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Historical sources and meandering river systems in urban sites: the case of Manchester, UK

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Abstract

Past geomorphological changes to meandering rivers due to urbanization derived from historical sources are used to explore three scales of channel adjustment in Greater Manchester. Human activity has often extended the first terrace narrowing the flood plain and raising flood heights, requiring later construction of flood walls and flood detention basins. Urban development near waterways often occurs over buried former meanders that potentially pose hazards during and after construction. The active post-glacial meandering channel of the Mersey Basin are not all totally controlled, marked changes in the Mersey River channel have occurred in the reach downstream of Ashton on Mersey. A comparison of the roles of pre-urban geomorphology and anthropogenic changes in Greater Manchester with those in São Paulo Brazil revealed the value of the analysis of past conditions for river management and urban construction in both older and newly industrialising cities across the continents.

Key Words

Meandering channels, urban geomorphology, fluvial dynamics, Anthropocene sediments, Mersey Basin, Manchester

Introduction

Throughout history towns and cities have been located close to rivers, but the huge urban expansion triggered by the industrial revolution led to changes to river channels and building on floodplain and lower terraces. With their headwaters dammed for water supplies, their water diverted to power water mills, their channels used for navigation and their floodplains increasingly occupied by urban structures, river experience altered flows, greatly increased sediment and pollutant loads and alteration of deposition and erosion along their meandering reaches. Urban expansion has led to drainage of land liable to flood; construction of reservoirs; rectification, straightening and widening of river channels; building of embankments and strengthening of levees; and to landfill disposal in flood plains. Many of these activities reduced the flood storage capacity of floodplains, even though flood control works have often increased river channel capacity (Douglas 1983; Hockin 1985; Gregory 1987).

Historical sources can provide impressive details for dating and analysing geomorphological processes over the last 100 years or more (Trimble 2008). Documentary and map evidence has been used to help in the reconstruction of the pre-industrial fluvial systems; in the determination of the rate, magnitude, components and location of changes; in the general prediction of instability to forecast the direction and style of future river changes, as well as the effects of new impacts and development; and to assess the extent and distribution or river channel adjustments (Petts *et al*. 1989; Gregory *et al*. 1992; Dodge & Perkins 2010).

Establishing former river meanders helps in identifying the active meander belt that corresponds to the most recent phase of channel migration. Such riverine zones are highly sensitive to urban occupation and engineering works because their geomorphological processes are highly dynamic. In addition, the overlapping artificial deposits may enhance the natural sensitivity, and it is important to know the land use history and people-made geomorphological changes to the land being built on (Douglas 2005).

The artificial deposits on floodplains have specific geotechnical implications due to the high vertical and lateral variability of the underlying fluvial deposits (Douglas 1985), particularly if former channels intersect one another (Hooke & Redmond 1989). Non-cohesive, poorly compacted artificial deposits may modify the water table and may contain contaminants from past land uses and waste deposits. Foundation problems on floodplains are associated with the depth of alluvial materials, pumping, moisture, hydrostatic uplift and depth to the water table (Leggett 1973).

Floodplains and the lowest terraces close to rivers are affected by flood events. Their natural function is to retain floodwater and reduce its velocity by providing a combination of storage and resistance, such storage effects and flood conveyance being termed the Natural Flood Attenuation (Scottish Executive Environment Group Research 2005). Urban development reduces this hydrodynamic function of the floodplain and lowest terraces, leading to a need to build artificial flood storage basins and detention ponds in upstream areas and on the remaining open floodplains. Reconstruction of meandering river systems and past river management from historical sources to has been carried out successfully in the Metropolitan Region of São Paulo, Brazil (Rodrigues 2010) and the same methodological approach is used here to examine the Mersey and Irwell rivers reconstruction of meandering river systems and river management in urban sites in Greater Manchester, UK.

Greater Manchester

Greater Manchester is the world's first industrial city and its rivers bear the legacy of the rapid industrial expansion, providing an ideal case of study of how the urban fluvial systems respond to the anthropic impacts derived of urbanisation (Lawson & Lindley 2008).

River Channel Dynamics in Greater Manchester

Greater Manchester is situated where the north-east part of the Cheshire plain abuts the Pennines to the east and the West Pennine Hills to the north (Figure 1). The main Mersey River's tributaries draining from the peat-covered Millstone Grit sandstones of the uplands are the Irwell, Tame and Bollin. Rising at up to 600 metres altitude, the streams descend to the Cheshire Plain where Pleistocene glacial deposits overlie Permian and Triassic sedimentary rocks, below 50 metres altitudes (Johnson 1985).

The modern channel morphology reflects both changing hydrological conditions and the character and quantities of sediments supplied from both Pleistocene deposits and pre-Pleistocene bedrock and hydrological conditions. Precipitation variability during the year is low but daily variability is high, characterized by a flashy regime influenced by rainfalls on the Pennines uplands that deliver over 1,000 mm per year, and sometimes cause flash floods in the upper reaches of the catchments. Close to the head of the River Etherow, a tributary of the Tame just east of the Greater Manchester boundary, mean annual precipitation between 1961 and 2004 was 1554 mm year^{-1} (range 1016–2080 mm). Mean summer and winter precipitation for the period were 373 mm (range 160 to 586 mm) and 419 mm (range 215 to 670 mm) respectively (Daniels *et al*. 2008). In the lower lands, flooding is mainly caused by widespread heavy rain and/or prolonged periods of wet weather (Environment Agency, 2008), with, however, several instances of localised pluvial flooding caused by high intensity thunderstorms.

The dominant geomorphological trend in the lowlands during the Holocene has been river incision into glacial and periglacial deposits of the Cheshire plain, with high proportions of the current floodplains having been created in the last 100 years (Harvey 1985). The current channel dynamics reflect the low-energy and low-slope fluvial meandering systems within these floodplains.

Three periods of sinuosity change have occurred over the last 160 years in a highly dynamic reach of the River Bollin, at the southern edge of Greater Manchester (Hooke 2004). Firstly, the sinuosity gradually increased by 1.36 in 125 years, from 1.52 in 1840 to 2.88 in 1965; after which 14 years of abrupt variations occurred with a reduction to 2.50

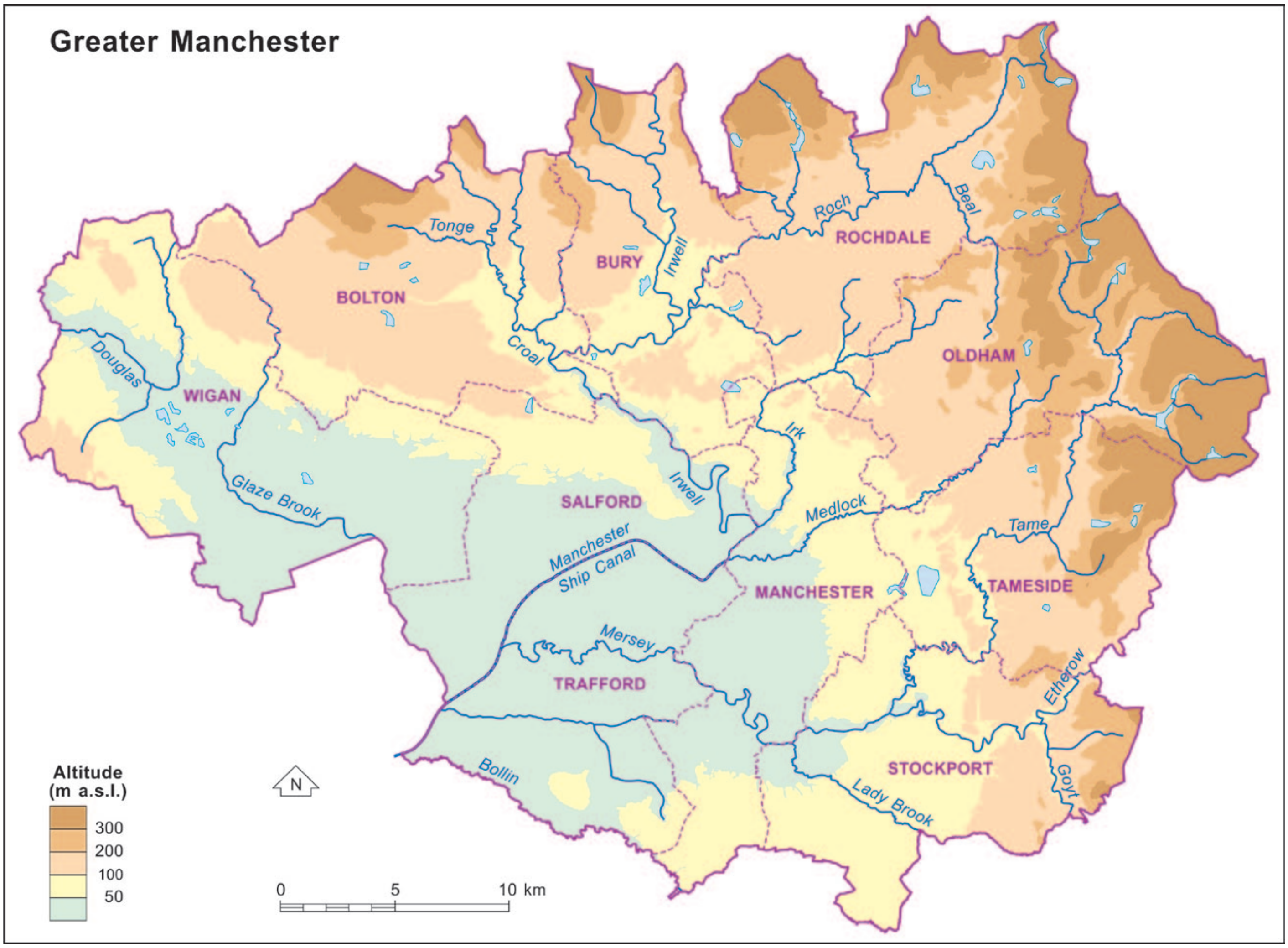


Figure 1: Greater Manchester main rivers.

in 1970 followed by the increase to 2.92 in 1979. Thereafter the sinuosity decreased rapidly to 1.40 in 2002. The increase of sinuosity was driven by downstream migration of individual bends, decreasing in wavelength and increasing in amplitude, while the last stage of sinuosity decrease has been driven by cut-offs, mainly between 1998 and 2001.

A progressive increase in sinuosity of the River Dane has been linked to the development of the modern floodplain (Harvey 1985; Hooke & Redmond 1989). The river Dane about 20 km south of Greater Manchester has the same natural conditions as the rivers in Greater Manchester, but little anthropic disturbance and thus provides an example of more natural river behaviour. A process of self-organising of the system can explain the changes in these rivers. The increasing of the channel sinuosity would reach a maximum, critical state, which is later decreased by cut-offs. High discharge events could trigger the main cut-off process when sinuosity is at a critical state, but if it is not at the critical state, high discharge would not be sufficient to trigger these changes (Hooke 2004; Hooke & Yorke 2010).

Urbanisation in Manchester

The river channels in Greater Manchester were heavily used for navigation and freight traffic during the industrial revolution. Firstly, natural channels were straightened by artificial cut-offs, and later artificial canals were constructed. The 58 km long Manchester Ship Canal connecting Manchester with Liverpool along part of the valley of the Mersey and the Irwell was opened in 1893. It is a remarkable engineering structure, 37 metres wide and around 8 meters deep.

Most of the headwaters have been dammed to provide drinking water to the population. The floodplains and river banks have been the venue to urban occupation through channels straightening and canalisations and man-made grounds on floodplains and river terraces (Dodge & Perkins 2010). Urbanisation has brought environmental problems such as water pollution and flooding, and the anthropic interventions in the fluvial systems have only partially solved these problems, which are often shifted further downstream (Douglas 1985).

Although the velocity of channel flows has increased, the channel capacity has been reduced due to the siltation and narrowing of cross-sectional area, as a result water levels rise rapidly when peak flows enter these narrow sections. In addition, the rapid expansion of built-up areas in the catchment has increased the storm runoff, while rural drainage works for pasture improvement have added to the increased peak discharges even after moderate storms, increasing the magnitude of seasonal floods (Douglas, 1985; Lawson & Lindley, 2008). During rain events at frequencies rarer than the annual flood the whole rural area gets saturated and the depth of runoff from rural areas is much the same as that from urban areas. It is such rare prolonged rain events that create widespread flooding along the streams and rivers of the Mersey Basin.

The post-1945 period saw industries decline, the population stabilize and the large scale migration from the core of the older urban centres to new housing estates in the urban periphery (Greenwood 1996) (Figure 2). Derelict land reclamation and environmental improvements programmes throughout the river systems of Greater Manchester have helped to establish a new, but more natural, geomorphology (Douglas 1985).

Methodology

Geomorphological actions by human activities in towns and cities are direct and effective agents of landform change (Douglas & Spencer 1982; Douglas & Lawson 2000). Thus, geomorphology provides both a powerful analytical methodological to examine spatial changes to the physical systems of urban environments and a framework for understanding the current and historical behaviour of these systems (Fookes & Lee 2005). The different stages of anthropic intervention in the natural systems must be established and the pre-urban system must be reconstituted, in order to gain a better understanding of the impact of urban interventions on the original geomorphological features and their dynamics (Nir 1983; Verstappen 1983; Gregory & Walling 1987; Toy & Hadley 1987; Goudie & Viles 1997).

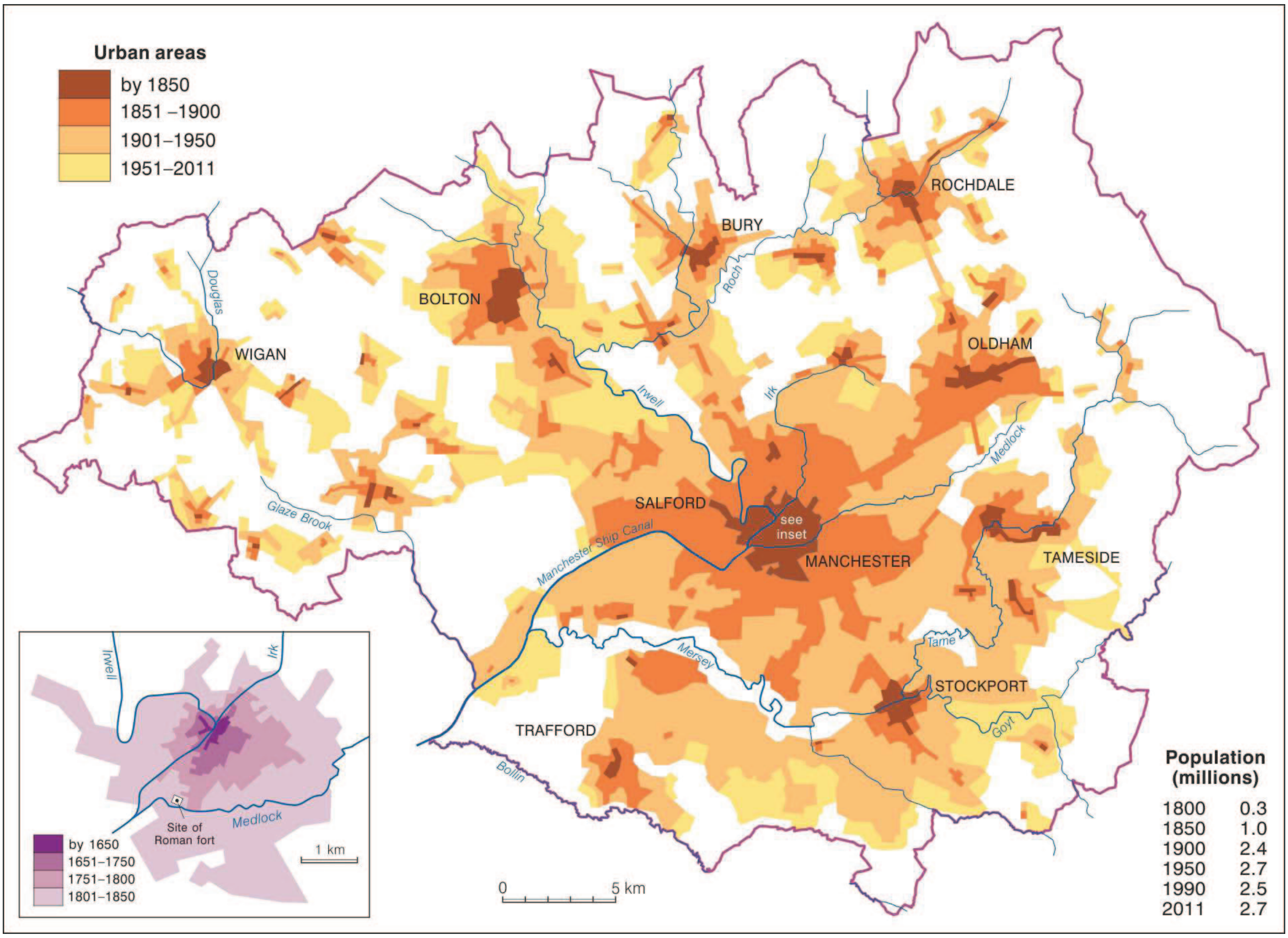


Figure 2: Urban growth in Greater Manchester.

Historical records, particularly maps, have been used to interpret former river channel courses, patterns of fluvial changes and the extent and dynamics of floods. Cartographic data help in the interpretation and measurement of past changes and in studying the evolution of landforms, enabling the rates and nature of changes to be quantified (Berger 1996; Coltrinari 1996; Gupta 2002; Rodrigues & Coltrinari 2004). Such information helps to establish the impact of people-made changes in urban areas on fluvial systems and their consequences for present and future urban construction, land development and river management.

In this investigation old maps and plans of the areas that now form Greater Manchester were used to reconstruct the original fluvial system and to identify the changes that occurred during the growth of cities and towns. The main data source was the Ordnance Survey historical maps from the 1840s to 1990s, particularly the County Series for 1:10,560, which are available on internet already georeferenced <http://www.digimap.edina.ac.uk>. Earlier maps and plans were examined in the historical archives in the City of Manchester Library and in collections available on the internet: The University of Manchester Library; The John Rylands Library; Chetham's Library; Genmaps <http://freepages.genealogy.rootsweb.ancestry.com/~genmaps/index.html>; and in the Lancashire County Council Old Maps website <http://www.lancashire.gov.uk/environment/oldmap/index.asp>.

The Ordnance Survey maps of different dates were inserted in a Geographical Information System (GIS) using ArcGis 10 software, along with the current topography and land-use provided by the Ordnance Survey (GB) and geological data provided by the British Geological Survey (BGS). Then, the rivers courses and fluvial landforms were mapped and the quantitative spatial data were calculated, enabling changes in such geomorphological indicators as floodplain area and flood attenuation capacity, type of artificial deposits and changes in the channel sinuosity to be established.

Meander channel adjustments are considered at three scales: 1) a 17 km reach of the lower Irwell; 2) a now buried, 1 km wavelength meander of the former course of the Irwell at Salford Quays and; 3) a 4 km long reach of currently actively eroding mobile meanders of the Mersey at Urmston and Carrington. Some cases of study in urban meandering fluvial systems in São Paulo-Brazil were studied under the same guidelines and one of them, the River Pinheiros, was described and compared with the Greater Manchester examples.

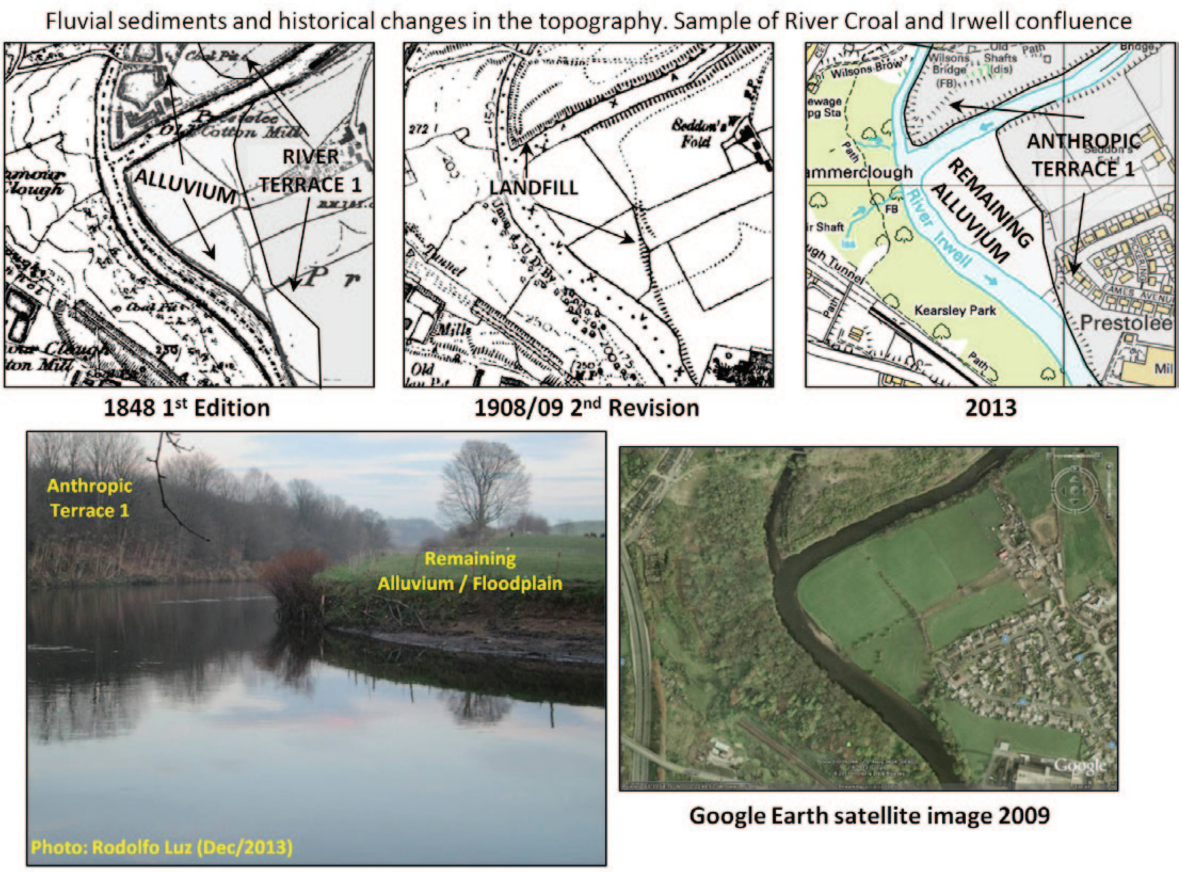


Figure 3: Sample of topographies changed by man and remaining lands.

Results

Geomorphological changes and flood storage capacity of the River Irwell in Salford

The reconstruction of the pre-urbanisation morphology of the River Irwell established the former topography of the area and the occurrence of fluvial sediments. Although not sufficiently detailed for a complete fluvial geomorphological survey, the historic Ordnance Survey maps helped in understanding pre-industrial topography. Former contours enabled the history of the land modifications to be traced, permitting the determination of whether specific elements of the current topography had been changed or remain similar to the pre-urban landforms.

Three units of fluvial deposits: alluvium, river terrace deposits 1 and river terrace deposits 2 extend along the River Irwell valley floor from Farnworth to Salford City Centre. (British Geological Survey (GB) 2013). These sediments are the product of Holocene fluvial processes that created the topography of the valley floor, the "alluvium" becoming the floodplain and the "rivers terraces 1 and 2" becoming the "first and second fluvial terraces" (Figure 3). The analysis of this Holocene geomorphology provides the natural geomorphology of the river before significant human impact (Figure 4) and the basis for understanding the changes to channel dynamics in the Anthropocene as a result of industrialisation, changes in sediment loads and landfilling encroachments on the floodplain and into the channel.

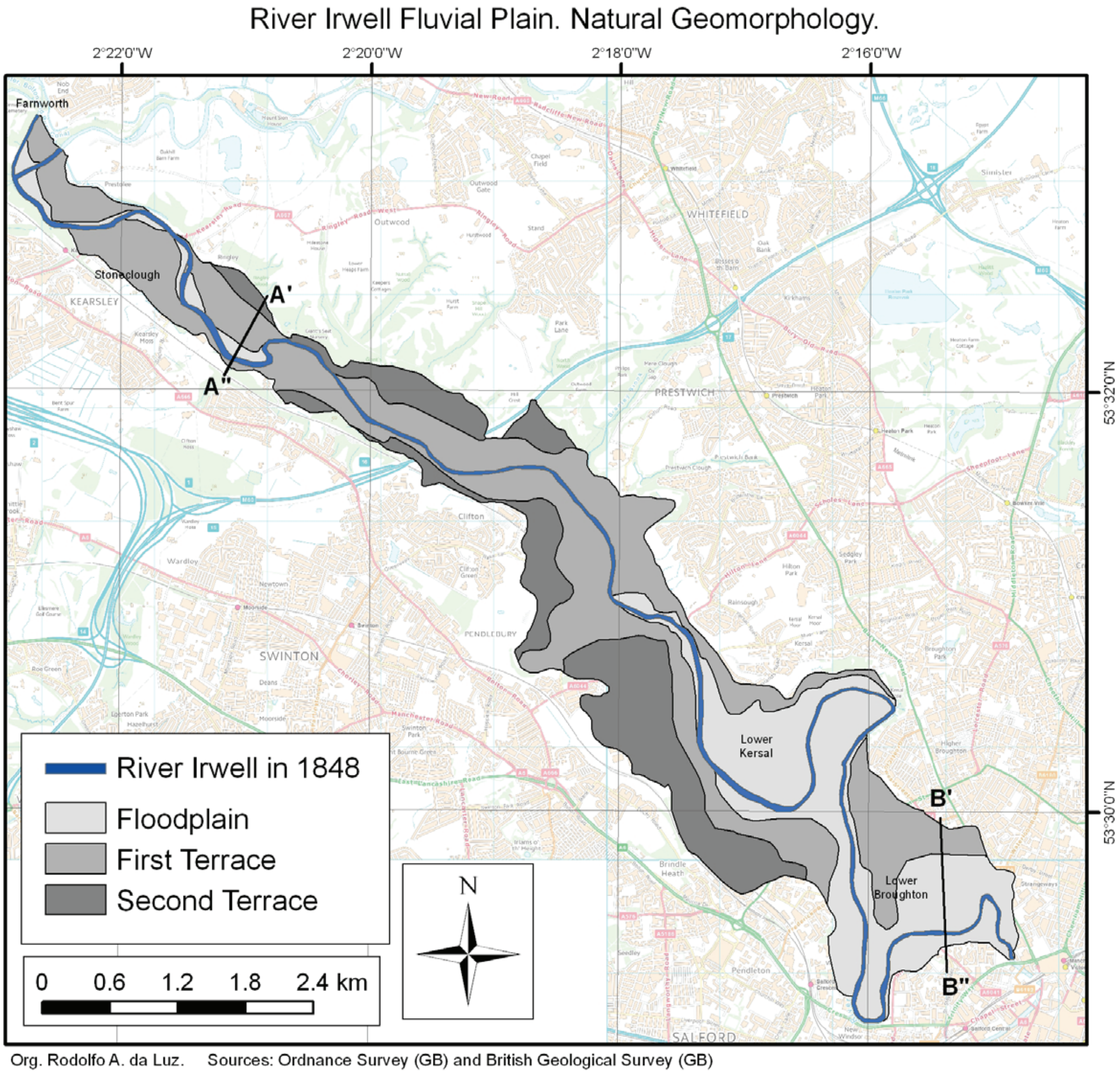


Figure 4: River Irwell Fluvial Plain Natural Geomorphology, based on Ordnance Survey (1848).

The lower reaches, particularly in Lower Broughton and Lower Kersal, where the natural floodplain is wider and the first terrace is more extensive, have a long history of flooding, usually after extended periods of widespread rain. For instance, in October 1946 some 81.5 mm of rain fell in 16 hours causing the river to rise some four metres in Salford and to inundate 243 hectares, affecting 5,000 residential and 300 industrial properties. In January 1954 the channel capacity exceeded after a prolonged rainfall, flooding 600 properties, while 50 mm of rainfall over a 48 hour period in October 1980, caused a flood that seriously impacted some 40 properties (Salford City Council 2007; Lawson and Carter 2009).

Using the reconstruction of the natural geomorphology, the role of urban occupation in altering the natural flood attenuation capacity of the floodplain and lowest terraces was established. The flood attenuation capacity of channels and floodplains is a function of the extent and depth of water flow (Scottish Executive Envionment Group Research 2005). The approximate water volume during a flood event can be estimated from the area of the geomorphological unit and from the height of the water column above the bankfull discharge stage. In this way, the volume of the floodplain seasonal floods and of the first terrace occasional floods may be estimated (Figure 5). As the water column is not homogeneous due to the variability of altitude of the geomorphological units, the average water column of each unit was assumed to be half of the maximum height between the top of the bankfull stage and the top of the unit, and the estimated water volume of the floodplain and lower terrace can be given by

$$V=a(h/2)$$

where a is the area of the geomorphological unit and h is the maximum height of the water column.

Applying the current digital elevation model (DEM) provided by the Ordnance Survey (2009) – OS Profile, with an accuracy of ±2.5 metres to the remaining lands identified from the historical series, analysis of typical geomorphological profiles of the original fluvial plain were established (Figure 6). These profiles and the DEM analysis suggest that the floodplain is located up to 2 metres above the bankfull stage and that the first terrace is situated up to 6 metres above bankfull (Table 1).

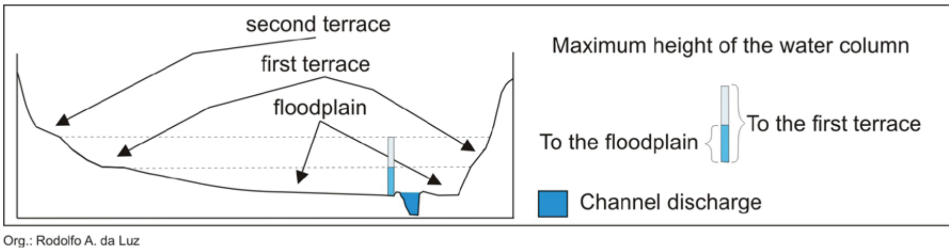


Figure 5: Estimation of the water column in a fluvial plain.

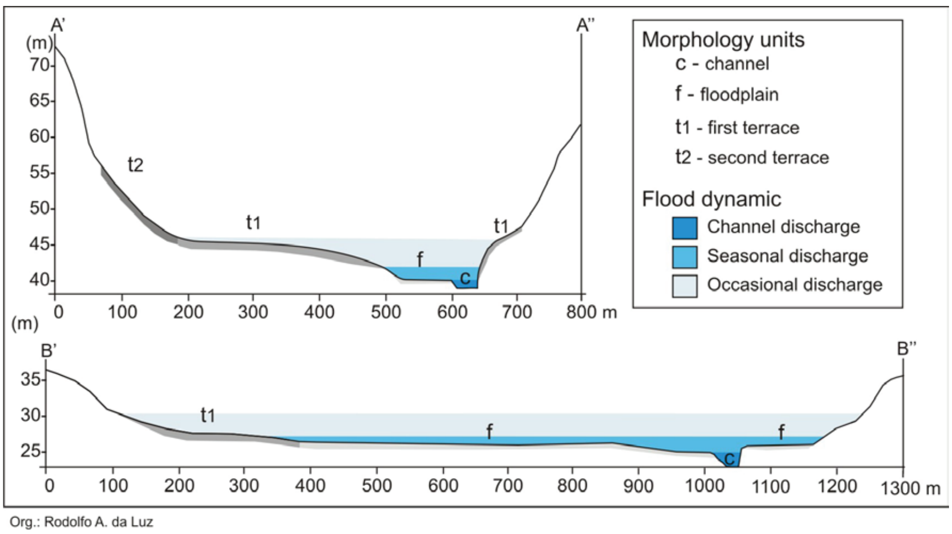


Figure 6: Original geomorphological profiles and flood dynamics. The profile locations are shown in Figure 4.

Table 1: Natural Flood Attenuation Capacity by Geomorphological Unit.

Geomorphological unit	Area (m²)	Maximum water column height (m)	Volume (m³)
Floodplain	3,151,705	2	3,151,705
First Terrace	5,036,351	6	15,109,053

The wide implications of human occupation of the Irwell Valley for flood dynamics were investigated by establishing the areas affected by urban occupation and/or artificial deposits (Ford *et al.* 2010), and the raised flood defences according to the National Flood and Coastal Defence Database (Manchester City; Salford City; Trafford Councils, 2010) (Figure 7). The historical occupation on the fluvial plain changed the original geomorphology, resulting in made and landscaped grounds (Figure 8). 60.4% of the current floodplain consists anthropogenic landforms and 53.6% of its natural flood attenuation capacity is over such features. Anthropic landforms cover 70.1% of the current first terrace and contribute that percentage of the natural flood attenuation capacity (Table 2).

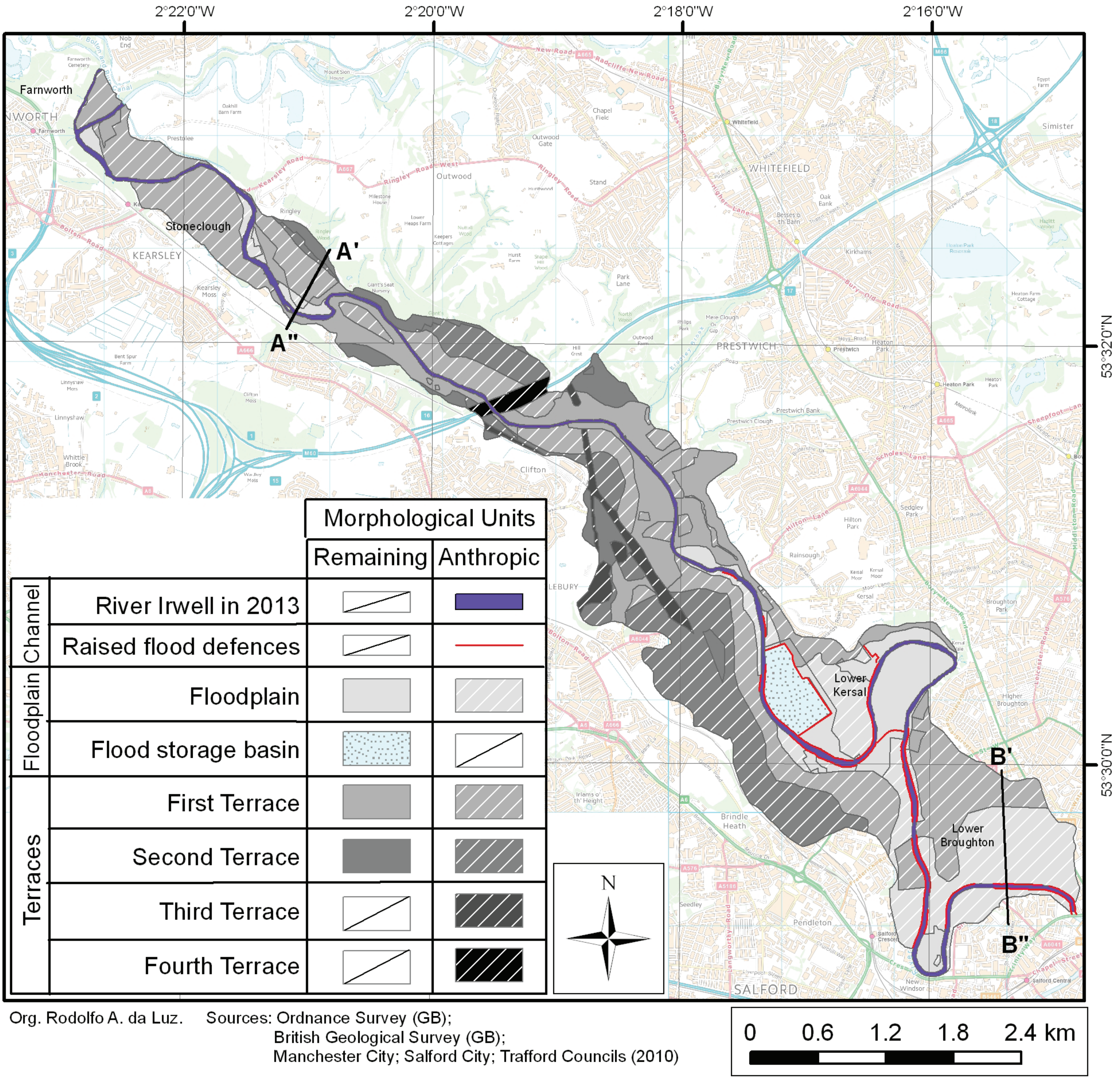


Figure 7: River Irwell Fluvial Plain Anthropic Geomorphology.

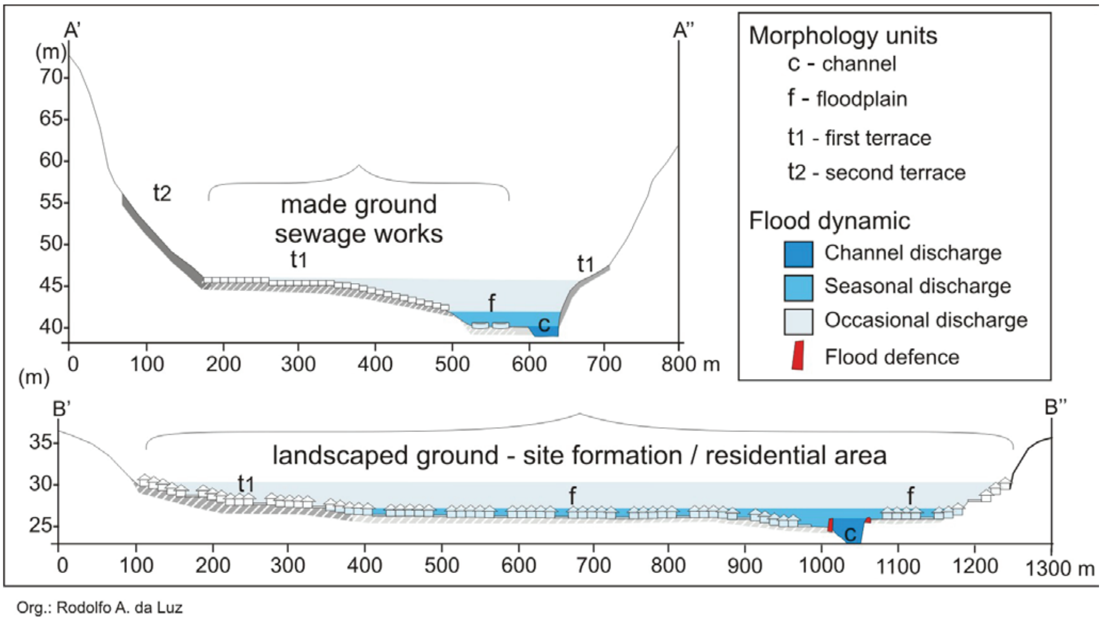


Figure 8: Anthropic geomorphological profiles and flood dynamics. Profile locations in figure 7.

Table 2: Flood Attenuation Capacity by Geomorphological Unit.

Geomorphological Unit		Area (m²)	Half of the maximum water column height (m)	Volume (m³)	Percentage of the geomorphological unit area	Percentage of the geomorphological unit volume capacity
Floodplain	Anthropic	1,796,036	1	1,796,036	60.4	53.6
	Remaining	902,083	1	902,083	30.4	26.9
	Flood Storage Basin	274,513	N/A*	650,000*	9.2	19.4
	Remaining Foodplain + Flood Storage Basin	1,176,596	N/A	1,552,083	39.6	46.4
	Total	2,972,632	N/A	3,348,119	100.0	100.00
First Terrace	Anthropic	3,523,942	3	10,571,826	70.1	70.1
	Remaining	1,502,610	3	4,507,832	29.9	29.9
	Total	5,026,553	N/A	15,079,659	100.0	100.0

* Irwell Catchment Flood Management Plan: Summary Report, managing flood risk. Environment Agency, 2008.

Due to their relative lack of human use and modification, the remaining unmodified valley floor landforms are areas where floods have little impact and pose few risks to people. Such little modified areas now occupy only 37.3% of their original extent on the floodplain, only 29.8% on the first terrace and 46.7% on the second terrace. However, two higher terrace levels have been created by embankment construction and landfilling (Table 3).

Table 3: Changes in the Geomorphological Unit Area (Remaining – Original Lands).

Geomorphological Unit	Area (m²)	(%)
Floodplain	−1,975,109	−62.7
First Terrace	−3,533,740	−70.2
Second Terrace	−1,334,668	−53.3
Third Terrace	+282,894	+100.0
Fouth Terrace	+96,419	+100.0

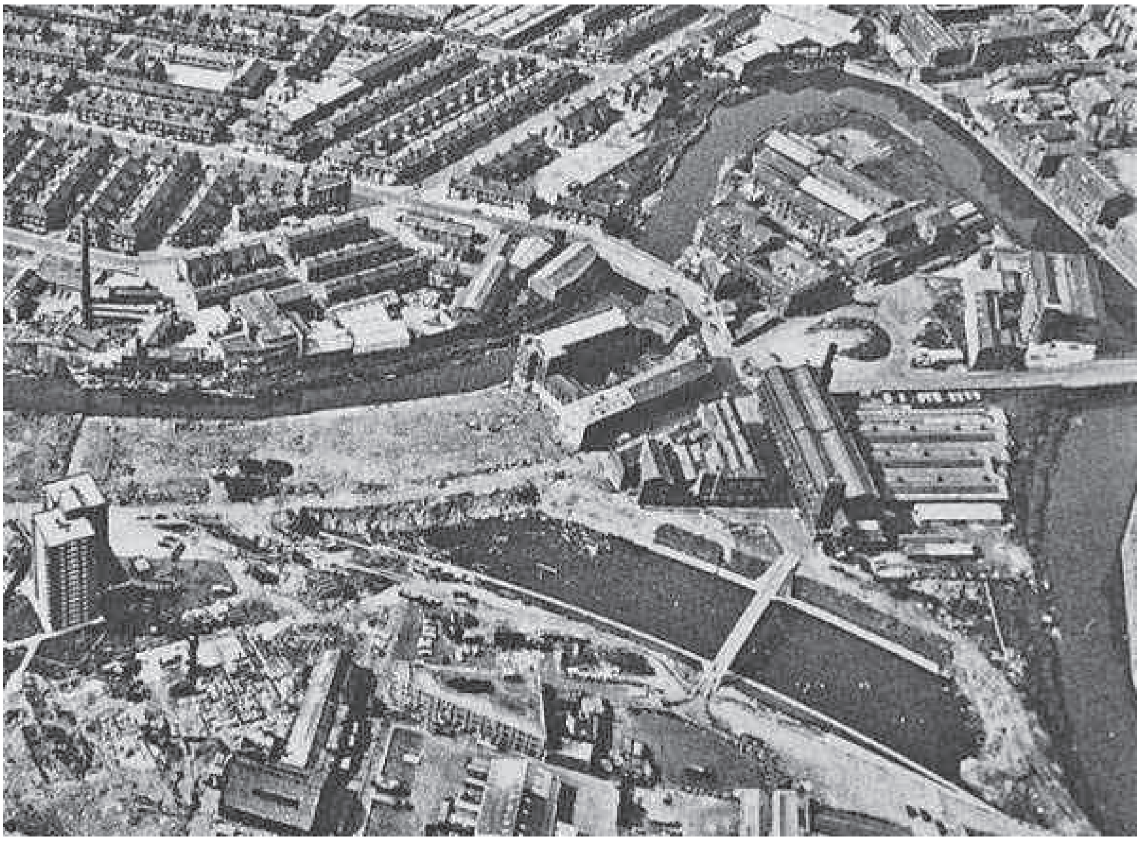


Figure 9: The Anaconda Cut under construction.
Source: http://www.flickr.com/photos/soundman/2830040495/.

This reduction of the floodplain and fluvial terrace areas with little economic and social risk associated with flooding has occurred over a period when the frequency of severe flooding is increasing due to urban growth and more rapid surface runoff in the Irwell catchment area. Moreover, anthropogenic modifications have produced considerable variations in the River Irwell channel capacity, arising from such processes such as siltation, encroachment of many structures into the river, meander narrowing and an artificial cut-off in Lower Broughton, called the Anaconda Cut (Figure 9). Such modifications have enhanced the rapid rises of the river level produced by the storms (Douglas 1985).

Flood risks in the area have been reduced by increasing the channel capacity (construction of flood defences/embankments and artificial cut-off), and by increasing in the amount of flood storage capacity of the system (construction of an artificial Flood Storage Basin in Lower Kersal, Figure 10) (Environment Agency 2008). Flood reduction engineering works have helped to lower peaks in the main channel by off-channel storage and have protected many sectors of the floodplain that formerly were inundated every winter. However, flood embankments can impede drainage from small urbanised streams by causing water to back-up in tributary valleys whenever river levels are higher than those in the small side streams.

Hydrological changes due to urbanisation and climate change which will influence future hydrodynamics are reflected in the Irwell Catchment Flood Management Plan (Environment Agency 2008) which anticipates that flood levels in Salford will increase by 1 metre by 2100, and notes that such an increase in water level would exceed the freeboard levels designed in current defences.

This historical analysis of the fluvial geomorphology of the River shows how, despite the construction of flood defences and flood storage basins, river channel adjustments continue and human responses to these adjustments will remain necessary. Additional urban drainage and increase in impervious areas are likely to continue to lead to further occasional flooding of areas close to the river.

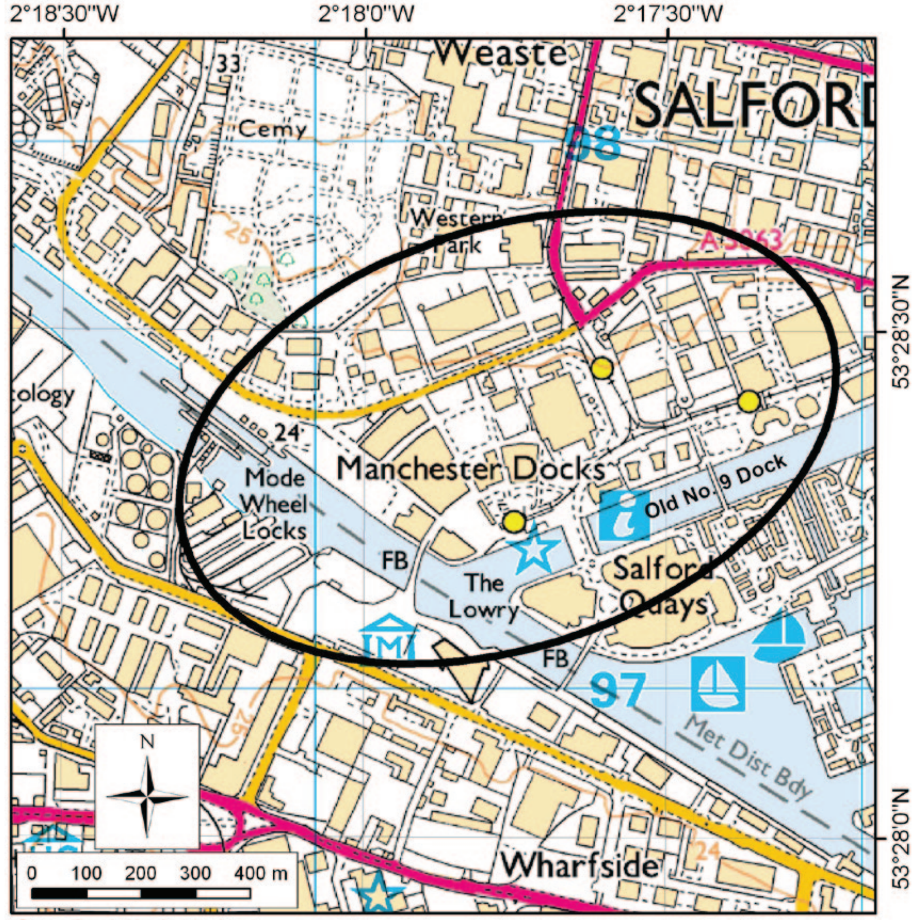
Salford Quays and the buried former River Irwell meander

Analysis of old maps and navigation plans of the River Irwell reveals a meander loop where Salford Quays stand today, close to the old No. 9 Dock and the Media City UK (Figure 11 and Figure 12). This former meander is usually neglected in studies reconstructing the original River Irwell channel, probably because it was straightened before the first comprehensive spatially accurate maps were published in 1848, those of the Ordinance Survey – First Edition (Figure 13).

Figure 10: Flood storage Basin in Lower Kersal: a) Warning Sign; b) and c) Outfall Debris Screen; d) Outfall Debris Screen foreground and Inlet Weir background right.

Figure 11: Manchester Ship Canal, Media City and part of the old No.9 Dock (Photo: Nigel Lawson, Dec. 2013).

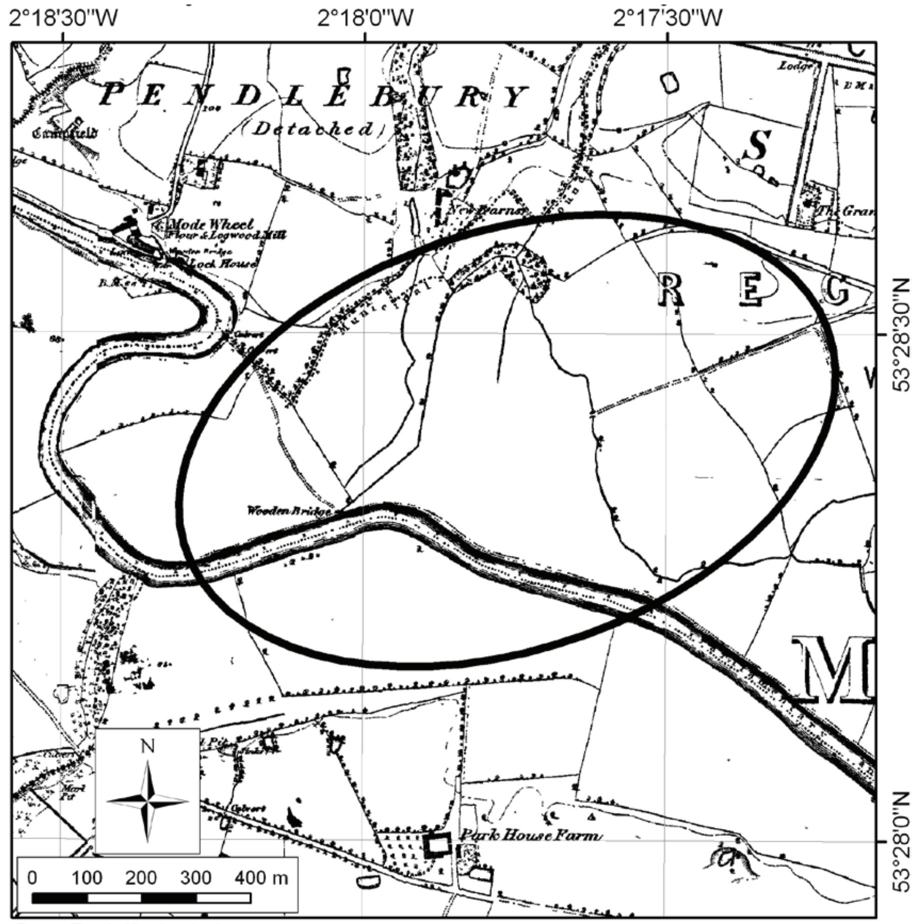
Figure 12: *Map of the River Irwell in Salford Quays.*



Org.: Rodolfo A. da Luz
Source: Ordnance Survey (GB)

Figure 13: Salford Quays area in 1848.

Source: Ordnance Survey – First Edition.



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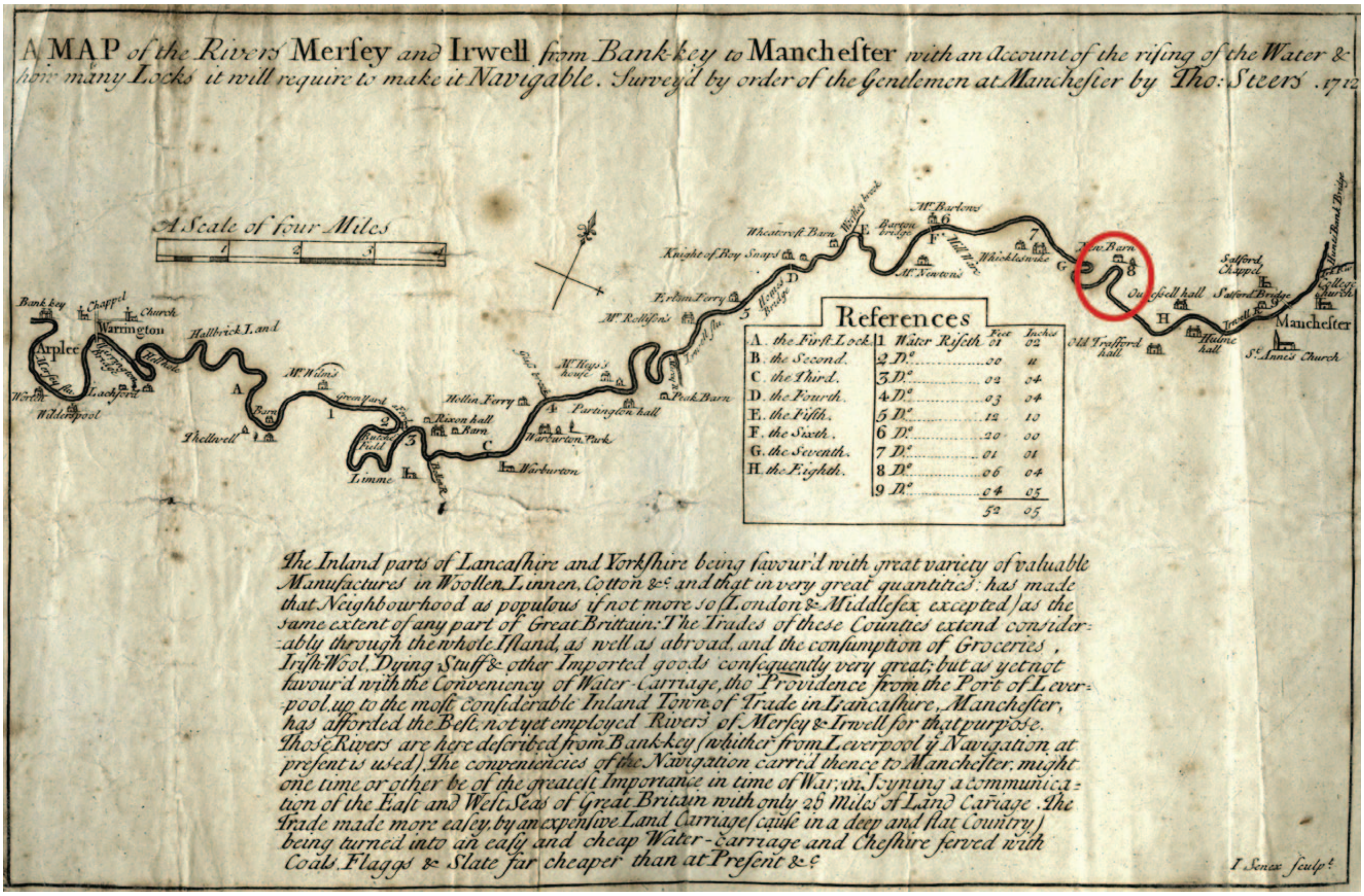

Figure 14: Location of the meander in 1712.

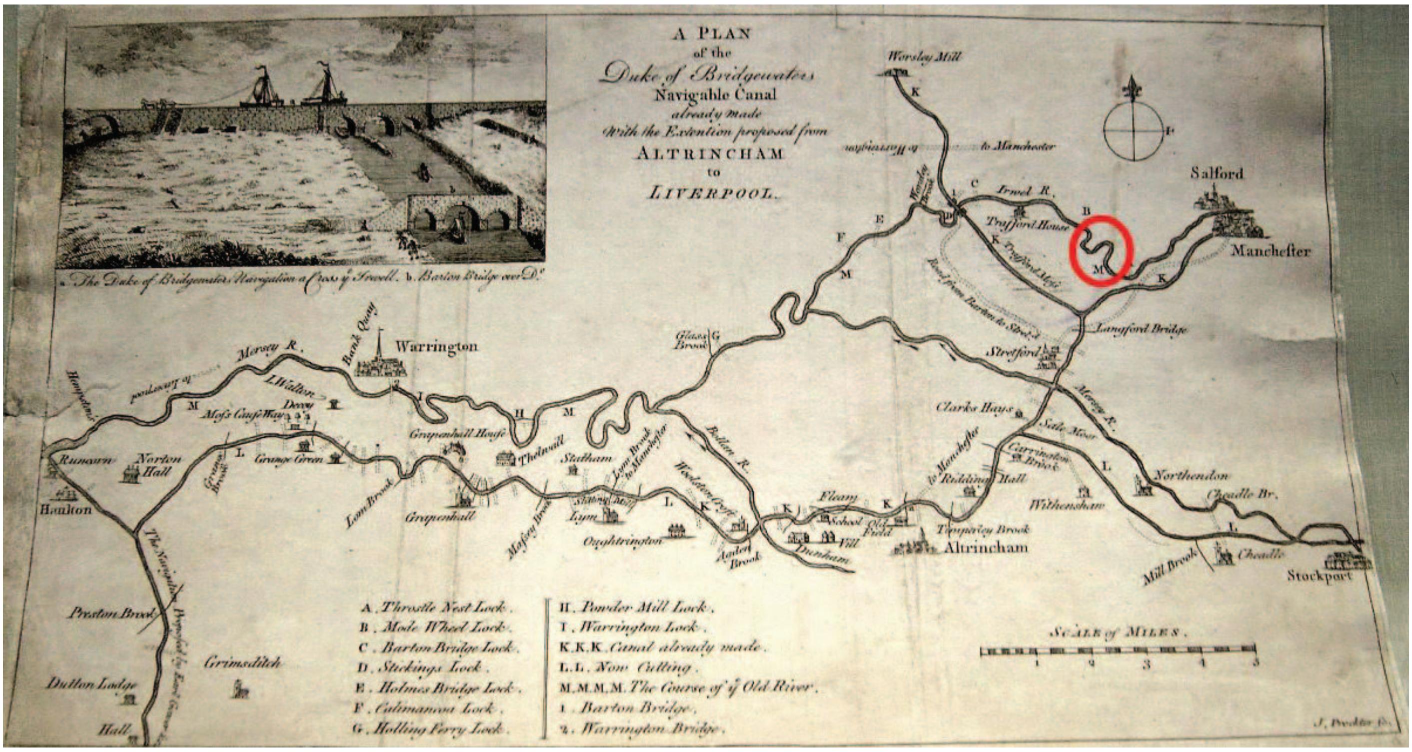

Figure 15: Location of the meander in 1766.

The oldest historical document found on which this meander appears is the 1712 *"A Map of the Rivers Mersey and Irwell from Bank-key to Manchester with an account of the rising of the Water and how many Locks it will require to make it Navigable. Surveyd by order of the Gentlemen at Manchester by Tho:Steers"* (Figure 14).

Subsequently, the same meander may be identified in plans relating to the early years of the operation of the Bridgewater Canal:

- *"A Plan of the Duke of Bridgewater's Navigable Canal already Made With the Extention proposed from Altrincham to Liverpool"*, dated 1766 (Figure 15);
- *"A Plan of the Old Navigation from Liverpool to Manchester (in part) and of the Duke of Bridgewater's Navigable Canal from the Coal Mine to Manchester and to Stradford"*, dated 1766 (Figure 16);
- *"A Plan of the Duke of Bridgewater's Navigable Canal"*, dated 1776 (Figure 17).

Figure 16: Location of the meander in 1766.

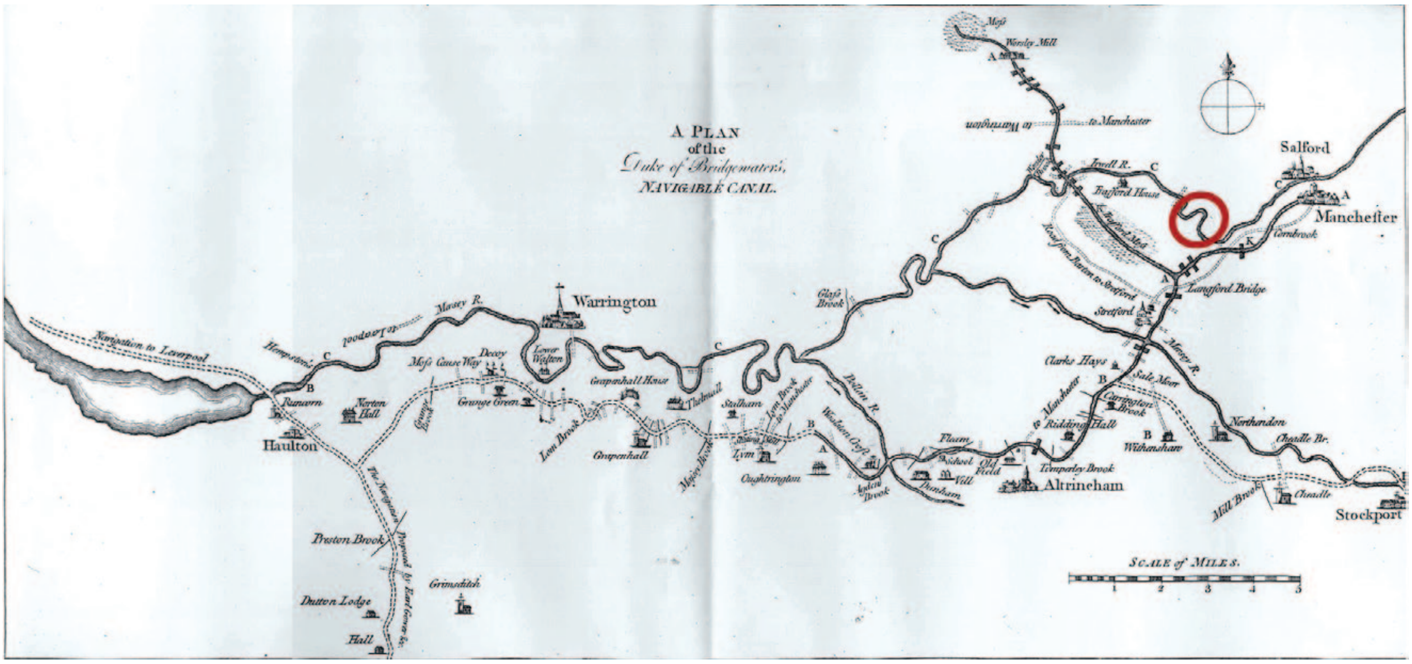

Figure 17: Location of the meander in 1776.

The questionable cartographic accuracy of these plans does not permit the conclusive determination of the existence and exact position of this feature. Nevertheless, a more accurate indication of this meander is found on *"William Yates's Map of Lancashire"* dated 1787 (Figure 18). Despite its smaller scale, this survey is a landmark achievement in the mapping of Lancashire being the first local map to be based on trigonometrical survey, which led to much improved cartographical accuracy (Harley 1963). Interestingly this map shows a meander cut-off by a straight canal (Figure 18), probably made to improve navigation, which may explain why cartographical surveys made after 1787 do not show the meander.

Although the old maps do not provide the exact size and shape of the feature, their varied, independent sources provide enough external corroboration to confirm the presence of the old meander (Hooke and Kain 1982). These maps also reveal that, beside the rivers hidden under the city, the past positions of these features may also be hidden from public knowledge (Dodge & Perkins 2010).

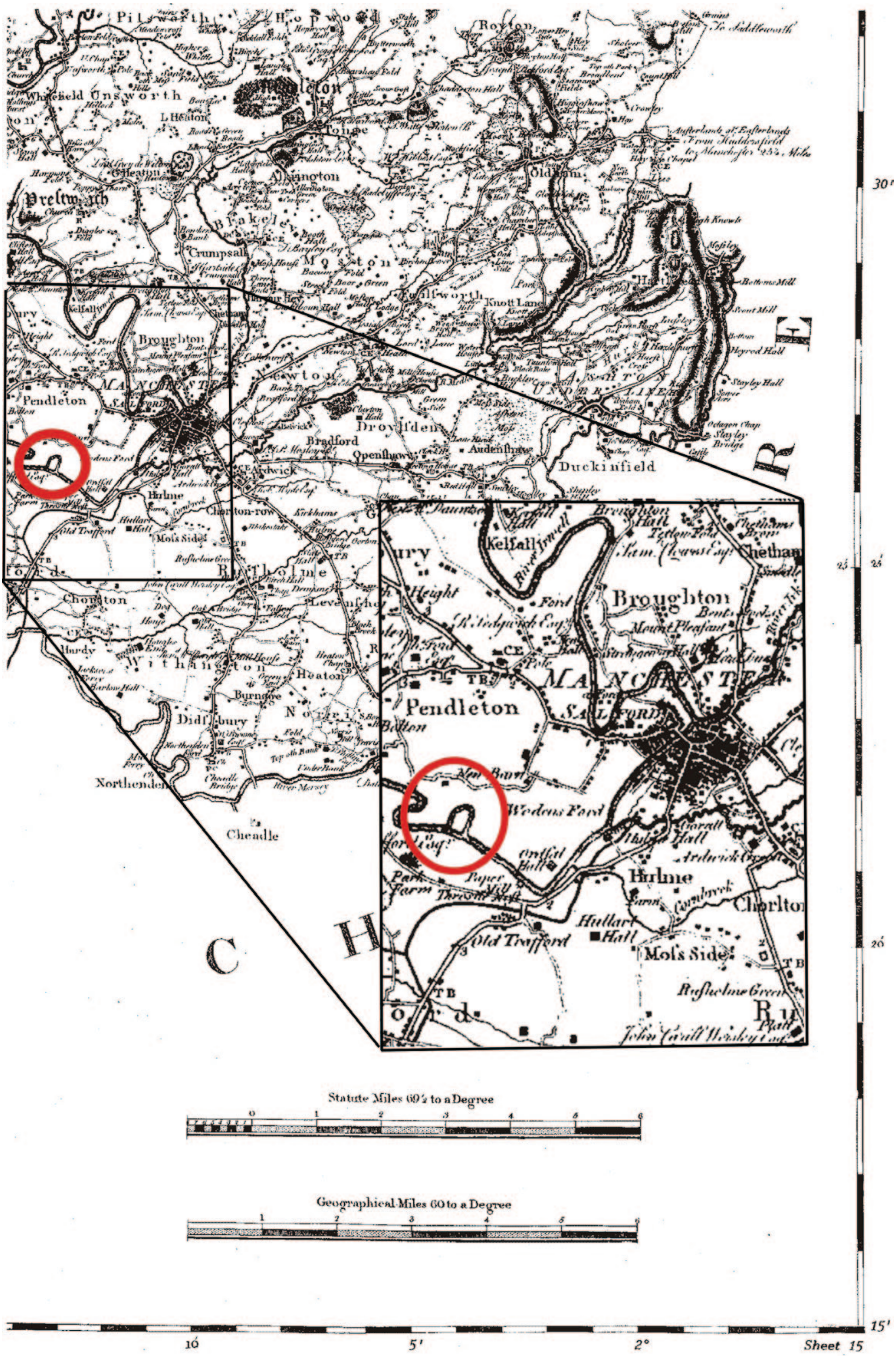

Figure 18: Location of the meander cut-off in 1787.

Stratigraphical setting

Borehole data were used to identify specific sedimentological and stratigraphic fluvial deposition characteristics. According to the British Geological Survey borehole database borehole record viewer (British Geological Survey (GB) 2013) the subsurface of the area, specifically along Broadway in Salford, consists predominantly of artificial deposits of up to 5 metres thick overlying fluvial sediment (Figure 19). The artificial deposits comprise mainly ash and cinders, with frequent bricks and occasional rubble and cobblestones.

The 2008 "Environmental Risk Assessments, Remedial Strategy and Implementation Plan", undertaken by Jacobs UK Ltd. during pre-construction investigations for Media City UK, identified similar artificial deposits in the area: "generally comprises a granular mixture of sands, gravels, ash, clinker and rubble, with a lesser proportion of silts or clays. The granular layer is commonly underlain by more cohesive fill at depth."

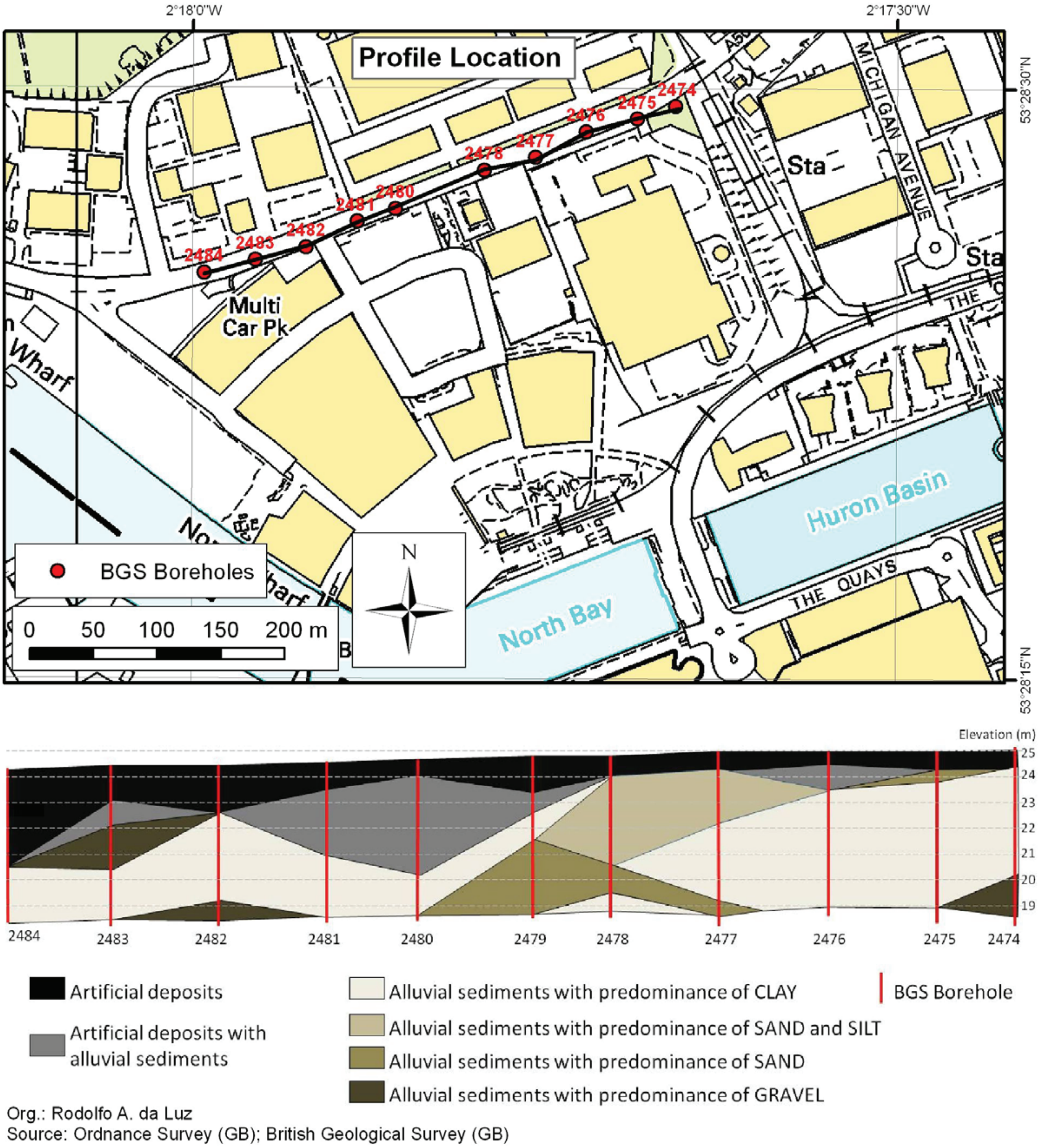

Figure 19: Geological profile came from BGS Boreholes.

The artificial deposits around this site (Figure 20) have been classified as (Bridge *et al.* 2010):

1. Made Ground Trafford Park Industrial Estate: Material associated with extensive industrial development after World War II, which included the establishment of many chemical manufacturing industries. Also, material excavated during the construction of the Manchester Ship Canal used to raise land adjacent to the main navigation.
2. Made Ground River Irwell: Meander loops of the River Irwell, infilled during construction of the Manchester Ship Canal; colliery spoil and material excavated from the main channel of the Manchester Ship Canal; organic and inorganic domestic refuse also proved by drilling; and infilling of the River Irwell predating the development of Trafford Park, which now extends across the former meander belt. Ground conditions in this complex area of Made Ground are, therefore likely to be highly variable.

The "Made Ground River Irwell" category (Figure 20) corresponds to the old River Irwell channel. Re-examination of the artificial deposits at Salford Quays, close to the old No. 9 Dock and Media City UK, indicated that the old River Irwell channel included the now buried meander whose deposits fall into this "Made Ground River Irwell" category.

Borehole data and geological profiles in the Media City UK report and Bridge *et al.* (2010) show that these artificial deposits are commonly 3 to 7 metres thick and overlie fluvial sediments. However they are up to 10.3 metres thick around the Manchester Ship Canal and the old No. 9 Dock, this being related to the excavation of these structures (Figure 21 and Figure 22). Both the past channel dynamics and the extensive of anthropogenic impact on this old fluvial system have led to specific geotechnical conditions (Jacobs UK Limited Report 2008; Bridge *et al.* 2010):

- Made ground. High variability of the plasticity, consistency and density; lower bound to the effective overburden pressure close to the surface; presence of hazardous waste and contaminated ground.
- Fluvial deposits. Poor foundation; presence of soft highly compressible zones; differential settlement; risk of running sand into an excavation.

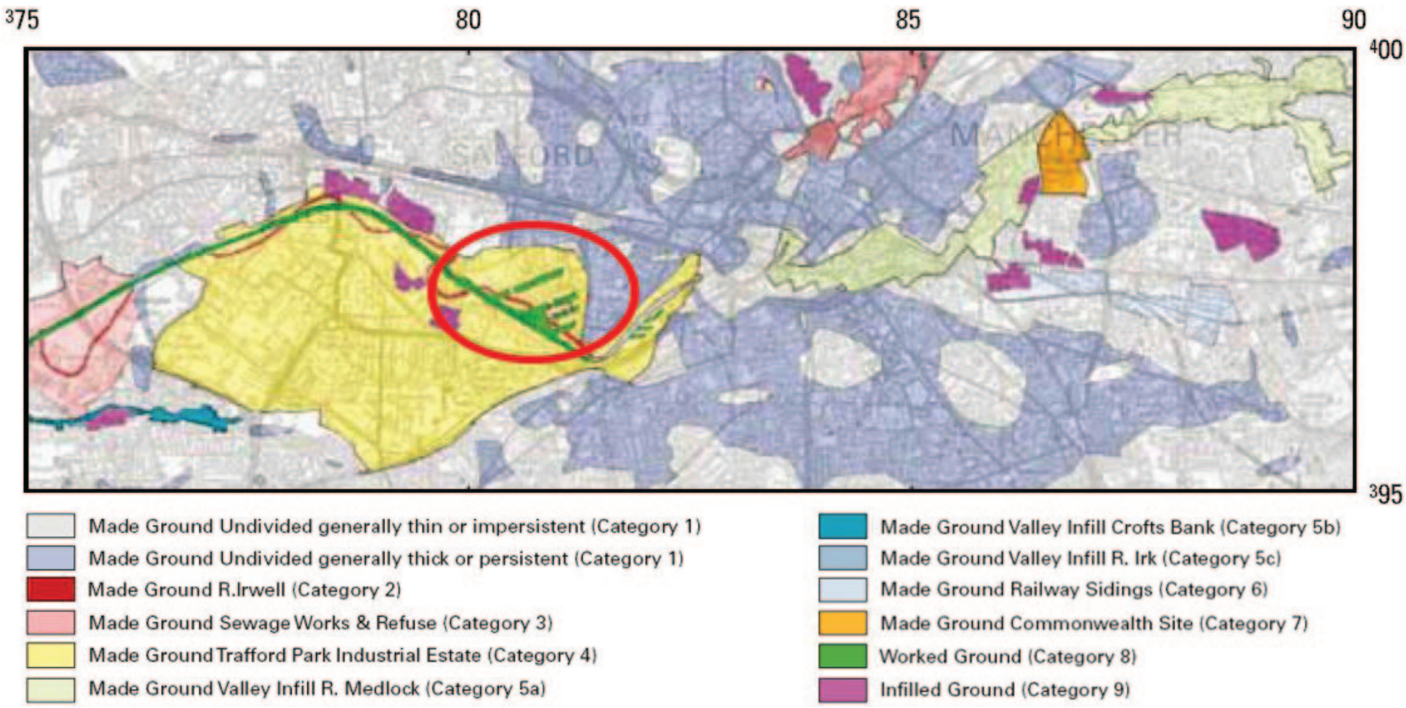

Figure 20: Types of artificial deposit according to Bridge *et al.* (2010).

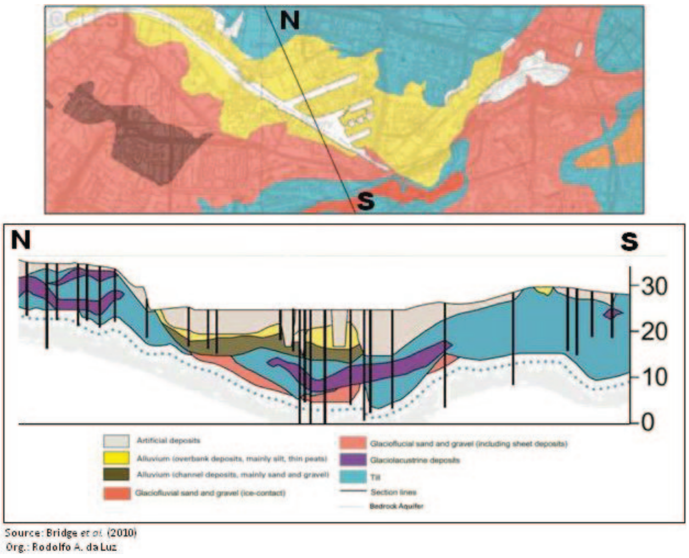

Figure 21: Geological profile in Salford Quays.

The geotechnical character of these deposits stems from the original natural fluvial processes and the subsequent anthropogenic excavations, infilling and land use changes. They help in the identification of the pre-urban fluvial system and the phases of artificial deposition. Engineering structures and urban land-uses in this former floodplain should be built with full awareness of possible problems arising from the varied earth surface materials in the pre-urban active meander belt and the overlying artificial deposits.

River Mersey channel changes in Urmston and Carrington.

The River Mersey downstream from the confluence with the River Irwell was completely transformed due to the construction of Manchester Ship Canal (1887-1893). Above the confluence many reaches have been embanked since 1588 and have had their flood defences augmented by a series of flood storage basins. The defences were built-up gradually and were originally rather unstable. The more solid embankments constructed later resisted erosion resulting in no change in the channel sinuosity upstream of Ashton Weir since 1848 (Leng 1989). However, there is a reach in Urmston and Carrington between the Ashton Weir and Irlam Weir that is relatively free of engineering structures (Figure 23).

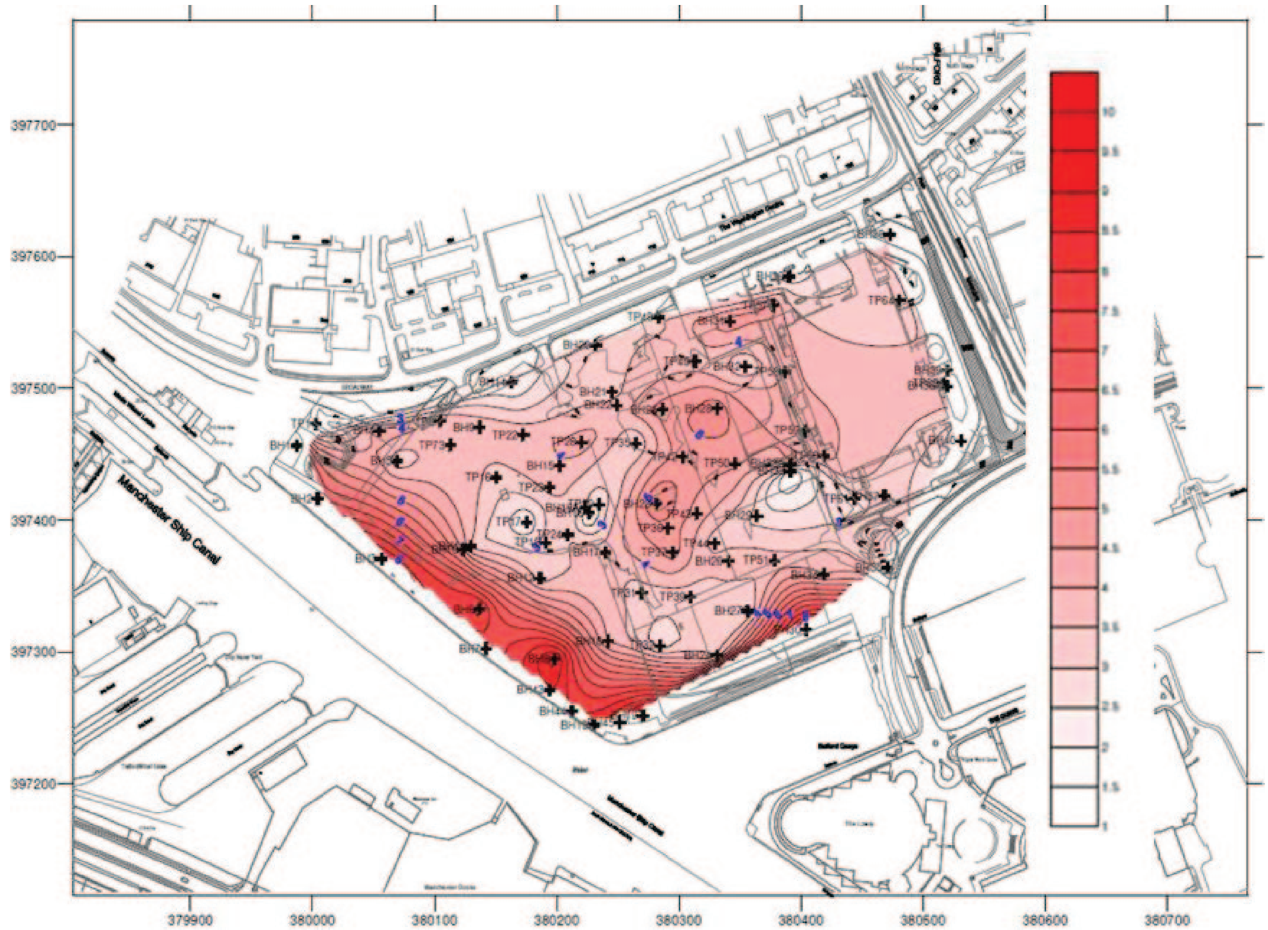

Figure 22: Depth of the made ground in Media City.

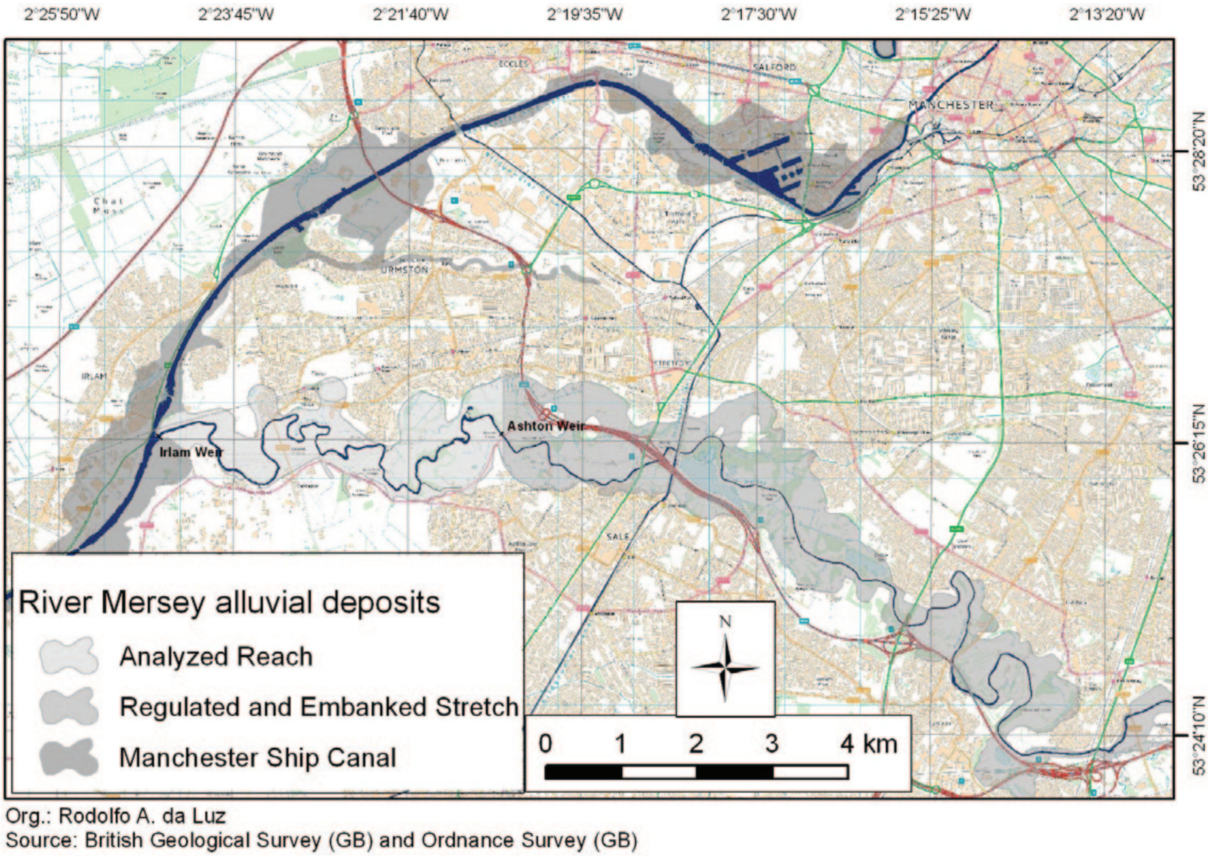

Figure 23: Location of the analyzed reach.

When the Manchester Ship Canal was built, the local base level was lowered and the Mersey began to incise and undercut its meanders upstream its confluence with the Irwell, leading the upstream channel to enhance the undercut erosion. This prompted considerable channel adjustments in the relatively free floodplain between Urmston and Carrington. These natural meander dynamics have been enhanced by the energy of high river flows constrained within the channelized reaches upstream which then become free to erode below Ashton Weir, causing channel sinuosity reduction by meander cut-off and straightening (Douglas, 1985; Leng, 1989).

Historical cartography, using Ordnance Survey data for the period 1848 to 1996 and a Google earth image for 2009 enabled the changing role of the direct anthropic interference in the fluvial system at nine different dates to be assessed, confirming the trend to reduction in channel sinuosity (Figure 24 and 25). The fluvial channel showed a slow decrease of sinuosity after the construction of the Manchester Ship Canal in 1893, but this process became pronounced by the 1940s. The causes must be subject to further research; however they may be related to a time lag response to the decreasing in the base level and/or to the enhancing of the urbanisation of the catchment. The reduction in the sinuosity process seems to have increased after construction of flood storage basins upstream in Didsbury and Sale in 1970s (Figure 25). However, the reduction in sinuosity is not homogeneous, with two reaches being more affected than others (Figure 26).

In the Urmston reach, immediately below Ashton Weir, the channel sinuosity was greater than in the rest of the channel in 1848, but this reach has experienced a high rate of sinuosity reduction since then (Figure 27). Over 165 years the channel's sinuosity index fell from 2.2 to 1.2 with this reach of the river now being below the average sinuosity of all the reaches considered here. However, a slight increase in the channel sinuosity since 1996 is suggested by the 2009 satellite image (from 1.24 to 1.26). Some meander loops have experienced substantial erosion and deposition. For example near Urmston Cemetery, where a neck narrowing process identified from 1938 to 1971 was enhanced by two natural cut-offs between 1971 and 1986 (Leng, 1989). The 2009 situation indicates that these processes have continued, (Figure 28).

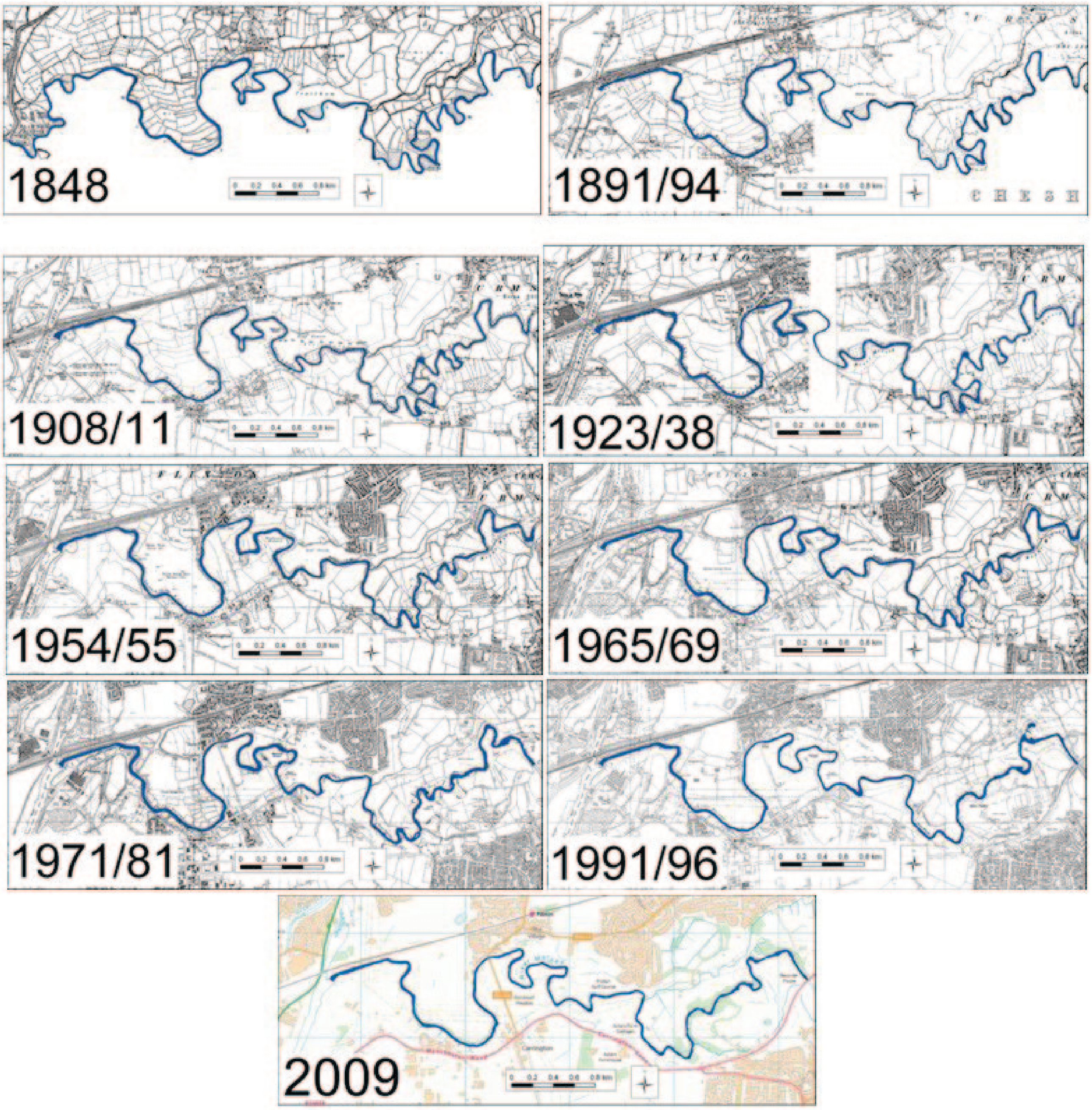

Figure 24: River Mersey in different historical moments.

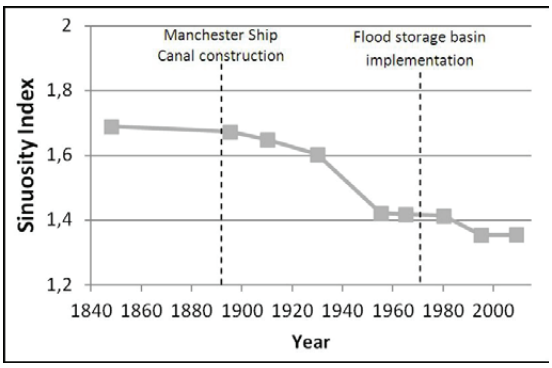

Figure 25: Sinuosity index temporal variation and direct anthropic interventions.

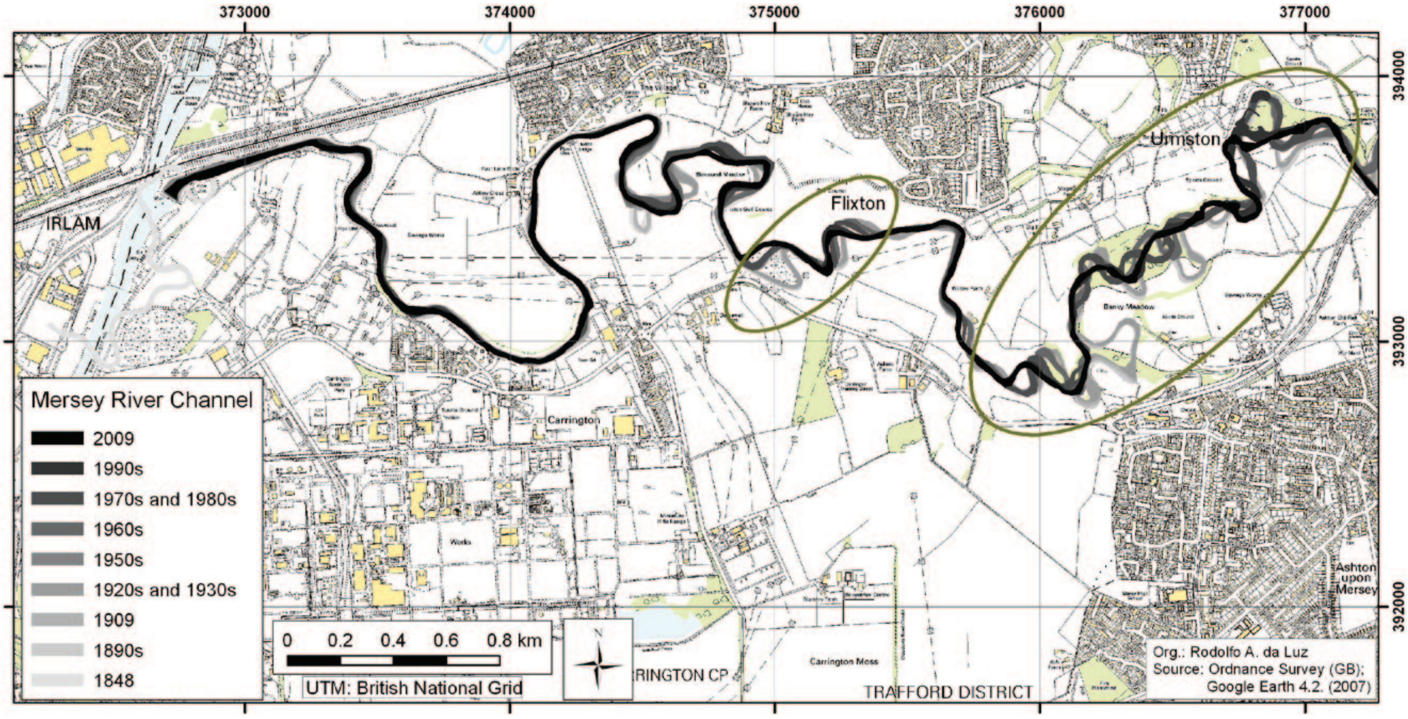

Figure 26: River Mersey channel evolution.

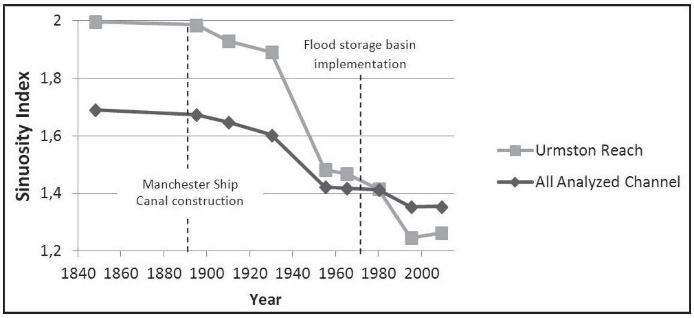

Figure 27: Comparison of the sinuosity index temporal variation in Urmston and in the River Mersey.

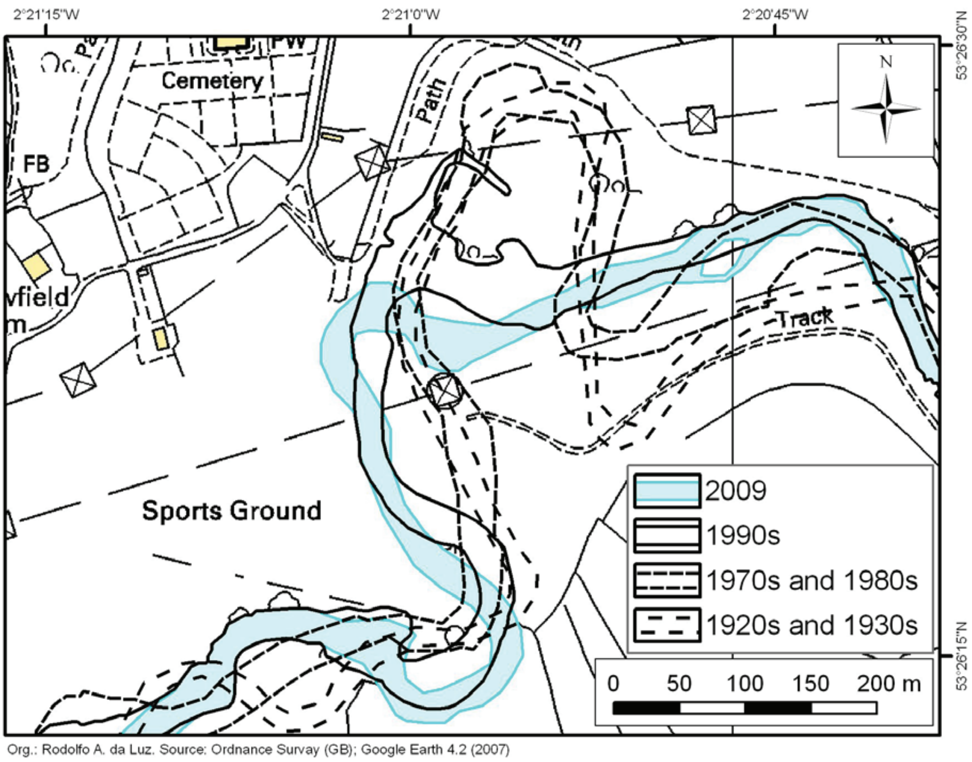

Figure 28: Channel evolution near Urmston Cemetery.

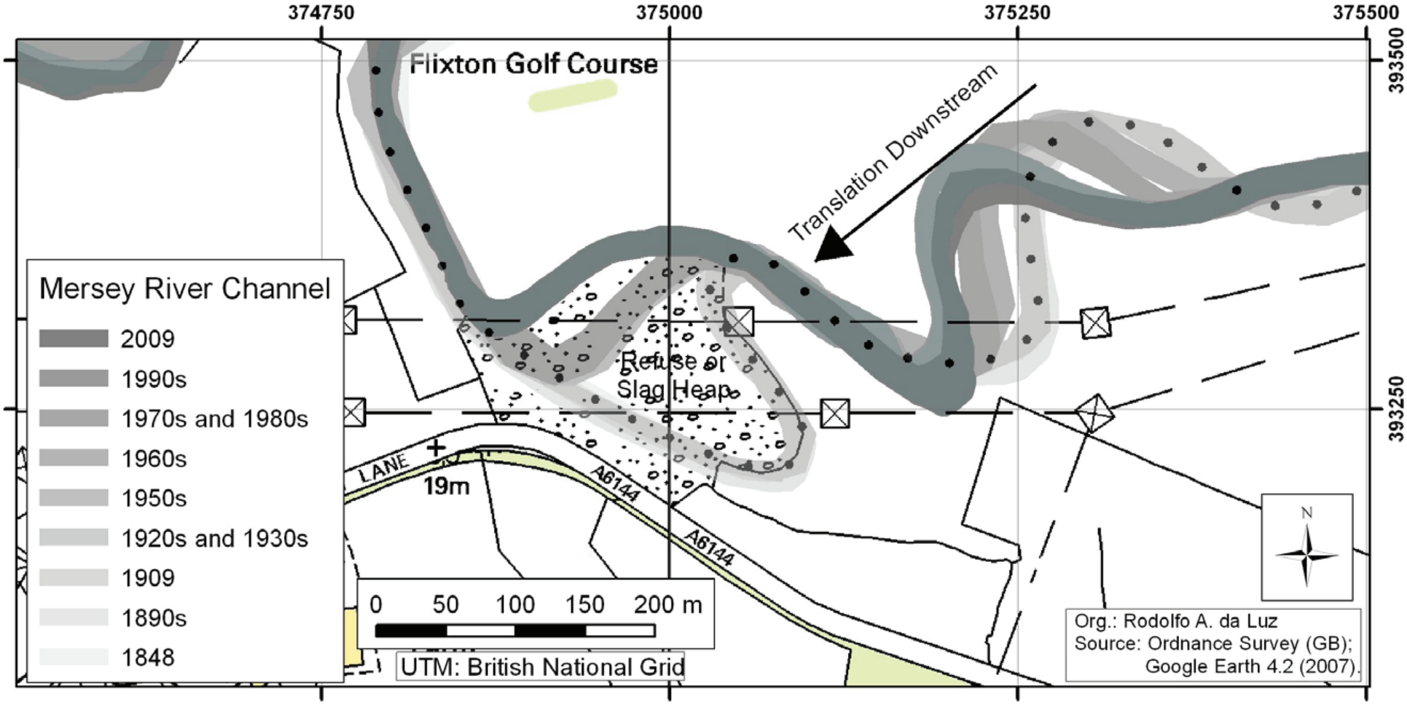

Figure 29: Meander translation towards downstream in Flixton.

The second highly dynamic reach is near Flixton where a meander moved about 110 metres downstream in 165 years and it will probably continue to migrate in this way towards a landfill site (Figure 29 and Figure 30). According to the Environment Agency waste and landfill database (http://www.environment-agency.gov.uk/business/topics/waste/default.aspx), the waste received at this site which operated from 1966 until its closure in 1993 comprised inert, industrial, household and liquids/sludge materials. If the meander continues to migrate it will erode these deposits and add potentially contaminated material to the river water.

Historical data reveals dramatic changes in the evolution of river channels including bank erosion, channel migration and straightening, characteristic of the meandering river systems of South Lancashire and North Cheshire, which here are greatly enhanced by anthropic actions. Engineering structures adjacent to these dynamic channels are potentially at risk, as demonstrates by an electricity pylon in Urmston that had to be relocated due to the channel bank erosion, at a cost of £ 500,000 (Figure 30). In addition to the direct anthropic changes to the rivers, such as the diversion into the Manchester Ship Canal and flood embankment construction, indirect interventions have been occurring throughout the catchment, from reservoir construction in the headwaters to increasing extensions of impermeable surfaces and small stream culverting or channelization. Thus the current dynamics of the river and its floodplain are typical of the Anthropcene and pose challenges for urban hydrology and urban geomorphology.

Discussion

Understanding the human role in changing river channels helps to improve the management of urban river channels (Gregory 2006). Historical analysis of changes in the urban environment provides guidance for the present and future management of waterways in towns and cities. The influence on flood risk of past urban occupation on the floodplains and the lowest terrace areas is well demonstrated on the River Irwell in Salford where the remaining floodplain and the artificial flood storage basin represent just 46.4% of the

Figure 30: Electrical pylon relocation in Urmston.

natural flood attenuation capacity. In the River Tamanduateí floodplain in São Paulo, Brazil, Moroz-Caccia Gouveia (2010) estimated that 17 detention ponds implanted in the catchment correspond to only 7.9% of the natural flood attenuation capacity of the fluvial system. Urbanisation and geomorphological changes on naturally flooded land create a need for artificial flood control by creation of extra spaces for flood waters, either in the river channel through straightening, deepening, widening and raised embankments, or in the floodplain and uplands through flood storage basins and detention ponds. However, these artificial constructions are invariably inadequate and may merely serve to shift the flood problems further downstream.

The buildings constructed over old meander channels, as illustrated by the buried meander of the former River Irwell in Salford Quays, may face future geotechnical problems. The complex vertical and lateral variability of technogenic deposits, fluvial sediments and basement rocks with differing degrees of weathering and the high groundwater levels was believed to be influential in an underground railway station tunnel collapse that occurred during the construction in the buried River Pinheiros meander belt in São Paulo (Luz and Rodrigues, 2013). The accident on 12th January 2007 killed seven people and caused considerable damage to infrastructure (Figure 31). Technical report and studies made to investigate the causes of the accident demonstrate clearly that the excavation did not take into account the complex geologic-geomorphological features and materials (including historical anthropogenic deposits) in the area of the excavation and its surroundings and those containing the water column above the tunnel (IPT 2009). Thorough understanding of the geotechnical conditions in urbanized fluvial systems is essential for carrying out excavations safely. Knowledge of the underlying rock and the overlying Quaternary fluvial sediments, including any anthropogenic materials, particularly of their lateral and vertical relations, and soil water conditions helps to avoid geotechnical difficulties and plays an important role in land management and hazard assessment.

The channel dynamics of the meander systems may bring future problems for engineering structures, as the relocated pylon in the River Mersey between Urmston and Carrington demonstrates. Identification of river dynamics and tendencies is crucial for management of the environment, urban planning and construction. For instance, understanding the effects of the regulated reaches of the River Mersey above Ashton weir on erosion downstream at Urmston helps in understanding the impacts of urbanization on rivers in Greater Manchester.

The meandering rivers across the post-glacial deposits of the North Cheshire and South Lancashire plain are naturally highly dynamic and have changed their courses considerably in recent decades. The example of the River Mersey demonstrates that channel changes related to the natural highly dynamic meandering of rivers in the region has brought problems in engineering structures on the floodplain. The channels banks and the urban development of Greater Manchester may be enhancing these processes, but have not caused them.

Figure 31: Railway station tunnel collapse in São Paulo.
Source: http://photos1.blogger.com/x/blogger/275/1738/1600/274647/OC-Metro-EstacaoPinheiros.jpg

Conclusion

The changes in urban river systems and the scope of adjustments have been well established. The answers to questions such as what causes changes and how do the changes come about are relatively well known, but the reasons why changes occur, and where and when, are less well known (Gregory 2006). Examination of historical sources and analysis of indicators of change in the urban environment can help to provide some of these answers. Future, present and past of the natural and urbanised river systems can be evaluated, aiding in the river management and in the analysis of the human impact on river channels as part of a more holistic approach (Gregory 2006; Lawson and Lindley 2008),

The legacy of the historical industrialisation in Greater Manchester and its impacts on the urban environment may help in planning and river management in modern newly industrialising cities, such as São Paulo in Brazil. Greater Manchester has been in a process of industrial decline and stabilization of population since after the Second World War, when the environmental urban problems such as pollution and floods became high on the political agenda. São Paulo Metropolitan Region has approximately 20 million inhabitants and can be considered one of the most spectacular examples of environmental change in Brazil (Rodrigues 2006), and the former naturally meandering river systems of the city have been entirely modified (Figure 32). São Paulo did not experience industrial decline and stabilization of its population until after the 1990s. Nowadays it has similar environmental problems to those faced by Manchester in the past.

The examples of old industrial cities provide ways of understanding the environmental problems of modern cities. In addition, modern cities usually have historical records, particularly maps, which, having been produced before rapid urban expansion, show the original systems more accurately, and therefore provide detailed maps of great value for urban planning and river management.

Figure 32: Top – River Pinheiros meander system in 1930, source: Ab'Saber, 1957.
Bottom – Satellite Image from the same area in 2008.

References

Ab'Saber A N 1957 *Geomorfologia do sítio urbano de São Paulo.* Ateliê Editoral, Cotia- São Paulo (Edição Fac-Similar 50 anos editada em 2007).

Berger A R 1996 The geoindicator concept and its application: an introduction in Berger A R and Iams W J eds *Geoindicators: assessing rapid environmental changes in Earth systems*. Balkema, Rotterdam 1-14

Bridge D M, Butcher A, Hough E, Kessler H, Lelliott M, Price SJ, Reeves H J, Tye AM, Wildman G and Brown S 2010 *Ground conditions in central Manchester and Salford: the use of the 3D geoscientific model as a basis for decision support in the built environment.* Nottingham, UK, British Geological Survey, (RR/10/006), 88pp.

British Geological Survey (GB) 2013 Borehole record viewer Using Geology of Britain Viewer (http://www.bgs.ac.uk/data/boreholescans/home.html) (accessed 17th September 2013).

Coltrinari L 1996 Natural and anthropogenic interactions in the Brazilian tropics in Berger A R and Iams W J eds *Geoindicators: assessing rapid environmental changes in Earth systems*. Balkema, Rotterdam 295-310.

Daniels S M, Agnew C T, Allott T E H and Evans M G 2008 Water table variability and runoff generation in an eroded peatland, South Pennines, UK *Journal of Hydrology* 361 214-226

Dodge M and Perkins C 2010 Maps, Memories and Manchester: The Cartographic Imagination of the Hidden Networks of the Hydraulic City. *Paper for Mapping, Memory and the City: An International Interdisciplinary Conference.* University of Liverpool, 25-26th February 2010. Available in: http://personalpages.manchester.ac.uk/staff/ m.dodge/Dodge_Perkins-Hydraulic_City_submitted.pdf. (accessed 17th March 2015)

Douglas I 1983 *The urban environment*. Edward Arnold, London.

Douglas I 1985 Geomorphology and urban development in the Manchester area in Johnson, R H ed *The Geomorphology of North-West England*. Manchester, Manchester University Press 337-352.

Douglas I 2005 Hot wetlands in Fookes P G, Lee E M and Griffiths J S eds *Geomorphology for engineers*. Whittles, Dunbeath 473-500.

Douglas I and Spencer T. 1982 Applied geomorphology in the tropics. *Zeitschrift für Geomorphologie, Supplementbände, n. 44,* Gebrüder Boentraeger, Berlin..

Douglas I and Lawson N 2000 The Human Dimensions of Geomorphological Work in Britain. *Journal of Industrial Ecology* 2 9–33.

Environment Agency (United Kingdom) 2008 *Irwell Catchment Flood Management Plan: Final Report 2008, managing flood risk*. Environment Agency, London.

Ford J, Kessler H, Cooper A H, Price S J and Humpage A J 2010 An Enhanced Classification For Artificial Ground. *British Geological Survey Open Report*, OR/10/036. 32pp.

Fookes P G and Lee E M 2005 Introduction to Engineering Geomorphology in Fookes P G, Lee E M and Griffiths J S eds *Geomorphology for engineers*. Whittles, Dunbeath 1-28.

Goudie A S and Viles H A 1997 *The Earth Transformed: An Introduction to Human Impacts on the Environment*. Blackwell: Oxford.

Greenwood E F ed 1996 *Ecology and Landscape Development: a history of the Mersey Basin*. Proceedings of a Conference Held at Merseyside Maritime Museum, Liverpool, 5-6 July, 1996. University of Liverpool Press, Liverpool,

Gregory K J 1987 River channels in Gregory K J and Walling D E eds *Human activity and environmental processes*. Wiley, Chichester and New York 207-235.

Gregory K J 2006 The human role in changing river channels. *Geomorphology* 79 172-191.

Gregory K J, Davis R J and Downs P W 1992 Identification of river channel change to due to urbanization. *Applied Geography* 12 299-318.

Gregory K J and Walling D E eds 1987 *Human activity and environmental processes*. Wiley, Chichester and New York.

Gupta A 2002 Geoindicators for tropical urbanization. *Environmental Geology* 42 736-742.

Harley J B 1963 William Yates and Peter Burdett: their role in the mapping of Lancashire and Cheshire during the late eighteenth century. *Transactions of the Historic Society of Lancashire and Cheshire* 115 107-131.

Harvey, A. M. 1985 The river systems of North-west England in Johnson R H ed *The Geomorphology of North-West England*. Manchester University Press, Manchester 122-142.

Hockin D L 1985 Channelization: Some Engineering Aspects. *The Geographical Journal* 151 54-57.

Hooke J M and Kain R J P 1982 *Historical change in the physical environment: a guide to sources and techniques*. Butterworth Scientific, London and Boston.

Hooke J M and Redmond C E 1989 River channel changes in England and Wales. *Water and Environment Journal* 3 328–335.

Hooke J M 2004 Cutoffs galore! occurrence and causes of multiple cutoffs on a meandering river**.** *Geomorphology* 61 225–238.

Hooke J M and Yorke L 2010 Rates, distributions and mechanisms of change in meander morphology over decadal timescales, River Dane, UK. *Earth Surface Processes and Landforms* 35 1601–1614.

Instituto de Pesquisas Tecnológicas (IPT) 2009 Relatório sobre o acidente na Estação Pinheiros do Metrô de São Paulo (Report about the accident in the Pinheiros Station of Metro in Sao Paulo). 7 videos, visualized: Dec. 03 2013. 1 http://www.youtube.com/watch?v=e9V6P2Qs0so; 2 - http://ww.youtube.com/watch?v=YKowYfw7pCs; 3-http://www.youtube.com/watch?v=Jx9JJLKnVIY; 4 - http://www.youtube.com/watch?v=FzueTwxXkc8; 5 - http://www.youtube.com/watch?v=zVeyronVrOY; 6 - http://www.youtube.com/watch?v=muHx2Nsa3mY; 7 - http://www. youtube.com/watch?v=BNBuKR5hUIw.

Jacobs UK Limited. 2008 *Environmental Risk Assessments, Remedial Strategy and Implementation Plan of the Media City:UK development*. Peel Media Ltd, Manchester 2 volumes.

Johnson R H 1985 The geomorphology of the regions around Manchester: an introductory review. in Johnson R H ed *The Geomorphology of North-West England*. Manchester University Press, Manchester 1-23.

Lawson N and Carter J 2009 *Greater Manchester Local Climate Impacts Profile (GMLCIP) and assessing Manchester City Council's vulnerability to current and future weather and climate: A report on the development of a LCLIP for Greater Manchester and on the vulnerability assessment of Manchester City Council with reference to meeting the requirement of Level 1 of NI 188*. Eco Cities, University of Manchester.

Lawson N and Lindley S 2008 A deeper understanding of climate induced risk to urban infrastructure: case studies of past events in Greater Manchester. *North West Geography* 8 4-18.

Legget R F 1973 *Cities and Geology*. McGraw-Hill, New York.

Leng X L 1989 *The impact of urbanization on the River Mersey.* Unpublished M.Sc. Thesis, School of Geography, University of Manchester.

Luz R A and Rodrigues C 2013 Reconstituição geomorfológica de planícies fluviais urbanizadas: o caso do rio pinheiros, São Paulo-SP (Geomorphological reconstitution of urbanised fluvial plains: the case of River Pinheiros, Sao Paulo-SP) *Revista Brasileira de Geomorfologia* 14 47-57

Manchester City, Salford City and Trafford Councils 2010 *Manchester City, Salford City and Trafford Councils Level 2 Hybrid Strategic Flood Risk Assessment (SFRA): Level 1 SFRA, Final, March 2010*. JBA Consulting, Manchester.

Moroz-Caccia Gouveia I C 2010 Da originalidade do sítio urbano de São Paulo às formas antrópicas: aplicação da abordagem da Geomorfologia Antropogênica na Bacia Hidrográfica do Rio Tamanduateí, na Região Metropolitana de São Paulo (Originality of the urban Sao Paulo anthropogenic landforms: application of the approach of Anthropogenic Geomorphology in River Tamaduatei Catchment in the Metropolitan Region of Sao Paulo) Unpublished PhD. thesis Departamento de Geografia, Universidade de São Paulo

Nir D 1983 *Man, a geomorphological agent: an introduction to Anthropic Geomorphology*. D. Reidel, Boston and Keter Publishing House, Jerusalem.

Petts G E, Möller H and Roux A L eds 1989 *Historical change of large alluvial rivers: Western Europe*. Wiley, Chichester.

Rodrigues C Org 2006 *Guia de Excursão VI SINAGEO: Sistemas geomorfológicos e o impacto da urbanização na metrópole de São Paulo. VI SIMPÓSIO NACIONAL DE GEOMORFOLOGIA*, Goiânia, São Paulo.

Rodrigues C 2010 Avaliação do impacto humano da urbanização em sistemas hidro-geomorfológicos: Desenvolvimento e aplicação de metodologia na Grande São Paulo. *Revista do Departamento de Geografia*, 20 DG-FFLCH-USP 111-125.

Rodrigues C and Coltrinari L 2004 Geoindicators of urbanization effects in humid tropical environment: São Paulo (Brazil) Metropolitan Area. *32º International Geological Congress,* 2, Florença, Salford (UK), 976.

Salford City Council 2007 *Broughton, Lower Kersal and Chalestown flood response plan. Version 1.0 (Final Draft)*. Salford City Council, Emergency Planning Unit, Salford.

Scottish Executive Environment Group Research 2005 *Natural Flood Storage and Extreme Flood Events: Final Report.* JBA Consulting, Edinburgh.

Toy T J and Hadley R F 1987 *Geomorphology and reclamation of disturbed lands*. Academic Press, Orlando.

Trimble A W 2008 The use of historical data and artifacts in geomorphology. *Progress in Physical Geography* 32 3-29.

Verstappen H T 1983 *Applied geomorphology: geomorphological surveys for environmental development*. Elsevier Scientific, Amsterdam.

Cartographical references

A Map of the Rivers Mersey and Irwell from Bank-key to Manchester with an account of the rising of the Water and how many Locks it will require to make it Navigable. Surveyd by order of the Gentlemen at Manchester by Tho:Steers, 1712. Original is in Chetham's Library, Manchester.

A Plan of the Old Navigation Canal from Liverpool to Manchester (in part), and of the Duke of Bridgewater's Canal from the Coal Mine to Manchester and to Stradford. Gentleman's Magazine, 1766. Available in <http://freepages.genealogy.rootsweb.ancestry.com/~genmaps/genfiles/COU_ Pages/ENG_pages/lan.htm>, Downloaded: Mon Sep 06 2013.

A Plan of the Duke of Bridgewater's Navigable Canal already made with the Extention proposed from Altrincham to Liverpool. in Prockter J 1766 *The History of Inland Navigation, Particularly that of the Duke of Bridgewater*. London. Available in <http://freepages.genealogy.rootsweb.ancestry.com/~genmaps/genfiles/COU_ Pages/ENG_pages/lan.htm>, Downloaded: Mon Sep 06 2013.

British Geological Survey (GB) Vector [SHAPE FILES geospatial data], *Scale 1:50000, Tiles: Rochdale, Stockport, Glossop, Manchester, Runcorn, Chapel and Wigan*. British Geological Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Tue Jun 25 12:25:37 BST 2013.

Google Earth 4.2.0205.5730. *DigitalGlobe*, Getmapping plc, Infoterra Ltd and Bluesky, The GeoInformation Group, Imagery Jun 2, 2009. Build Date: Nov 13 2007

2006.Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10560, County Series, Lancashire 1^{st} Edition, 1848*. Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Mon Oct 07 21:27:02 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10560, County Series, Lancashire 1^{st} Revision, 1894-1896*. Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Fri, 28 Jun 2013 17:30:12 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10560, County Series, Lancashire 2^{nd} Revision, 1908-1909*. Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Fri, 28 Jun 2013 17:38:25 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10560, County Series, Lancashire 3^{rd} Revision, 1922-1938.* Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Fri, 28 Jun 2013 17:49:52 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10560, National Grid, Tile sj79, 1954-1955.* Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Mon, 23 Sep 2013 20:26:34 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10560, National Grid, Tile sj79, 2^{nd} Revision 1965-1969.* Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Tue, 24 Sep 2013 13:46:12 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10000 National Grid, Tiles sj79, 1^{st} Metric Edition, 1971-1981*. Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Mon, 23 Sep 2013 20:34:02 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10000 National Grid, Tiles sj79, Latest Edition, 1991-1996*. Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Mon, 23 Sep 2013 19:11:13 BST 2013.

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:50000, Tiles: sj78, sj79, sj88 and sj89. Updated: 2013,* Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Fri Jun 14 16:02:44 GMT 2013

Ordnance Survey (GB) Raster [TIFF geospatial data], *Scale 1:10000, Tiles: sd70, sd80, sj79 and sj89. Updated: June 2013*, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Fri, 28 Jun 2013 17:58:02 BST 2013.

Ordnance Survey (GB) Vector Profile DTM [CAD FILES geospatial data], *Scale 1:10000, Tiles: sd70, sd80 e sj89. Updated: November 2009*, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: Thu, 04 Jul 2013 15:05:26 BST 2013.

Plan of the Duke of Bridgewater's Canal, Liverpool to Manchester. Gentleman's Magazine, 1766. Available in <http://freepages.genealogy.rootsweb.ancestry.com/~genmaps/genfiles/COU_ Pages/ENG_pages/lan.htm>, Downloaded: Mon Sep 06 2013.

Yates W 1787. *Map of Lancashire*. Available in <http://www.lancashire.gov.uk/environment/oldmap/Yates/index.asp>, Downloaded: Mon Sep 06 2013.