.
289 Geoffrey John Greenhough, 'The Present Use of the River Cam in Relation to its Historical Perspective.' Unpub. Master of Letters thesis. Univ. of Cambridge. 1980.
290 Coram Rege Roll, Hil., 7 Richard II. Rex 22. Cited in *Public Works in Mediaeval Law, Volume I.* Editor C.T. Flower, Selden Society. Vol. 32. 1915, 43-44.
291 Enid Porter, 'The River Trade of old Cambridgeshire.' *Cambridgeshire and Peterborough Life.* October 1969, 24-26, 24.
292 J.B. Mitchell, 'The Growth of Cambridge.' In J.A. Steers, Ed. *The Cambridge Region,* London: The British Association for the Advancement of Science. 1965, 176.
293 Charles Henry Cooper, *Annals of Cambridge. Volume II.* Cambridge: Warwick & Co. 1843, 366.
294 Rev. D. Stokes, 'The Old Mills of Cambridge.' *Proceedings of the Cambridge Antiquarian Society.* Vol. XIV. (New Series VIII.) 1909-1910, 201.

2.6.9 River Ant

There was a presentment in the King's Bench in 1360 that the Ant was stopped

> by nobody's default … because the river fell out of use at the time of the pestilence and nothing was carried on it so that weeds continually grew in it from that time until the present time: that it was not known who ought to clean it because none had cleaned it since the memory of man: that the towns that advantage and profit from the said river were Stalham, Sutton, Catfield, Ludham, Smallburgh, Barton Turf and Irstead.[295]

Blair used this example to illustrate what he claimed was a cycle of decline in the use of water transport after 1250.[296] Gardiner considered that the blockage may have been due to a reduction in the transport of peat to the Broads after they were flooded in the first half of the 14th century.[297]

Blair may have been unduly negative. There seems to have been active use of the river by seven villages until the pestilence and then a short period without use possibly due to the reduction in the transport of peat. Then many presentments were made to the local court and then an appeal to the king for the river to be reopened. The appeal was made only ten years after the first blockage. The blockage may not even have been due to disuse, for Bond considered that it may have been caused by the monks of the abbey of St Benet, Hulme diverting both the Ant and the Bure to reduce flooding and to keep access open for boats coming up to the abbey quay.[298]

[295] *Public Works in Medieval Law. Volume II.* Editor C.T. Flower. Selden Society. Vol. 40. 1923, 88-90.
[296] John Blair, 'Introduction.' In Blair, 2007, 5.
[297] Mark Gardiner, 'Hythes, Small Ports, and Other Landing Places in Later Medieval England.' In Blair, 2007, 106.
[298] James Bond, 'Canal Construction in the Early Middle Ages: An Introductory Review.' In Blair, 2007, 157.

2.6.10 River Hartlake

Leland stated that on the Somerset Levels at 'Hartelak' bridge the Sowey would flood all the surrounding areas if it were not kept from abundance of 'wedes'.[299] The river was straightened and embanked before 1326 but it is not known by which route the Hartlake river reached Meare Pool.[300]

2.6.11 Summary

The gradient of the nine rivers varied from 0 to 0.3 m km^{-1}. Inspection of Table 6 seems to indicate that there is no relationship between gradient and the amount of maintenance needed to maintain the channels.

All the rivers with mean discharge less than 1.5 $m^3 s^{-1}$ required regular maintenance to remain clear. It seems likely that with lesser discharge the rivers were so slow-flowing that reeds and sedges could grow and block the channel and that the winter flow was inadequate to remove the debris. Thus between 1268 and 1591 there are nearly a thousand instances in the rolls of Ramsey, Hepmangrove and Bury dealing with the blockage, narrowing or otherwise impeding of the several watercourses in the towns.[301]

There are no measurements of sediment transport available for the period prior to 1600. However the base flow index 'measures the proportion of the river runoff that derives from stored sources … and thus is an effective means of indexing catchment geology'.[302] It seems likely that spring water is clear but runoff water transports sediment. Thus a river with a high base flow index will have a low sediment supply. The Ant and Hull have the highest known base flow index and remained more usable than the other rivers except the Cam.

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299 *The Itinerary of John Leland in or about the years 1535-1543. Volume One.* Editor Lucy Toulmin Smith. Carbondale: Southern Illinois University Press. 1964, 147.
300 Michael Williams, *The Drainage of The Somerset Levels.* Cambridge: Cambridge University Press. 1970, 66, 67.
301 *The Court rolls of Ramsey, Hepmangrove, and Bury. 1268-1600.* Editor Edwin Brezette DeWindt. Toronto: Pontifical Institute of Mediaeval Studies. c1990, 49.
302 *Hydrological data UK 1996-2000.*

The present Base Flow Index at Cambridge is 0.65. However at Cambridge there were dams across the river and between Cambridge and Grantchester the channel is almost level. It would seem that most of the sediment would have been deposited in this section of the river. The miller at Cambridge was responsible for removing this silt.[303] Thus it seems that the quantity of sediment in the river downstream of Cambridge may have been comparable to the amounts in the Hull and Ant. Mill sites have not been identified on any of the other rivers.

The Glen and Witham were constrained within banks whereas the flood waters of the Hull and Cam covered the floodplain. More sediment is transported by a river during times of flood than at lower discharge rates. These high levels of sediment were retained in the channels of the Glen and Witham. This meant that the banks had to be continually raised to constrain the rivers. On the Hull, Ant and Cam in times of flood the sediment would have been distributed evenly over the channel and surrounding land and the stream power, aided in the case of the Ant by the disturbance of the water by boats, was great enough to remove the sediment from the rivers.

Building banks for a river is relatively easy, if expensive. To dredge the Cam the miller only needed to stop his millwheel, lower the sluices and shovel the sediment out of the channel. On a fast-flowing river it is only necessary to disturb the bed and the sediment flows away. On a slow-flowing river sediment could only be cleared by the use of scoop-like ditching tools.[304]

From the limited information available it seems that for rivers with a discharge of more than 1.5 $m^3 s^{-1}$ the sediment supply determined whether a river remained usable without maintenance.

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[303] Cambridge University Registry, *Sewers, &.*, 3. 2. 82 (108-113). Cited in Rev. D. Stokes, 'The Old Mills of Cambridge.' *Proceedings of the Cambridge Antiquarian Society.* Vol. XIV. (New Series VIII.) 1909-1910, 194.
[304] Illustrated in E.A. Ellis, *The Broads.* London: Collins. 1965, opp. 229.

Chapter 2.7 Usability from Source

Many rivers have at their source a pond or lake from which a small stream flows which is not, and was not, usable. Examples include Norman Norris pond in East Sussex from which flows a tributary of the Cuckmere and Stickle and Easedale Tarns in the Lake District. These are usable at their source, but not from their source, and they are not considered in this thesis.

The *BCU Guide* states that now only the River Aire is usable from its source. The subject of this chapter is the rivers which were historically usable from their source.

The River Thames is the longest river in England. It has had the most words written about it. This is partly because it was used to take supplies to the largest city, had a large population living near it and because the government has for much of the time been on its banks. Table 7 gives some indication of the extent to which writing about the Thames exceeds that of other rivers.

Table 7 Literature about the Thames

Column A. Number of rivers with the same name.

Column B. Number of entries in British Library Catalogue with “River” and “Thames (or other river name)” in the title.

Column C. Number of references in Edwards to each river in the Calendars of Patent Rolls, Liberate Rolls, Close Rolls, Memoranda Rolls, Charter Rolls, Chancery Rolls and Inquisitions Miscellaneous from 1066 to 1400.

	A	**B**	**C**
River Thames	1	1028	163
Severn	1	120	19
Ouse	4	79	74
Avon Large Small	3 3	72	28
Trent	1	70	39
Derwent	3	30	14
Total for other rivers		371	174

It seems that there may have been as much written about the Thames as about all the other rivers of England combined. There were almost as many references to the Thames in Government papers for the period 1066 to 1400 as for all the other rivers of England combined. No author has written about the history of any other river in the same detail as Thacker’s three volumes about the River Thames.[305] At least two books have been written about the rivers of London which now run in sewers.[306] No

[305] Fred S. Thacker, *The Stripling Thames.* London: Fred S. Thacker. 1909.
Fred S. Thacker, *The Thames Highway. Volume I: General History.* (First published 1914.) Newton Abbot: David & Charles. 1968.
Fred S. Thacker, *The Thames Highway. Volume II: Locks and Weirs.* (First published 1920.) Newton Abbot: David & Charles. 1968, 11.

[306] N.J. Barton, *The Lost Rivers of London.* London: Phoenix House Ltd and Leicester University Press. 1962.
A.S. Foord, *Springs, Streams and Spas of London.* London: T. Fisher Unwin. 1910.

book has been found about similar rivers in other cities, like the River Sherbourne in Coventry.

The importance of these facts, for this thesis, is that what is unknown about the River Thames it is not likely to be known about other rivers. It is only for the Thames that a comparison can be made between the conclusions of different authors about the usability of a river towards its source.

Various authors have described the historic use of the Thames. Their opinions as to the upper limit of use of the river are summarised in Table 8. [See also Appendix Q Map 1.]

Table 8 The Historic Limit of Use of the Thames

Author	**Size of boat**	**Date**	**Limit point**	**Distance to source miles**
Taunt.[307]	7 ton burden	Not known	Water Hay bridge	13
Belloc.[308]	Boats	Pre 1783	Cricklade	14
Prior.[309]	*Batelli*	Saxon – 1600	Radcot +	32
Wilson.[310]	6 – 7 tons	18th century	Cricklade	14
Edwards.[311]	1 ton	1271	Radcot	32
Langdon.[312]	Barges	1290 – 1348	Oxford	58
Blair.[313]	10 ft beam	Pre 1300	Radcot +	32

+ indicates that there was use at least to Radcot and possibly further upstream.

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307 Henry W. Taunt, *A New Map of the River Thames.* 3rd Edition. Oxford: Henry Taunt & Co. 1878, 10.
308 Hilaire Belloc, *The Historic Thames.* (1st Edition 1907.) London: J.M. Dent & Sons Ltd. No date, Written in 19th C. but first dated edition 1907, 15.
309 Mary Prior, *Fisher Row.* Oxford: Clarendon Press. 1982, 111.
310 David Gordon Wilson, *The Thames: Record of a Working Waterway.* London: B.T. Batsford. Ltd. 1987, 42.
311 J.F. Edwards, 'The Transport System of Medieval England and Wales.' Unpub. PhD thesis, Univ. of Salford. 1987.
312 John Langdon, 'Inland water transport in medieval England.' *Journal of Historical Geography,* Vol. 19, 1. (1993), 1-11.
313 John Blair, 'Transport on the Upper Thames.' In Blair, (2007), 254-294.

Taunt was a regular user of the Thames and he noted the storehouses at Lechlade and assumed that ‘cheese, corn etc.’ were taken there in small boats and then reloaded into larger boats for transport to London. Belloc quotes no authority for his statement that prior to the building of the Thames and Severn Canal ‘it was possible, and even common, for boats to reach Cricklade, or at any rate the mouth of the Churn’. Prior working from contemporary records noted the fact that there was a hythe in Oxford suitably located for boats coming from upstream and that stone was transported from Eynsham for the building of Merton College, that the region upstream of Oxford was wealthy and the people of Radcot prospered by trade on the river. She also noted the carrying services on the river and the drowning at Radcot in 1271. Wilson was a lock-keeper and he doubted if boats went beyond Cricklade because of the state of the river as he saw it. He seems not to have considered that the form and discharge of the river might have changed since the medieval period.

Edwards noted only the drowning at Radcot and from that one reference assumed that the river was navigable to Radcot. Langdon was explicit in stating that ‘Goods from the country upstream from Oxford came to the city by land’. Blair found ample contemporary written evidence of the use of the river upstream of Oxford including the construction of two canals for boats using the river and he concluded that ‘There must have been a great deal of coming and going around’ at the mill at Kyndelwere.

The value of this analysis lies not in establishing the use of the Thames upstream of Oxford, which could have been achieved by summarising Blair’s text, but in showing that the lists of written historic records, as compiled by Edwards and in Appendix A of this thesis, only give a very incomplete record of the actual use of the rivers. Prior and Blair, by considering the geography and economics of the region, achieved a much fuller description of the historic use.

These historic records may be compared with recent records of use of the Upper Thames. The opinions of some authors as to the upper limit of use during the last 140 years are summarised in Table 9.

Table 9 The Recent Limit of Use of the Thames

Author	**Type of vessel**	**Date**	**Limit place**	**Distance to source in miles**
All Year				
Taunt.[314]	Canoe or punt	1871	Oaklake bridge	12
Thacker.[315]	Canoe	1909	Cricklade	14
Bliss.[316]	Cedar wood canoe	1934	Ewen village	2
BCU Guide.[317]	Lathe & Canvas Canoe	1936	Lechlade	25
Wilson.[318]	Canoe	1987	Cricklade	14
Winter				
Taunt.[319]	Punt	1878	Source	0
BCU Guide.[320]	Lathe & Canvas Canoe	1936	Cricklade	14
Harris.[321]	Canoe or punt	1990	Source	0

Taunt stated that pumping had materially affected the discharge of the springs at the source during the summer but that pumping stopped in the winter when the springs

[314] Fred S. Thacker, *The Thames Highway. Volume II: Locks and Weirs.* (1st published 1920.) Newton Abbot: David & Charles. 1968, 19.
[315] Fred S. Thacker, *The Stripling Thames,* London: The author. 1909, 10.
[316] William Bliss, *Canoeing.* London: Methuen & Co. Ltd. 1934, 165.
[317] *BCU Guide,* 101.
[318] David Gordon Wilson, *The Thames: Record of a Working Waterway.* London: B.T. Batsford. Ltd. 1987, 42.
[319] Henry W. Taunt, *A New Map of the River Thames.* 3rd Edition. Oxford: Henry Taunt & Co. 1878, 10.
[320] *BCU Guide,* 101.
[321] Mollie Harris, *The Stripling Thames.* Stroud: Alan Sutton Publishing Ltd. 1994, 8.

were recharged. A difference between the winter and all year limits is thus to be expected.

Bliss used a cedar wood Canadian canoe and so was able to travel further upstream than those using lathe and canvas canoes. He refers to his canoe being able to stand ‘very much more rough usage than a smooth-strip canoe’. This is confirmation that usability depends on the type of boat being used. It is claimed here that historically logboats would normally have been able to reach the source of the Thames during the winter.

If the river was usable then actual use would depend on demand. Taint described the ground near the source:

> The grass-covered ground in places looks baggy, and small hillocks are formed at intervals, which resemble a sponge when filled with water. Standing on one we force a stick for some distance through its covering of turf, and on withdrawing it, a fountain of water suddenly spurts out to the height of perhaps two feet, and continues gushing up some time, until the hillock on which we stand has sunk down to the level of the mead around.[322]

It would seem that this turf would have been very suitable, after drying, for burning. In addition the sedges and reeds near the source of the rivers would have been suitable both for burning and for thatching. Since the demand was downstream the easiest method of transporting the turfs, sedges and reeds would have been by water. It is not surprising that this movement has not been recorded. We have few records of wood being collected from ‘waste’ ground yet it is assumed that it happened.

It is possibly of interest that a map dated ‘after AD 1534’ shows the source of the Thames as a ring of water around an island.[323] In 1573 Humphrey Lloyd showed the source as a pond,[324] as did Saxton in 1579[325] and Blaeu in 1645.[326]

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[322] Henry W. Taunt, *A New Map of the River Thames.* 3rd Edition. Oxford: Henry Taunt & Co. 1878, 8.
[323] Anonymous: ‘Anglia figura. . .’, after A.D. 1534, British Museum, Cotton MS. Aug.i.i,f.9. Contained in Royal Geographical Society, *Early Maps of the British Isles. A.D. 1000 – A.D. 1579.* London: Royal Geographical Society. 1961.

If it is accepted that boats were used to the source of the Thames then consideration needs to be given to the use of other rivers to their source. In medieval times it was thought that 'all rivers had their source in lakes'.[327] The Gough map shows how this belief was shown by the cartographers. Such a belief was wrong, but it does suggest that some, or many, rivers did rise in lakes or marshes.
Leland records that 'In the ponde in Milbyri Parke risith an hedde of Ivel River. The hedde of Shirburn Water riseth in Blakmore. From water risith in a valley a 3. or 4. miles above Fromton. There cummith also a streame to it out of the pond in Hoke Parke.'[328] He describes four rivers, two rise in ponds, one in a moor and the other in a valley. The three may have been usable from their sources, the other probably would not.

Hawkins observed that the Great and Little Wilbraham, which are now little more than ditches, had during his lifetime been usable by boats near to, if not to, their sources.[329] Drainage, abstraction and the lowering of water tables have materially affected the form of many rivers near their sources.

The problem is to move from considering the particular to consideration of the general. It may be suggested that one subset of the rivers which were usable from their source is those where the source lies in an Internal Drainage Districts which exist where the land is liable to flooding. It seems reasonable to assume that if land is now liable to flooding then historically it did flood. Where the land was regularly flooded boats would have been used and so the river sources in those areas would have been accessible by boat.

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[324] Humphrey Lhyd: 'Angiae . . . nova description.' Antwerp, A.D. 1573. In Ortelius: 'Theatrum orbis'. Contained in Royal Geographical Society, *Early Maps of the British Isles. A.D. 1000 – A.D. 1579.* London: Royal Geographical Society. 1961.
[325] Christopher Saxton, *Christopher Saxtons's 16th Century Maps.* Shrewsbury: Chatsworth Library. 1992, 53.
[326] John Blaeu, *Blaeu's Atlas of England Scotland Wales and Ireland.* London: Thames and Hudson. Undated. Pages un-numbered.
[327] E.J.S. Parsons, *The Map of Great Britain circa A.D. 1360 known as The Gough Map.* Oxford: Bodlean Library. 1958, 8.
[328] *The Itinerary of John Leland in or about the years 1535-1543. Volume 4.* Editor Lucy Toulmin Smith. Carbondale: Southern Illinois University Press. 1964, 73-74..
[329] T.D. Hawkins, *The drainage of Wilbraham Fulbourn and Teversham Fens.* Cambridge: The Author. 2000, 52.

In 1271 William Whiteside fell from a boat and drowned at Eaton, Bedfordshire near the source of the Ouzel.[330] This is now in an Internal Drainage District. Since the draining of the marsh such an event is unlikely to recur. There are contemporary written records which indicate that boats could travel from the Little Ouse to the Waveney.[331] Again the area between the sources of the two rivers is in an Internal Drainage District.

There are 248 Internal Drainage Districts in England which have within them the sources of many rivers. Harrison, Camden and others have described rivers as rising in a lake or mere but never commented as to whether the river flowing out was usable or not. The Wetlands surveys of Shropshire, Lancashire, Yorkshire and the Fens provide much information about the wetlands but not about the usability of the rivers.

In 1902 Cornish wrote that 'the hidden cisterns of the springs are now sucked dry. … where formerly streams gushed out unbidden, they are now at pains to raise the needed water by all the resources of modern machinery.'[332] This desiccation of the countryside has reduced the usability of these streams near the sources making it difficult to establish their historic form.

It has long been noted that the Salisbury Avon, Bristol Avon, Severn and Warwickshire Avon form a river route from the South Coast to Northamptonshire with only a two mile gap near Devizes.[333] It has not been so well noticed that Leland referred to the Nene as the Avon[334] and that Saxton described it as the Avona.[335] There is scarcely a gap of half a mile between the Warwickshire Avon and the Nene

[330] *Select Cases from the Coroners' Rolls, 1265-1413.* Editor Charles Gross. Selden Society, Vol. 9. (1895), 16.
[331] J. Thirsk and J.P. Cooper, Eds. *Seventeenth-century Economic Documents.* Oxford: Clarendon Press. 1972, 343.
[332] C.J. Cornish, *The Naturalist on the Thames.* London: Seeley and Co. Limited. 1902, 59.
[333] Eg. Henry Bradley, 'Some Prehistoric River-Names.' Mario Praz, Editor, *Miscellany.* Rome: For the British Council by Edizioni di "Storia e Letteratura". 1950, 10-15.
[334] *The Itinerary of John Leland in or about the years 1535-1543. Volume 1.* Editor Lucy Toulmin Smith, Carbondale: Southern Illinois University Press. 1964, 3-7 and others.
[335] Map of Northamptonshire bound into William Camden, *Britain.* (1st Edition 1586.) Translator Philemon Holland, London: Joyce Norton and Richard Whitaker. 1637.
Morden – Aufona that is Avfona
Harrison – both Nene and Avon
Speed – Nyne.

across Kelmarsh. Thus the five rivers form a water route from Christchurch to the Wash with only a two mile gap.

Ekwall notes only three other very much smaller Avons in England. He makes no mention of the alternative name for the Nene. He writes of the name Avon, 'so far as it is old, [it] is generally applied to rivers of some considerable importance.'[336] His comment seems to be an inadequate description of the location of the four rivers named Avon.

The name 'Kelmarsh' is considered to be derived from 'Pole marsh'. Watts states that 'The allusion is probably to a guide-post in the marsh.'[337] This, or these, guide-post(s), presumably, were placed for the benefit of people travelling from a distance who did not know the local area well.
It would be a remarkable coincidence if the four rivers were given the same name without there being any other connection between them. Possibly the connection is that goods were regularly taken upstream on one and downstream on another.

Around most of the lakes, ponds or meres at the source of rivers there would have been reeds and sedges which could be used for fuel or thatching. Where there was usability and goods for which there was a demand it would seem that there is a probability of use. However there will need to be considerable further research before it can be established which rivers were usable to their source.

[336] Eilert Ekwall, *English River Names.* Oxford: Clarendon Press. 1968, 20-23.
[337] Victor Watts, Editor, *The Cambridge Dictionary of English Place-Names.* Cambridge: Cambridge University Press. 2004, 338.

Chapter 2.8. Conclusion.

The object of this chapter is to compare and contrast the rivers of the period 1189-1600 and of the 21st century. It is impossible usefully to compare the canalized rivers with their premodified form. They are deeper, slower, their profile is like steps, not a slope, and they often have a different course. The Medway at Teston looks like a large river, for England. The Itchin at Highbridge is little more than a stream in which the anglers wade. Yet the mean discharge at Teston is only double that at Highbridge. To study the canalized rivers in their premodified form one must consider their probable discharge, gradient and other controlling factors.

The greatest change in the rivers is the fact that historically they inundated their floodplain almost every winter often to a depth of one metre or more. Bates has already been quoted 'Water would be pouring down, everywhere, throughout the whole width of the valley, three feet deep, … It was a great wild wateriness'.[338] This was true not only of the Nene but of every river where there was a floodplain. They are dotted about the Highland Region and widespread in the Lowland. Many were wide, 4½ miles at Chippenham on the Bristol Avon. Economically they were of great importance. The value of an area of meadow was four to ten times as much as arable because it was regularly watered and fertilised by the overflowing of the river.[339] Where the depth of the water was more than 0.5 m there was a usable area of water. In winter boats were used to reach the islands in the floodplains. The Chapter of Wells said that their newly built weir did not obstruct the boats as in summer there was not enough water for boats to use the river and in winter the boats could go over the meadows.[340]

Secondly the flow of the water was slower due to the rivers being longer and the growth of vegetation. Chertsey Abbey was founded on an island in the 7th century. It

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[338] H.E. Bates, *Down the River.* (1st Edition 1937.) London: Victor Gollancz Ltd. 1987, 50-51
[339] A.E. Wilson, 'Custumals of the manors of Laughton, Willingdon and Goring.' *Sussex Record Society.* Vol. 60. 1961, 79.
[340] Wells MSS. Chapter Act Book, ff. 115 et seq. Cited in P.J.Helm 'The Somerset Levels in the Middle Ages (1086-1539).' *Journal of the British Archaeological Association.* Vol. 12. (1949), 48.

is now half a mile from the Thames.[341] Historical maps and fieldwork indicate that on the Wear a neck of a loop has been cut off upstream of Durham.[342] Each change was insignificant but their combined effect was not. On many rivers there is now control of vegetation which increases the speed of the water. Both changes have made the rivers shallower.

Many rivers are wider due to the increase in their channel size because of flood control works. It seems likely that the lowering of the water-tables has increased ground flow and reduced the discharge in rivers. Again both effects result in the rivers becoming shallower.

The discharge in the rivers has varied especially in the East where the effect of evapotranspiration is greater. Some rivers are now flashier due to quicker runoff, drainage of marshes and meres and the straightening and clearance of the channels. Other rivers are less flashy because of the construction of flood control reservoirs. In general, it would seem that a flashy river is less usable than one with more stable discharge. It is known that the discharge of some rivers has been materially reduced by abstraction which has reduced their usability.

There is evidence that the form of some rivers has changed and that the use of some of the larger rivers was limited due to their braided or multi-channel pattern and on others usability has changed due to aggradation and siltation.

In Chapter 2.1 reasons were given why, in the past, the historic usability of rivers has not been established. However by consideration of the gradient, discharge, bed material, width-depth ratio and possibly other factors improved estimations of the historic limits of usability may be possible in the future. In particular work has started on determining the historic velocity of rivers from insect and vegetation remains.[343]

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[341] Susan Reynolds, 'Chertsey, Surrey, and Laleham, Middlesex, mid- or late 15th century.' In R.A. Skelton and P.D.A. Harvey, *Local Maps and Plans from Medieval England.* Oxford: Clarendon Press. 1986, 240.

[342] M.G. Snape, 'Durham *circa* 1440x1446.' In R.A. Skelton and P.D.A. Harvey, *Local Maps and Plans from Medieval England.* Oxford: Clarendon Press. 1986, 206.

[343] eg. F.W. Shotton, 'Archaeological inferences from the study of alluvium in the lower Severn-Avon valleys.' In Susan Limbrey and J.G. Evans, Eds. *The Effect of man on the landscape: the Lowland Zone.* Council for British Archaeology Research Report No 21. 1978, 27-32.

Archaeological investigation of the relict channels where there were historic anthropological modifications may provide information about the channel form, width-depth ratio and bed material. The work which has been carried out on the rivers Tyne, Trent and Severn do not provide a large enough set for the results to be extrapolated to other rivers.

It seems that for barges there is a greater length of river which is now navigable and that these additional sections can be identified with reasonable confidence in most cases. For boats there has been a reduction in the length of the rivers which are usable and the lengths where use is no longer possible are often not easily identified. Thus it is difficult or impossible to identify the historic upper limit of physical usability on many rivers or to know if a river could be used to its source. There is no section of a river which has been identified in the present study which can be used now but is known to have been unusable throughout the period 1189-1600 assuming that individual obstructions were portaged.

While the term 'limit of use' has been used in this Part of the thesis, it needs to be remembered that this is not a fixed place on the river even for a given type of boat. It is neither fixed nor a place. It is not fixed because it moves, often a long way, with the change in discharge of the river. It is not a place because it is rather a section of the river containing a series of increasingly difficult mini-sections. It is a moving section which some users will not wish to use due to the difficulties but which others will use when sufficiently motivated. The one exception to this is when the limit of use was the source of the river.