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MERSEY GATEWAY

MORPHOLOGICAL MONITORING - FINAL REPORT

Halton Borough Council
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MERSEY GATEWAY

MORPHOLOGICAL MONITORING - FINAL REPORT

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2. INTRODUCTION

2.2 Background

1.1.1 Halton Borough Council is currently promoting a second crossing of the River Mersey within the Borough, between Runcorn and Widnes. Gifford were appointed as Project Manager and Lead Consultant in July 2001 to undertake the further studies necessary to take the project forward.

1.1.2 This report is the eighth in a series that provides baseline information on the Upper Mersey. These reports will feed into the Environmental Statement (ES), the concluding document of the Environmental Impact Assessment (EIA) of the bridge scheme. This report follows on from the previous report B4027/TR03/07. The reader is referred to seven previous reports as follows:

B4027/TR03/01 – Technical Report 3, Hydrodynamics
B4027/TR03/02 – Addendum to Technical Report 3, Route 3A Hydrodynamics
B4027/TR03/03 – Morphology Desk Study
B4027/TR03/04 – Case Study of Bridges Constructed in Highly Mobile Estuaries or River Beds
B4027/TR03/05 – Hydrodynamic interpretative report – Phase II detailed modelling (this report has been superseded by the following report)
B4027/TR03/06 – Hydrodynamic construction and operation phase interpretative report – Phase II detailed modelling
B4027/TR03/07 – Morphological monitoring interpretive report

2.3 Report aims and objectives

1.2.1 The main aim of this report is to continue the detailed analysis that has been presented in report B4027/TR0307 in order to provide increased understanding of the historical and contemporary geomorphological changes that occur in the Upper Mersey Estuary.

1.2.2 The analysis is based on the Historical Trend Analysis (HTA) approach using historical records of Upper Mersey Navigation Commission charts, aerial photographs from 1945 to 2000, surveys undertaken between April 2005 and March 2007 and a series of oblique aerial photos taken at regular intervals of daily, weekly and monthly from March 2005 until June 2007.

1.2.3 This report will provide further technical evidence for the hydrodynamics assessment of the Environmental Statement, and consider key concerns raised by consultees for the proposed crossing (including English Nature, Environment Agency, Manchester Ship Canal Company (MSCC) and the Acting Mersey Conservator (DfT)). These concerns included:

(i) A lack of understanding of the key controls and mechanisms of channel change within the estuary;
(ii) The potential for the channels to become ‘attached’ to the proposed bridge structure and thus lose the ‘randomness’ and changing nature of the present morphology.

1.2.3 The main objectives of this report are:

(i) To understand the historical geomorphological behaviour of the Estuary;
(ii) To provide baseline information against which future change can be compared;
(iii) To propose a conceptual model of estuary form and process;
(iv) To discuss the potential for channels to become attached to the proposed bridge structure based on the results from this report.

2.4 Study area

1.3.1 The Mersey Estuary is on the North West coast of England between the Dee and Ribble Estuaries, and falls within sediment cell 11a (see definitions above), which runs from Great Orme Head to Southport Pier (HR Wallingford, 1994). The estuary can be divided into four main areas as shown in Figure 1.1. It is the Upper Estuary, particularly upstream of the Runcorn Gap, that forms the focus of this report. This area is shown in more detail in Figure 1.2. This area lies approximately 32km from the mouth and 15km downstream of the tidal limit of the Estuary at Howley Weir. This area consists of a highly mobile sand/mudflat area, parts of which are exposed in all but the highest tides. The entire area is relatively shallow and is dominated by a number of low flow channels. There are three main areas of intertidal salt-marsh within the study area; Astmoor Salt-marsh, which lies on the southern bank and Cuerdley Marsh and Widnes Warth, which lie on the northern bank.

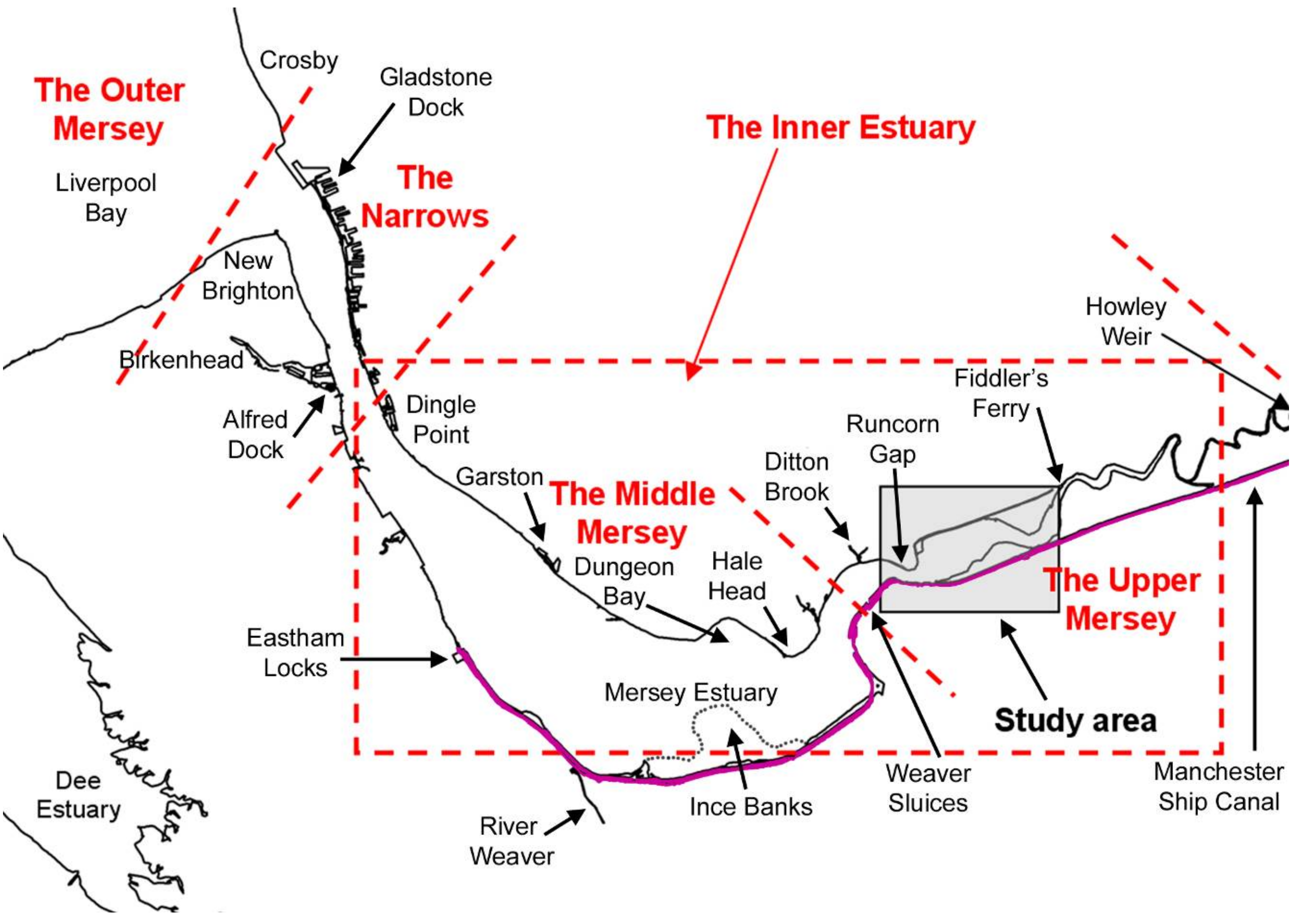


Figure 1.1 The Mersey Estuary

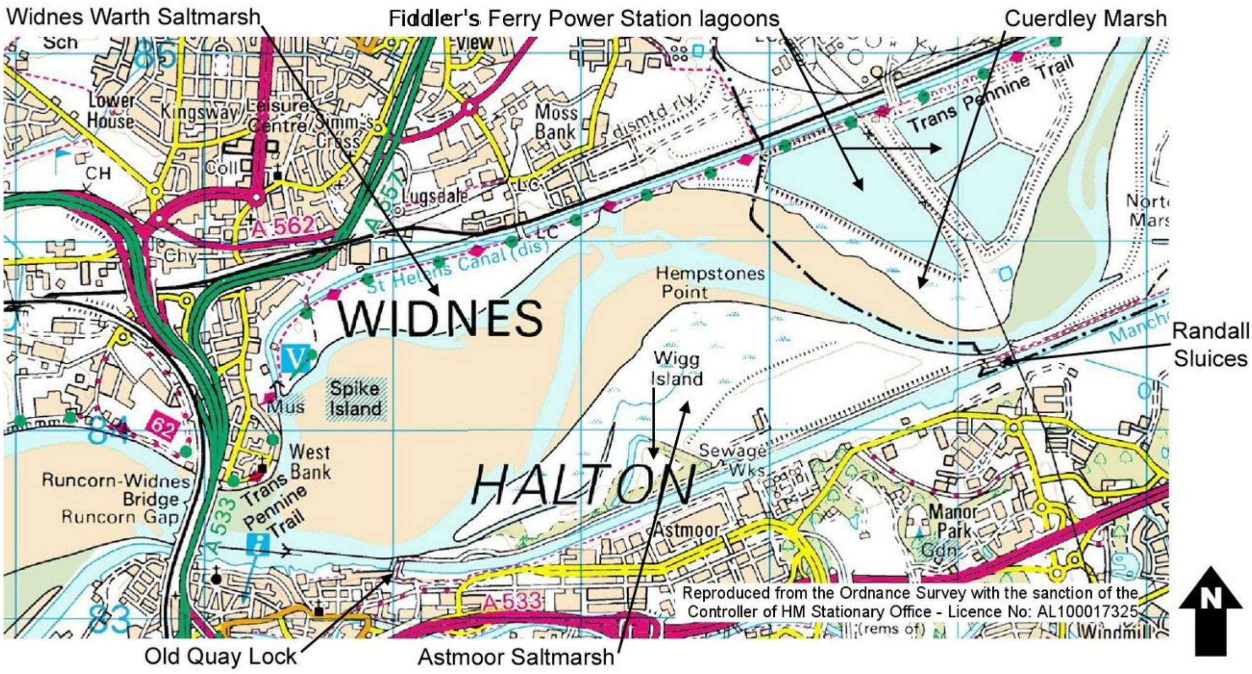


Figure 1.2 Study Area for the Proposed Crossing

3. PRINCIPLES AND THEORIES (CONTEXT: EXISTING RESEARCH)

3.2 Literature Review of Estuarine Geomorphology

2.1.1 An estuary is a partially enclosed coastal body of water in which river water is mixed with seawater. A two-way flow of water, and the factors that control the water mass balance between these two flows, is therefore a defining characteristic of an estuary. Estuaries can be classified in various ways – by their origin, by their morphology, by their tides, by the amount of mixing that occurs between fresh and salt water (EMPASYS Consortium, 2000). The Mersey Estuary can be defined as a highly dynamic Estuary with a high tidal range.

2.1.2 Fresh water and salt water have different densities, and therefore tend not to mix readily (Leeder, 1999). Mixing depends on the presence of physical processes that promote turbulent transfer between the two water bodies. These physical processes are controlled by estuary shape, tidal streams, wind-driven currents and wave energy. These factors together define the process regime of a given estuary, where fixed estuary edges confine the system, and a malleable bed provides an area within which morphological changes can occur.

2.1.3 Channels within an estuary can be classified by which component of the tide (flood or ebb) is the dominant force in their creation (Robinson, 1960). Early work on estuary geomorphology by van Veen (1950) and Robinson (1960) describe flood and ebb channels that are differentiated from each other by the volume of flood or ebb flow they carry.

2.1.4 Flood and ebb channels are often described as being mutually evasive (van Veen, 1950; Robinson, 1960; Masselink and Hughes, 2003) because their flow vectors are (usually) in opposite directions: the incoming flood flows tend to deflect ebb flows. This effect is probably due to form roughness, which is a generic term used to describe all types of resistance to changes in flow direction (Richards, 1982, Knighton, 1994, Bridge, 2003). In any distinct channel (whether ebb, flood or fluvial), morphological features such as bends, bars, vegetation and bedforms cause flow to change direction, and this results in frictional energy losses; that is, a coherent body of water flowing in a particular direction displays an internal resistance to changes in flow direction. Within an estuary, in addition to morphological features such as bars and bends, another type of flow resistance is encountered where one flow travels in a different direction to a second flow. In such a case, the path of least resistance would be for the first water body to flow next to the second water body, so the two flows keep their separate identities rather than merging into each other fully (van Veen, 1950, Robinson, 1960). Between the two water bodies would typically be a shear zone where turbulent eddies caused by the opposing flows detach from the parent water body: this is a dynamic area where energy is lost, and represents another type of form roughness (Knight and Shiono, 1996).

2.1.5 Thus, flood and ebb flows tend to oppose each other and occupy different spatial zones. Within the part of an estuary dominated by ebb flow, where the ebb channel is dominant and continuous (such as in the Upper Mersey), the flood tide meets with physical opposition; and van Veen (1950) and Robinson (1960) both explain that within such ebb-dominated areas a flood channel is created where flow cuts into a bar, creating a channel that within a short distance leads to a blind-end hemmed by a curved ridge (Figure 2.1). van Veen (1950) and Robinson (1960) refer to these ridges as sills. Within this report, we define ‘sills’ or ridges as a curved morphological feature that separates a flood channel from an ebb channel (Figure 2.1). Although no literature describes the process, it is possible to hypothesise that the ridges cause flow to spread, reducing velocity and sediment transport capability, and leading to deposition. Eventually all flow ebbs back down the estuary, giving a closed loop pattern of sediment and water movement (Figure 2.1). Despite the early recognition of such features, little work has been undertaken on flood channels.

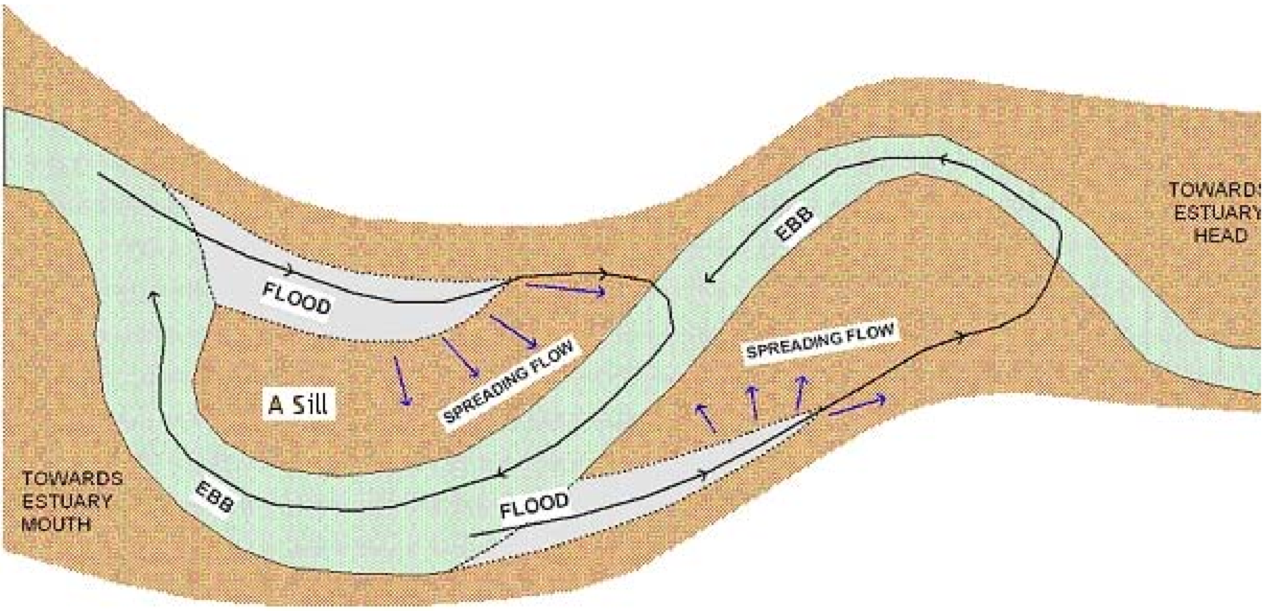


Figure 2.1 Ebb and flood channels with a closed cell pattern of circulation. Modified from van Veen (1950) and Robinson (1960)

2.1.6 Within an ebb dominated estuary, two process regimes can be identified:

(i) ebb-channel processes, which can be investigated using concepts from fluvial geomorphology
(ii) flood-channel processes, which can be investigated using concepts of estuary geomorphology

2.1.7 The interaction between the two leads to a distinct pattern of ebb and flood channels that are likely to change in a coherent way over time.

2.1.8 Estuary functioning is a key controller in the morphology, and can be regarded as a form-process interaction whch is a result of natural forcing and variability, and the history of human influence on the estuary. Six processes generally control the estuary functioning which are:

- Hydrodynamics;
- Sediment dynamics;
- Morphology;
- Water quality;
- Ecology; and
- Human activities.

2.1.9 This report will focus on the morphology of the estuary and its process of change. The results from this report will feed into the hydrodynamics assessment.

3.3 The long term geomorphology of the Mersey Estuary

Introduction

2.2.1 Estuaries are geomorphological systems that operate over a range of time scales (Whitehouse *et al*., 2005); see Table 2.1 Previous studies of the Mersey Estuary (B4027/TR03/03) have focused on historical and event timescales (years to centuries). The Morphology Desk Study Report (B4027/TR03/03) used historic mapping, bathymetric surveys and aerial photographs to show that ebb channel movement within the study area varies considerably over time. However, these data sources were too infrequent to identify the pattern and timescale of this change. In order to address this gap in knowledge, this report focuses on event timescales, which can be days to months.

2.2.2 It is essential to set the current study in context both in terms of geomorphological history and in terms of processes operating. The Mersey Estuary originated as a valley created under permafrost conditions during the last ice age. Lower sea levels led to river valleys extending beyond the present-day shoreline. As sea levels rose (by as much as 170m), the valley became drowned and filled with sediment, leading to today's system (DEFRA, 2006b). The Mersey Estuary is classified as a ria (a drowned river valley) without an enclosing spit (a bar extending across the estuary mouth) (DEFRA, 2006b). The shape of the estuary is therefore inherited from an earlier valley planform, which is why the estuary has a sinuous planform upstream of Runcorn Gap. This sinuous shape is critical in controlling the general direction of the tidal flows. The estuary is a sink of sediment from offshore, and is considered to act as a store of mud and sand (DEFRA 2006b).

Table 2.1 Definition of spatial and temporal scales involved in estuarine development (after Whitehouse et al., 2005)

	Timescale	Physical	Anthropogenic impacts
Geological	Millennia	Development of continental shelf. Geology of estuaries. Holocene leading to the formation of modern estuaries	Bronze age land clearance
Historical	Centuries	Creation of hydrological catchments and river and estuary basins. Development of salt-marsh.	Land reclamation, impact of agriculture. Impacts of industry and of major engineering scheme such as dredging and training wall schemes
Event	Decades	Creation of salt-marsh, development of mudflats, spits and deltas	Post war - impacts of dredging and port development, salt-marsh loss
	Years	Changes in estuary sub-systems, mudflats and creek	
	Seasonal	Channel switching and dune development	
Instantaneous	Days	Development of tidal bedforms	
	Spring-Neap cycle		
	Hours	Formation of a ripple	
	Seconds	Erosion or deposition of particles	

System controls

2.2.3 Water movement within the estuary is dominated by geological constrictions (Figure 1.1) that promote mixing. This shape – and particularly bedrock constrictions at the Narrows and Runcorn Gap - significantly control the influx and efflux of tidal streams: the flood tide upstream of the Runcorn Gap lasts around 2 hours, compared with 10 hours of ebb flow (B4027/TR03/03). Thus, although the flooding tide in the Mersey is fast and even violent when viewed from the shore, it is short-lived. Many processes that occur within the Mersey Estuary upstream of the Runcorn Gap are influenced by ebbing flow, with linear bars generally oriented down-estuary, and a dominant channel visible. These patterns are consistent with those observed in estuaries elsewhere (e.g. van Veen, 1950; Robinson, 1960; Leeder, 1999).

2.2.4 Fluvial inputs to the system are fairly low and vary seasonally. Due to the presence of the Manchester Ship Canal there is a limited fluvial input into the Study Area controlled by Howley Weir with the main outflow of the canal being downstream at the Eastham Locks. ABPmer (2001) report that the total volume of the Mersey Estuary at MHW is $881x10^6m^3$ and at MLW 164 $x10^6m^3$. Therefore, the maximum average volume of water that enters the estuary and discharges each day is $717x10^6m^3$. The average discharge of the River Mersey is 30.34 m^3/sec (cubic metres per second), which equates to an average daily volume of $2.62x10^6m^3$ (B4027/TR03/03). Thus, fluvial flows comprise around 0.3% of the ebb discharge. Even during fluvial floods, when the river discharge may reach 200 m^3/sec (B4027/TR03/03), which equates to a daily volume of 17.2 $x10^6m^3$, fluvial flows will comprise no more than 2.2% of the ebb discharge.

2.2.5 Thus, the Upper Mersey Estuary has limited fluvial flows, and, for the majority of the tidal cycle, water ebbs down the estuary in discrete channels that are morphologically similar to a river channel. Therefore it is valid to use concepts from fluvial geomorphology to assess and explain channel changes that result from the downstream (ebb) component of the tidal flow. However, unlike river channels, a huge surge of water flows back up the estuary twice daily, and this creates a second type of channel change whose vector is oriented upstream. Typically, this change results in the presence of flood channels (van Veen, 1950; Robinson, 1960; see figure 2.1)

Anthropogenic controls on the system

2.2.6 Anthropogenic effects are a major agent influencing the morphology of an estuary either directly by means of engineering works and/or indirectly by modifying the physical, biological and chemical processes within the estuary. The main anthropogenic controls on the study area are rock training walls in the Outer Mersey and Liverpool bay; dredging activity; reclamation of intertidal areas; and the construction of the Manchester Ship Canal.

2.2.7 The training walls were constructed along the face of Taylor's Bank in the Outer Mersey in 1909 initially to prevent the continued Northward movement of the Crosby Channel, and also to prevent a smaller channel breaking through Taylor's Bank. The training walls were extended during the period 1910 to 1957, and included the Queens North, South, Askew Spit, Crosby West and Crosby East Training Banks (Van der Wal and Pye, 2000).

2.2.8 The construction of the training walls in the Outer Mersey and Liverpool bay suppressed channel meandering and confined a greater part of the ebb flow within the trained channel. This led to a stronger flood tide along the North Wirral and Lancashire coastlines, which Price and Kendrick (1963) report caused an increase in net sediment delivery to the estuary, leading to siltation in both the trained channel and in the estuary itself.

2.2.9 Dredging in Liverpool Bay started in 1833 to provide access to the Ports of Liverpool and Birkenhead and maintain navigation channels. However, regular dredging of the channel only commenced after 1890 and by the time of training wall construction in 1909, there was already significant dredging to maintain the approaches to the port of Liverpool. Volumes of material removed through dredging peaked between 1912 and 1950, with 320 x 10^6 m^3 (8.4 x 10^6 m^3 per year) being removed in comparison to 100 x 10^6 m^3 between 1950 and 1988 (2.6 x 10^6 m^3 per year). Currently, on average, 0.4 x 10^6 m^3 of sediment is removed from the Mersey Estuary per year (Van der Wal and Pye, 2000). Prandle (2000) estimated that peak dredging levels in the first half of the century were of the order of 10 million tonnes/year, which was reduced to approximately 1 million tonnes/year after 1950. Prandle also estimated that about 10% of the total dredged material was deposited within the estuary system during this period.

2.2.10 The Manchester Ship Canal was constructed between 1887 and 1894 to provide industries in the northwest with access to sea-going vessels. The canal also performs a land drainage function, and the Rivers Irwell, Bollin and Mersey flow into the Manchester Ship Canal. The canal acts as a sediment trap, and the removal of sediment by dredging has been periodically required to maintain the required navigation depths (Hydraulics Research Station, 1982).

Historical Trends Analysis of Long-Term Changes in Geomorphology

2.2.11 Morphological changes within an estuary are the result of a variety of different forcing factors on the estuary system. A systematic approach is used to study the long term morphological changes in medium to long term periods.

2.2.12 Historical Trend Analysis (HTA) is used which interrogates time series data in order to identify directional trends, rates of processes and morphological changes over varying periods.

2.2.13 In a previous Desk Study Report (B4027/TR03/03), an analysis of historical datasets was undertaken to provide an insight into the movement of the low water channels within the Study Area. However, in this report the aim is to complete the picture by widening the range of the historical datasets for the long/medium-term analyses and combine this with the analysis of the short-term phenomena.

2.2.14 Datasets included in the HTA are:

(i) A complete set of Upper Mersey Navigation Commission (UMNC) charts from July 1871 to March 1973;
(ii) A set of aerial photographs (vertical orientation) dated between 1945 and 2000.

<u>Upper Mersey Navigation Commission (UMNC) Charts</u>

2.2.15 The department of Transport in Hastings archived a large record of the Upper Mersey Navigation Commission (UMNC) Charts from July 1871 to March 1973 (Figure 2.2 shows an example of these charts). This historical record of charts constitutes a qualitative record of the navigable channels to the port of Runcorn within the Upper Estuary. The record terminates in 1973 when the UMNC disbanded as the Upper Estuary became un-navigable. The period of record indicates that in general, a chart of the location of the navigable channel was made every month. However, the record is incomplete. Some months were not covered and in some instances, there is no record for entire years (e.g. 1891; 1934; 1933; 1943; 1963-1965). In total, the dataset available to be investigated comprises 940 months of data out of a possible total of 1209 months in the period.

2.2.16 The aim of using the UMNC charts was to trace the history of the Estuary and understand the geomorphological behaviour of the Mersey Estuary in the last century. It is anticipated that these charts might help in:

- Observing any changes in the position of the navigable channel;
- Seeing whether the navigable channel coincided with the proposed alignment of the Mersey Gateway;
- Locating where the channel was situated in the Study Area
- Observing whether channel sinuosity increased, decreased or remained stable both upstream and downstream of Runcorn Gap and the results plotted as an running mean; and
- Monitoring the land use and engineering changes.

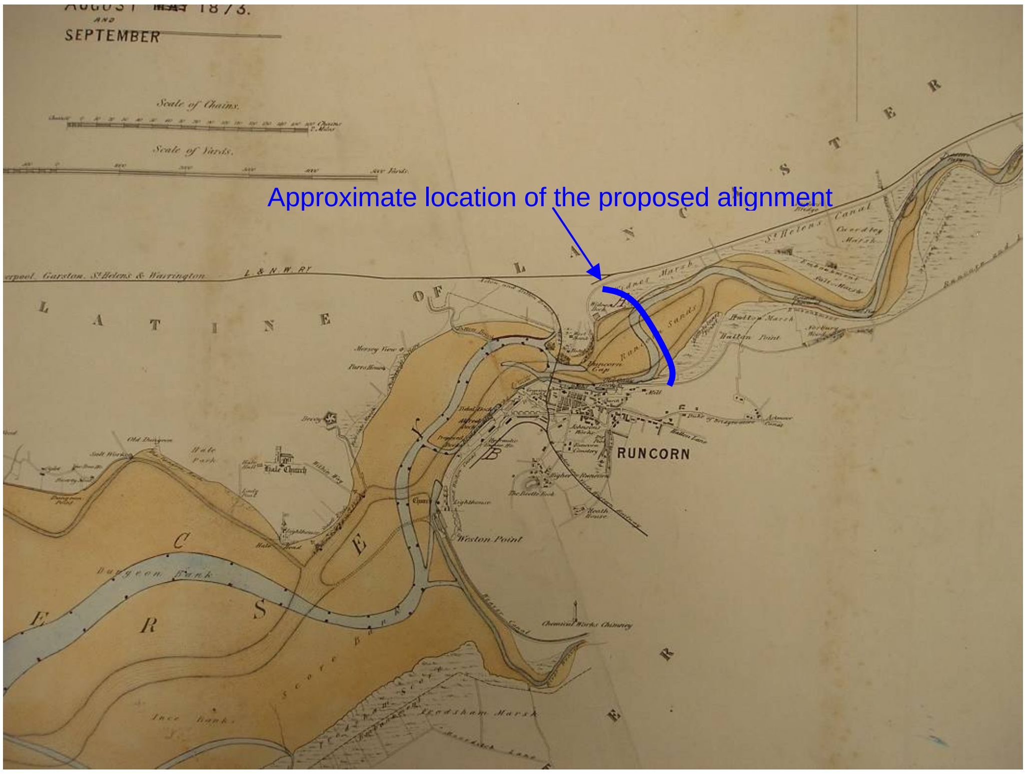


Figure 2.2 Example of the UMNC charts – September 1873.

2.2.17 The analysis showed that from the 940 available charts the navigable channel overwhelmingly did not commonly coincide with the proposed alignment of the Mersey Gateway. However, 22 charts (i.e. 22 months) out of 940 coincided with the alignment.

2.2.18 It was anticipated that analysis of the UMNC charts would provide data upon which to base an interpretation of how the low water channels have changed historically. A qualitative interpretation of the images of the UMNC charts photographed is the most appropriate means of analysing them. The images were rectified to each other (matched) and the channels digitised and subsequently overlain.

2.2.19 The Manchester Ship Canal was completed in 1894. It is interesting to note that observed change in the dynamism (frequency and degree of change) of the navigable channels downstream of Runcorn Gap reduced significantly from August 1896. There was much less change in channel position after this date to the end of record in 1973. The dynamism of the navigable channel upstream of Runcorn Gap was maintained following 1896; however the peaks and troughs in the data (i.e. the energy in the system) are not quite as pronounced as those records prior to 1896.

2.2.20 Prior to1896, the navigable channel downstream of Runcorn Gap showed a level of dynamism (observed by changes in sinuosity) similar to that of the navigable channel upstream of Runcorn Gap. In general, up to 1896, changes in dynamism both upstream and downstream of Runcorn Gap were observed in the same direction (increase or decrease in sinuosity) and at similar times.

Channel Mobility Model

2.2.21 A GIS model of the UNMC data was developed and applied to map the main navigable channel boundaries from chosen charts to reveal the geomorphological changes that have taken place and the mobility of the main channel. The use of GIS allowed the overlay of charts and permitted spatial analysis of the frequency of channels occupying a particular location. The aim of the model was to assess whether, and to what extent, the main navigable channel is mobile, particularly where the bridge towers are proposed.

2.1.22 Two sets of charts were chosen for the analysis:

a) For Chart Set 1, 15 charts were chosen on approximately a 10 year interval but for a variety of dates and to include most of the 22 charts where the main channel was found to coincide with the proposed location of the bridge towers;
b) For Chart Set 2, 10 charts were chosen on approximately a 10 year interval focusing on charts from December, representing the winter, in which channel sinuosity and the proposed alignment coincide.

Table 2.2 below lists the UMNC chart dates used in the model.

Table 2.2 List of the UMNC charts used in the channel mobility model

Chart Set 1 UMNC Chart Date	**Comments**	**Chart Set 2 UMNC Chart Date**	**Comments**
01/1973, 02/1973, 03/1973	Combined chart for Jan., Feb. & Mar.	01/1973, 02/1973, 03/1973	Combined chart for Jan., Feb. & Mar.
01/1969, 02/1969	Combined chart for Jan. & Feb.	11/1962	
01/1959, 02/1959	Combined chart for Jan. & Feb.	12/1953	
01/1949		12/1947	
02/1941		12/1935	
01/1936		12/1923	
01/1929		12/1913	
04/1919		12/1903	
01/1917		12/1893	
11/1907		12/1883	
02/1897		11/1873, 12/1873	Combined chart for Nov. & Dec.
11/1885			
02/1883			
01/1882			
01/1875, 02/1875	Combined chart for Jan. & Feb.		

2.2.23 The model used the channel boundary as a polygon. Channel locations were derived from the digitised channel boundaries from UMNC charts rectified to the national grid and the channel boundaries were digitised. Eleven channel locations were identified and included in the mobility model covering the last 100 years.

2.2.24 The model robustly overlaid these polygons and weighted the intersections between these polygons; the higher the intersected areas the higher the weight and vice versa. The higher the weight means that the channel occupies this location relatively frequently. This result was then shown as a channel mobility map overlain on the best rectified photograph of that viewpoint. Each polygon identified was then coloured according to the frequency at which a channel was located in that location. This exposed geomorphological changes and the mobility of the main channel.

2.2.25 Figures 2.3 and 2.4 show areas where the channel occurred frequently in bright green. Areas of low frequency of channel occurrence are shown in red, based on the fact that the channel was located in that position for at least one of the charts included in the analysis. Areas of where the channel was located frequently are shown in green, these areas may be considered to be relatively stable.

2.2.26 The Upper Estuary channels exhibit high sinuosity and are generally highly mobile, as can be seen by the large area where channels occur infrequently. However the main (ebb) channel frequently maintains it position along the south bank where it is now shown on the recent aerial photographs. Figure 2.4 shows that this part of the Estuary may be approximately divided into two zones. The first could be described as a dynamic zone where channels move frequently, as shown by channels occurring infrequently in any one location, under the Silver Jubilee Bridge. The second as a more stable zone, where channels have either not occurred at all in the charts analysed or else maintained a relatively stable position, this occurs in the area of the proposed bridge towers.

2.2.27 The use of the UMNC charts has helped in understanding the main channel behaviour in the last century and identified when and where it has coincided with the proposed alignment.

<u>Limitations</u>

2.2.28 The limitations in using these charts are summarised below:

- The temporal resolution is not ideal as channel location was studied at 10 year intervals and so all intervening channel movements have not been considered. However the data are sufficient to give a portrayal of past channel behaviour;
- The charts are hand-drawn documents and the precision of scanning and rectifying the charts to National Grid will have resulted in precision errors. However they were not used for quantitative analysis and such small errors are negligible for their use in qualitative and visual interpretation;
- The rectification to the National Grid is not at a high level of accuracy since accurate ground control points are absent;
- The digitised channel boundaries represent the navigational channel, which is the main channel; this means that any secondary channels have not been considered in the interpretation;
- It is understood that the bathymetric surveys needed to prepare the charts have taken up to six months to complete. In this period significant change would have occurred. Also, as the charts were for navigation purposes, it is unclear whether secondary or developing channels would have been routinely recorded.

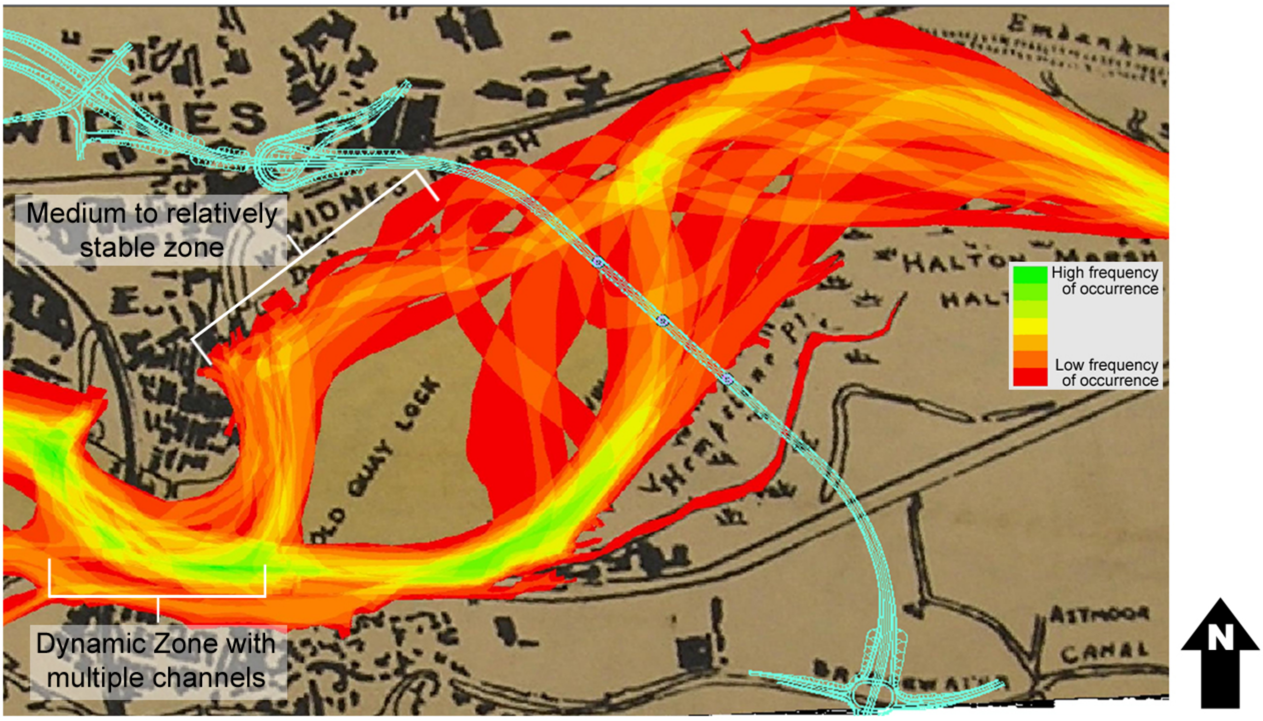


Figure 2.3 UMNC - Historical record of the channel mobility and sinuosity within the Upper Mersey estuary (Chart Set 1)

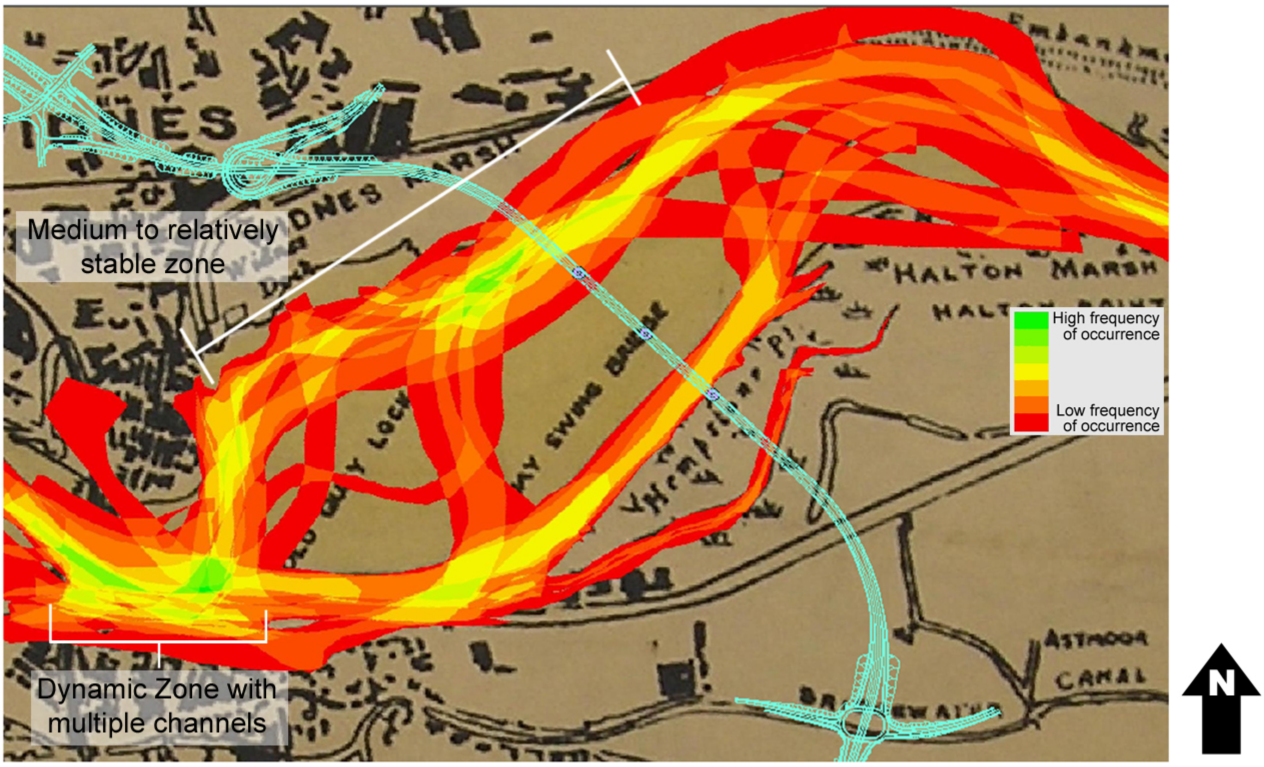


Figure 2.4 UMNC - Historical record of the channel mobility and sinuosity within the Upper Mersey estuary (Chart Set 2)

Aerial photos

2.2.29 The second set of data used in the Historical Trends Analyses (HTA) was a series of aerial photographs from 1945 to 2000. They were used to look at:

(i) changes in estuary edges
(ii) channel cross-sectional area;
(iii) planform shape and the location of the low water channels;
(iv) channel mobility.

2.2.30 Channel mobility was assessed using the same mobility model as for the UMNC charts above.

2.2.31 The main ebb channel usually splits into two just north of Hempstones Point and converges just upstream of Runcorn Gap. The two channels are very variable in position, and while they tend to run along the north and south banks of the salt-marshes, they are not permanently fixed to the banks. For example between 1966 and 2000 the southern channel meander in the vicinity of Hempstones Point, moves across the estuary (Figure 2.5). Extensive flats of mud or sand surround the channel, with some displaying more stability than others. For example, the flats between Hempstones Point and the bridge that lies on the southern bank opposite were reworked several times between 1945 and 2000; but Runcorn Sands, which lie to the northeast of Runcorn Gap, has been relatively stable (Figure 2.5).

2.2.32 General sedimentation within the estuary is probably caused by two factors: increased sediment delivery from offshore (after training wall construction); and reduction in fluvial discharge (after the Mersey Ship Canal construction). The Mersey Ship Canal would have reduced and regulated the volume of water discharged at Howley Weir and would therefore have reduced the density-driven currents within the estuary. Together these lead to an increase in estuary surface elevation, and the ebb channels are approximately 5% narrower and shallower as a result (B4027/TR03/03).

2.2.33 In order to enable use of the mobility model, the channel boundaries were digitised. Then the same GIS model developed and used with the UMNC charts was applied onto these channel boundaries. The positional accuracy of this dataset is likely to be high in relation to location of the bridge towers; however it is limited in number (i.e. temporal coverage) and there is a lack of information about the state of the tide at the time of imaging.

2.2.34 Figure 2.5 shows the digitised locations of the channel from the aerial photos in relation to the proposed Bridge towers.

2.2.35 Figure 2.6 shows the result of the model, it categories the Estuary into zones ranging from areas of low frequency of channel occurrence, shown in red, based on the fact that the channel was located in that position for at least one of the photographs included in the analysis. Areas of where the channel was located frequently are shown in green, these areas may be considered to be relatively stable. Figure 2.6 suggests that the main ebb channel is frequently positioned along the southern edge of the estuary at Runcorn Sands.

2.2.36 The results, as expected, show high agreement with the UMNC charts results (Figures 2.3 and 2.4), and it is possible to distinguish two approximate zones; a dynamic zone with high channel mobility under the Silver Jubilee Bridge and a fairly stable zone at the area of the proposed alignment.

2.2.37 It is interesting that the result of the model for this limited dataset shows that the proposed locations of the bridge towers are neither in, nor adjacent to, the main ebb channel.

2.2.38 In summary the outcomes of the analysis are:

(i) The estuary banks have changed relatively little (maximum loss 12m within 46 years);
(ii) The low water channel system is very dynamic with variability in channel positions;
(iii) The intertidal areas vary in stability, with Runcorn Sands (north east of Runcorn Gap) being more stable than the areas next to Hempstones Point.

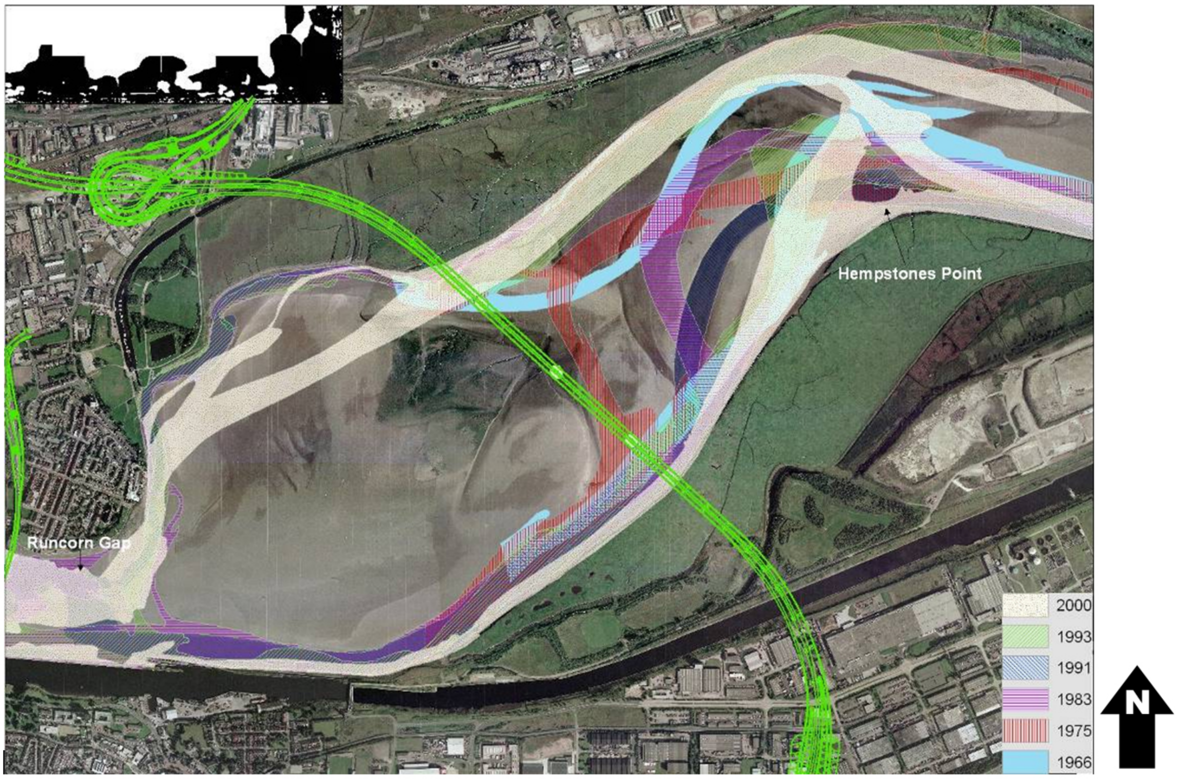


Figure 3.5 Patterns of historical record of the channel locations

Figure 2.6 Channel Mobility from Historical Aerial Photos from 1945 to 2000.

3. SHORT-TERM CHANGES IN MORPHOLOGY

3.1 Introduction

3.1.1 In order to study the short-term morphological changes a sequence of temporal data is needed. The data obtained for this purpose was from topographic field surveys and oblique aerial photos.

3.1.2 The study area was sub-divided into four broad sections as shown in Figure 3.1 namely:

S1 - Area between Cuerdley Marsh and Norton Marsh (Norton Marsh)
S2 – Active area around Wigg Island encompassing the proposed alignment area of the Mersey Gateway Bridge and terminating east of Hempstones Point (Wigg Island)
S3 – Area upstream of the Silver Jubilee Bridge at Runcorn Sands (Runcorn Sands)
S4 – Area downstream of the Silver Jubilee Bridge (Silver Jubilee Bridge)

The proposed alignment of the Mersey Gateway Bridge falls into the downstream part of S2. The names in parenthesis will be referred to as the section names for brevity.

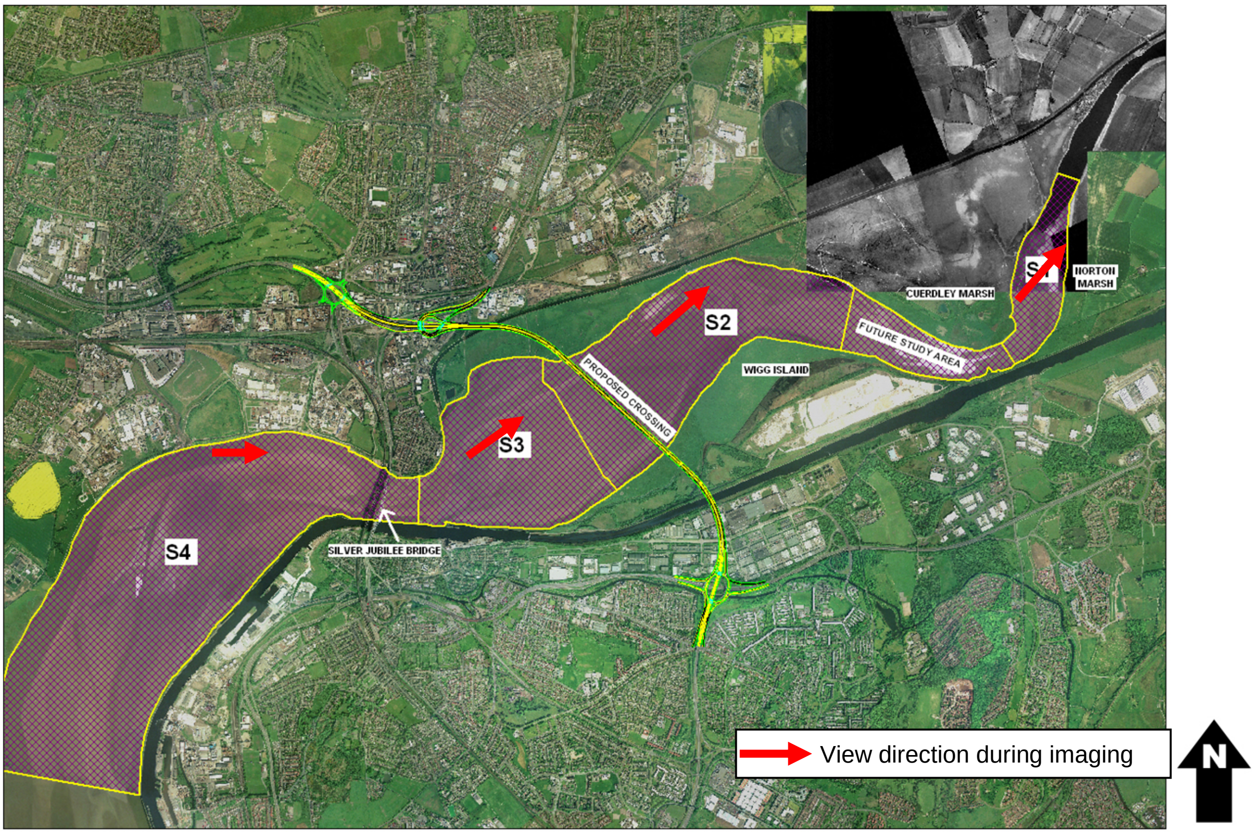


Figure 3.1 Location of the four sections within the Study Area

3.1.3 S1, S3 and S4 were included in order to document any channel changes upstream and downstream within the Study Area and to provide baseline information of the type of processes operating in adjacent parts of the estuary. Anecdotal evidence identified that the area around Hempstones Point in S2 appeared to be most dynamic in terms of changing patterns of low water channels.

3.2 Topographic Survey

3.2.1 Topographic survey data were used to provide levelling information of the entire Study Area and give an indication of the bathymetrical changes that occur between survey dates.

3.2.2 Eight topographic surveys were undertaken in 2005, 2006 and 2007 that covered the area of S3 and S2 to provide information about changes in bathymetry.

3.2.3 Estimations of the volume of the Estuary (i.e. sediment or water) above a base level were calculated to expose the volumetric changes in response to the geomorphological process in the Estuary and in order to allow predictions of the potential interaction between these processes and the proposed alignment. This would also show the amount of infill or loss among the Runcorn Sand area.

3.2.4 Surveys were undertaken on the following dates:

(i) April 2005 survey (27.04.05 to 30.04.05)
(ii) May 2005 survey (12.05.05 to 15.05.05)
(iii) July 2005 survey (11.07.05 to 14.07.05)
(iv) October 2005 survey (8.10.05 to 12.10.05)
(v) March 2006 survey (28.02.06 to 03.03.06)
(vi) April 2006 survey (17.04.06 to 21.04.06)
(vii) March 2007 survey (21.30.07 to 23.03.07)

3.2.5 The estuary was traversed by jet-ski, hovercraft or boat, and the data measured using a Leica 500 system GPS. A control survey was undertaken in January 2005 which formed the basis of the method for the subsequent detailed topographical surveys. The repeat surveys included the same control points to ensure comparability and all surveys were undertaken at low water.

3.2.6 The data collected were co-ordinated and converted to National Grid OSGB (36) and Ordnance Datum at Newlyn. Data points were spaced on a 25-50m grid according to the level of access possible. Data points were more densely located in easy to access locations, whilst areas which were difficult/dangerous could only be afforded sparse coverage. Each survey took 3-5 days, depending on access and weather conditions.

3.2.7 Bathymetric changes are caused by spatial divergence and convergences in the small net sediment movements that take place as a result of the differences between fluxes on the flood and on the ebb tides. The 3-D topographic shape is used to give an understanding of the sediment movements in relation to the proposed alignment of the bridge. This is particularly relevant where the bridge towers are to be installed.

3.2.8 Figures 3.2 to 3.5 show the changes in bathymetry through the time of the topographic surveys. They show that, whilst the whole area is relatively dynamic, the major changes were in the main sand bar.

3.2.9 The main flow channel has maintained its route to the southern bank (bottom of the figure – blue colour) of the estuary at Runcorn Sands from December 2004 to October 2005. However, a bi-furcating is shown of a new secondary channel which dug its way northwards from March 2006 to March 2007. The main sand bar maintained a similar shape between December 2004 and March 2006, however a change occurred from April 2006 to March 2007.

3.2.10 Although seven topographic surveys were undertaken from April 2005 to March 2007 due to practical surveying difficulties only four of these surveys had enough survey points over exactly the same area to be directly comparable in calculations of estuary volume. These were the surveys from October 2005, March 2006, April 2006 and March 2007. The volume was calculated as the volume of the estuary between the measured bathymetry and Mean High Water Spring tide levels within the surveyed area. The results are set out in Table 3.1 below.

Table 3.1 Topographic Survey dates and volume of the Estuary

Date of Survey	Tidal prism (m^3)
September 2005	5,151,650
March 2006	5,286,740
April 2006	4,891,680
March 2007	4,857,870

3.2.11 Comparison of these four surveys show the most significant change occurred between March and April 2006. A change of volume of 395,000m^3 occurred over a period of six weeks. This underlines the degree of mobility of bed material that exists within the Study Area. Given this, and the short period of this record (September 2005 – March 2007), it is not possible to determine whether there is any long term trend towards infilling of the estuary at this location.

3.2.12 In order to identify the spatial element of volumetric change the detailed topographic data gathered was used to create a topographic plan of the bed of the estuary. A GIS interface was used to create this 3-Dimension (3-D) plan for each of the four surveys. This enables identification of areas of significant transport in the Estuary (Figures 3.2-3.5). The specified boundary of the survey is defined by the white line bounding the 3-D figures. This line represents the survey area at low tide and varies from 0 to 0.85 meter AOSD (Above Ordnance Survey Datum) as the water surface of the estuary is not level.

3.2.13 The 3-D shows that the areas proposed to be affected by the alignment remained at the level zone of 1-2 meters for most of the survey dates; however fluctuations of infill and loss of sediment interrupt this levelling to reach the next level zone of 3-4 meters. It also shows that the main channel route is likely to coincide with the proposed northern and southern bridge towers, however the central tower would be situated in the central sand bar.

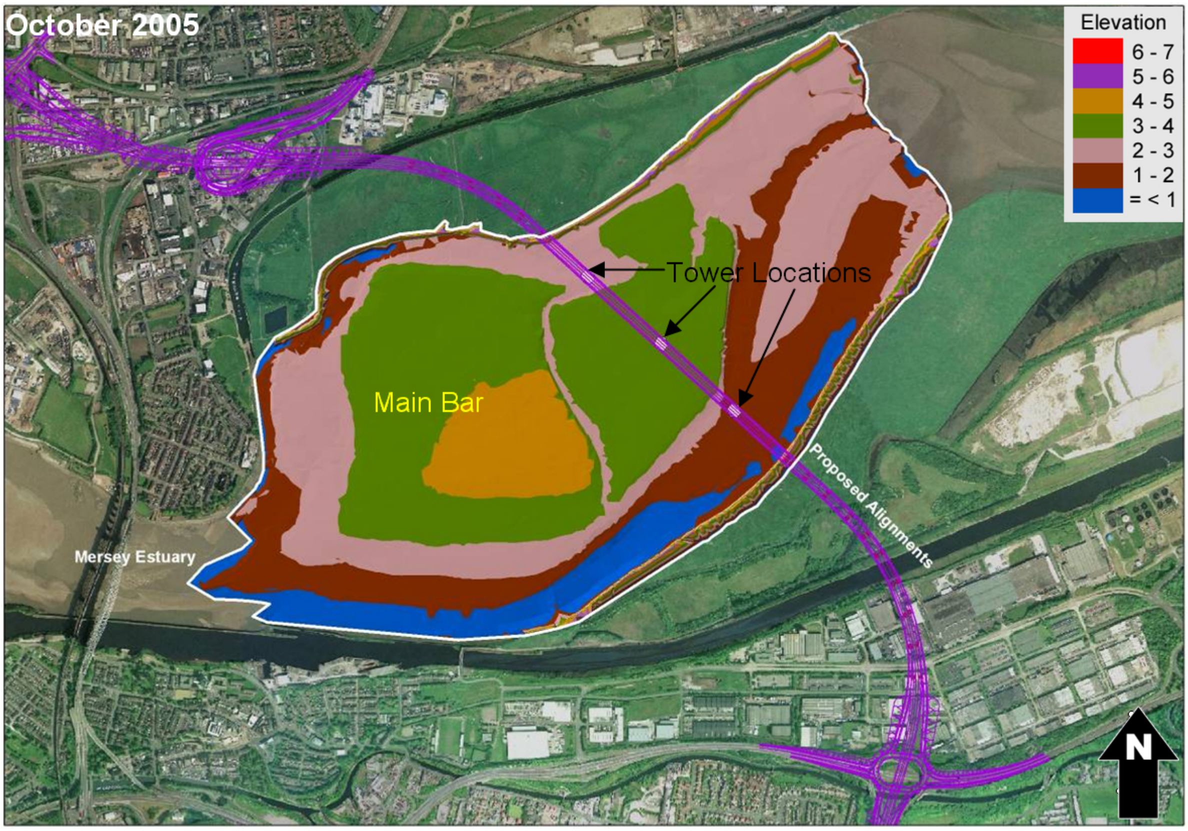


Figure 3.2 3-D shows the topographic levelling on the area of study – October 2005

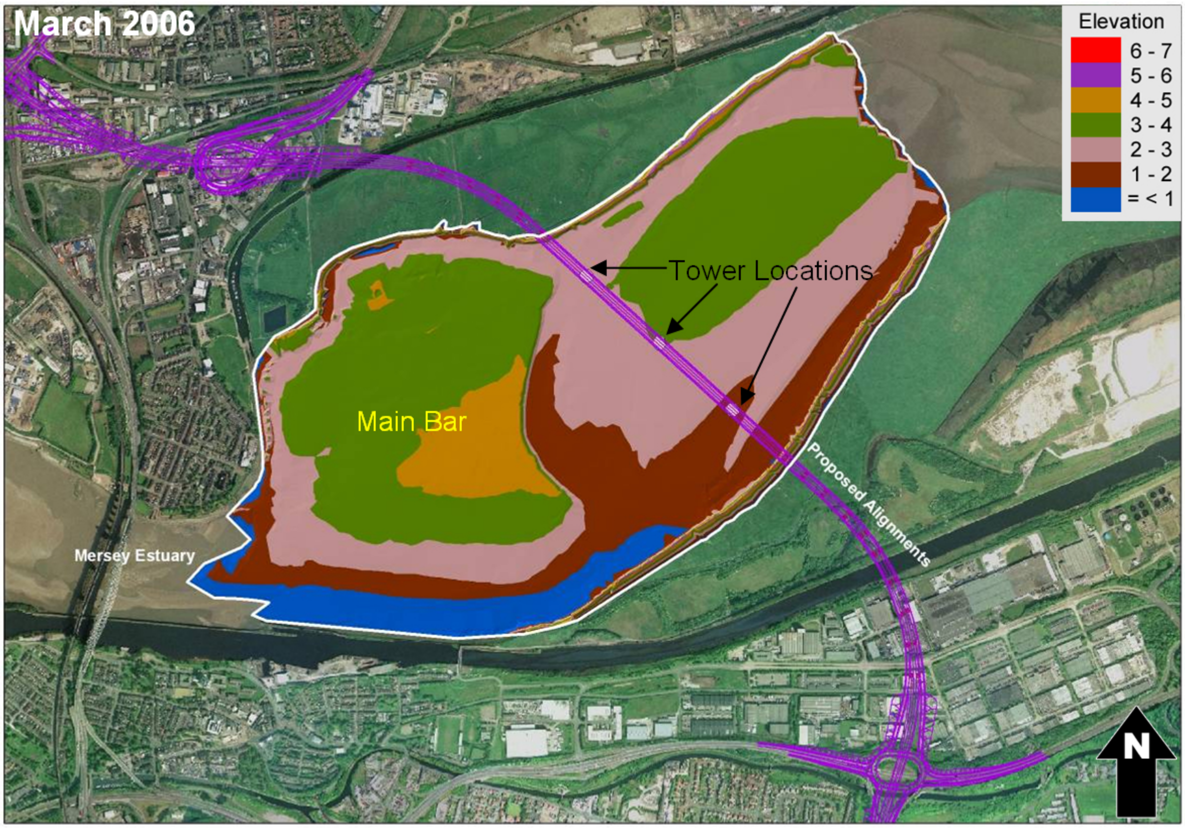


Figure 3.3 3-D shows the topographic levelling on the area of study – March 2006

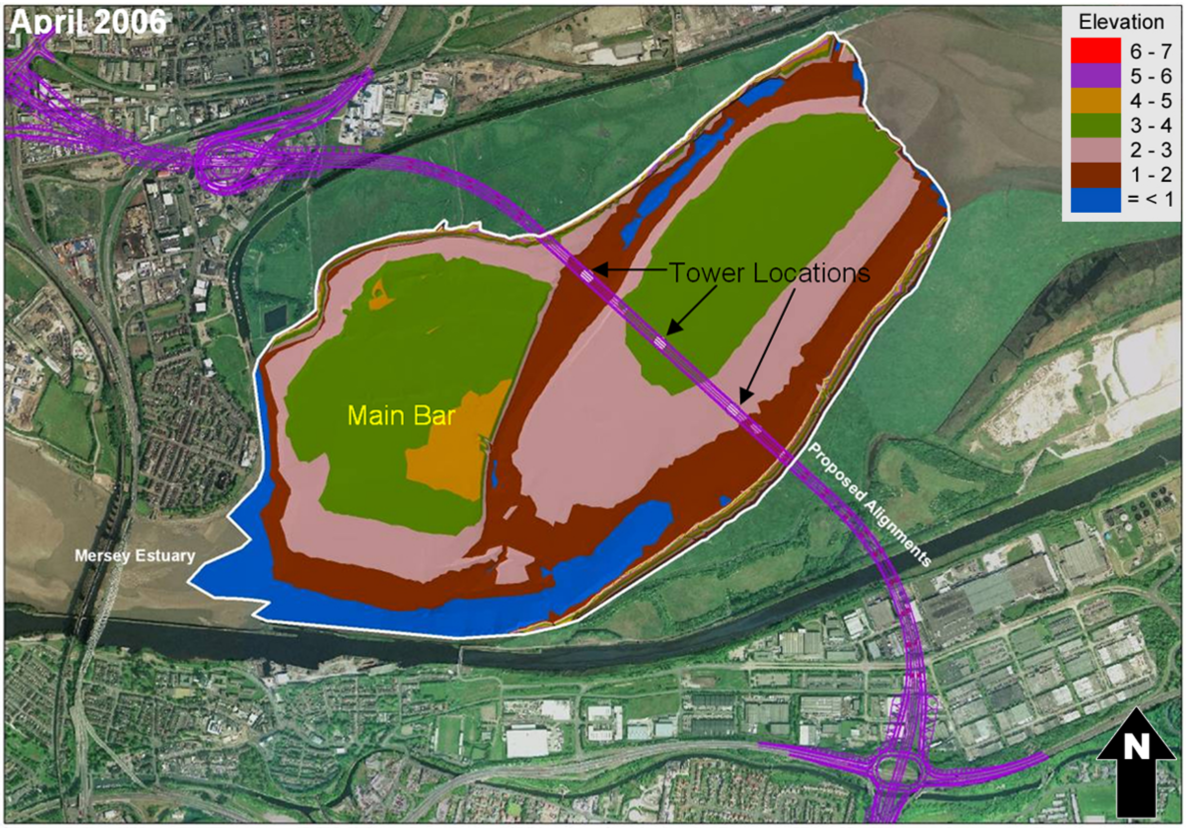


Figure 3.4 3-D shows the topographic levelling on the area of study – April 2006

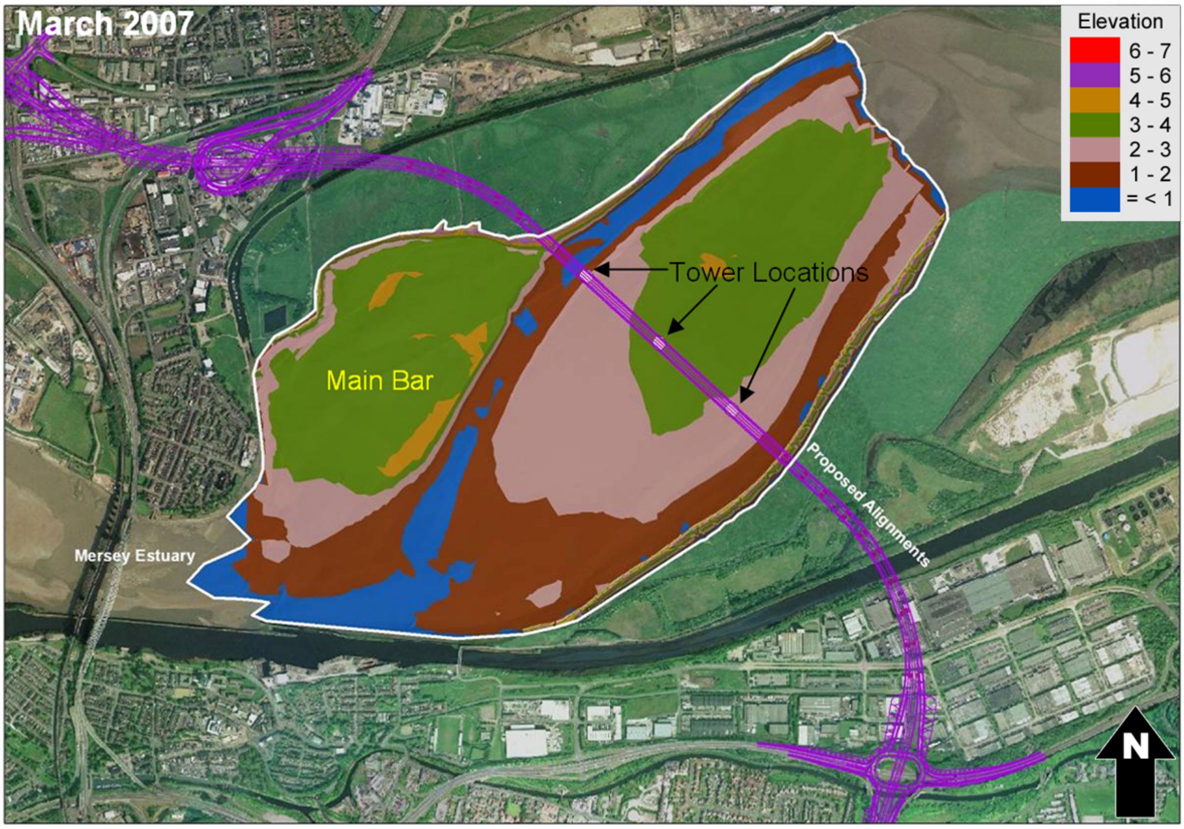


Figure 3.5 3-D shows the topographic levelling on the area of study – March 2007

3.3 Oblique aerial photographic survey and methodology of analysis

3.3.1 Oblique aerial photos have been used to provide frequent short-term (i.e. daily, weekly, monthly) information about the morphological changes occurring within the Mersey Estuary. These provide baseline information regarding the position of the sandbanks, main channel and salt-marsh edge within the Study Area.

3.3.2 The flights were predominantly made around the time of low water in order to show the locations of the low flow channels. However, a number of images were taken at high water to determine the extent of inundation on the salt-marshes. The flight path was identified to be in the middle of the Estuary and pictures of the Estuary were taken from different angles and positions to build up a full profile (Figure 3.6). The high altitude of 457m (1500 feet) was maintained during good weather conditions, however during cloud cover it lowered to less than 183m (600 feet).

3.3.3 In order to determine the frequency of channel dynamics, the flights were undertaken regularly on a daily, weekly and monthly basis according to the following schedule:

(i) Every day for one week (25.04.05 to 01.05.05)
(ii) Every other day for the following two weeks (02.05.05 to 15.05.05)
(iii) Every week for the following two months (16.05.05 to 14.07.05)
(iv) Every month for the following eleven months (15.07.05 to 15.05.06)

3.3.4 Appendix 1 includes the flight program and schedule of the oblique aerial photographs.

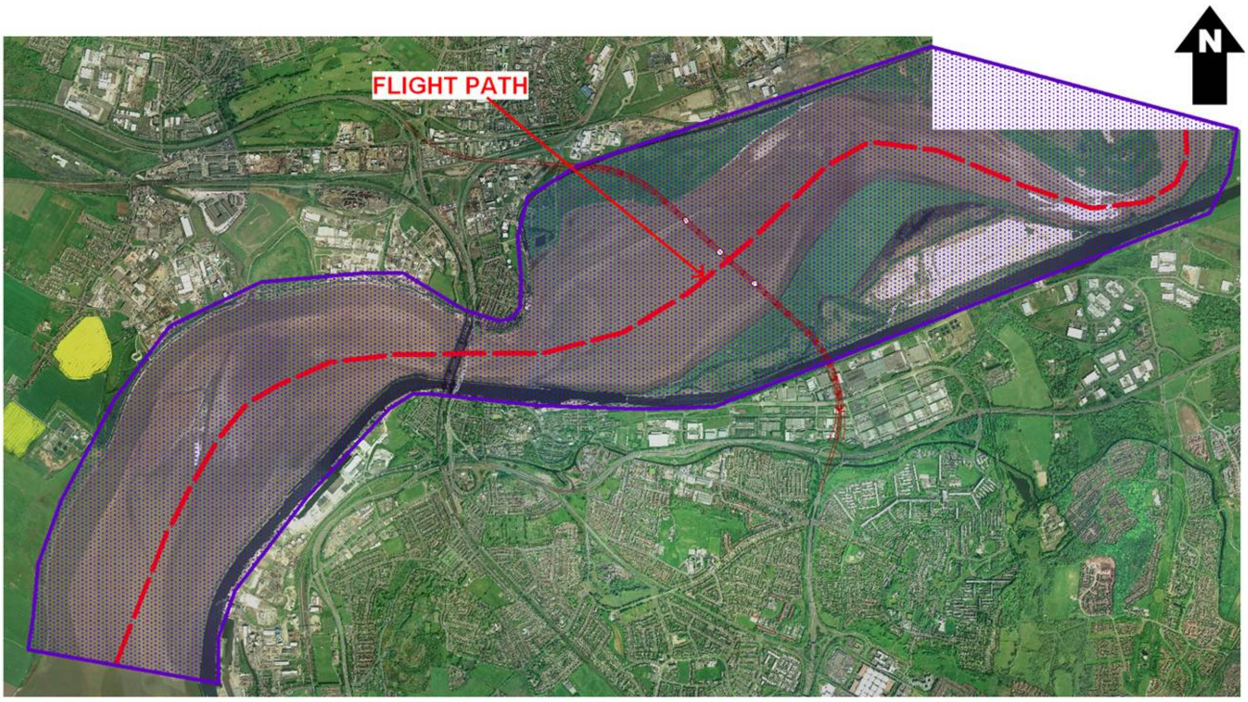


Figure 3.6 Flight path showing the spatial extent of the data capture of the oblique aerial photos within the Mersey Estuary

3.3.5 Additional daily flights were undertaken during the topographic surveys. The full schedule is given in Report No B4027.TR04.07. Figure 3.7 is an example of an oblique aerial photograph taken during the last topographic survey. The picture shows the channel behaviour and both the mobility and sinuosity of the channel (blue colour).

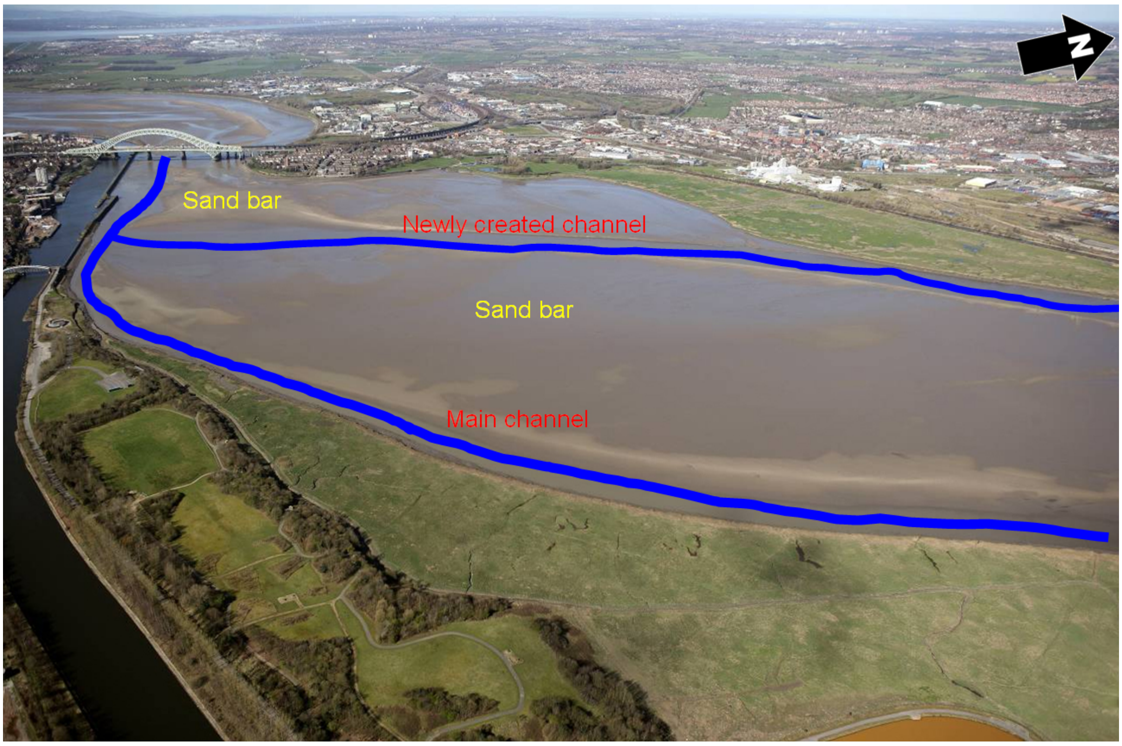


Figure 3.7 Oblique aerial photo taken on 17 March 2007 during the topographic Survey

Views chosen for analysis

3.3.6 Repeat aerial photographs from the same vantage point were taken. Five viewpoints were used. Two were chosen within S2 as this is the vicinity of the proposed crossing and historically, within the Study Area, this area commonly displayed the highest frequency of observable macro-scale morphological change.

3.3.7 The five views are:

a. View 1 (Figure 3.8)of S1 is taken from the southern edge of the estuary looking upstream across Norton Marsh;
b. View 2 (Figure 3.9) of S2 is taken from the northern edge of the estuary and looks south towards the apex of Wigg Island. The proposed Mersey Gateway would cross this view;
c. View 3 (Figure 3.10), also of S2, looks northwest with Wigg Island visible on the right. The proposed Mersey Gateway would cross this view;
d. View 4 (Figure 3.11) of S3 is from the southern edge of the estuary and shows the area immediately upstream of the Silver Jubilee Bridge; and
e. View 5 (Figure 3.12) of S4 covers the area down-estuary of the Silver Jubilee Bridge.

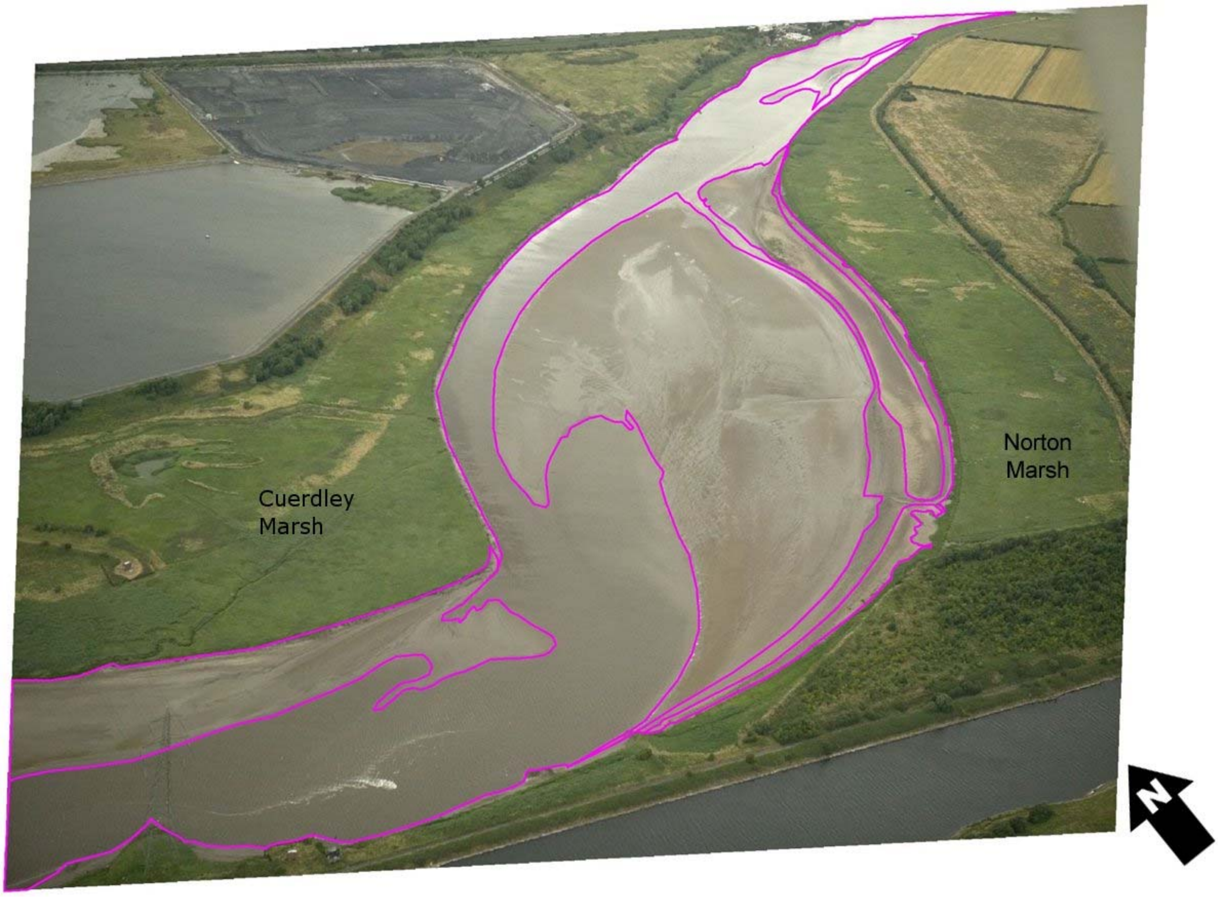


Figure 3.8 View 1 – Norton Marsh from the south west

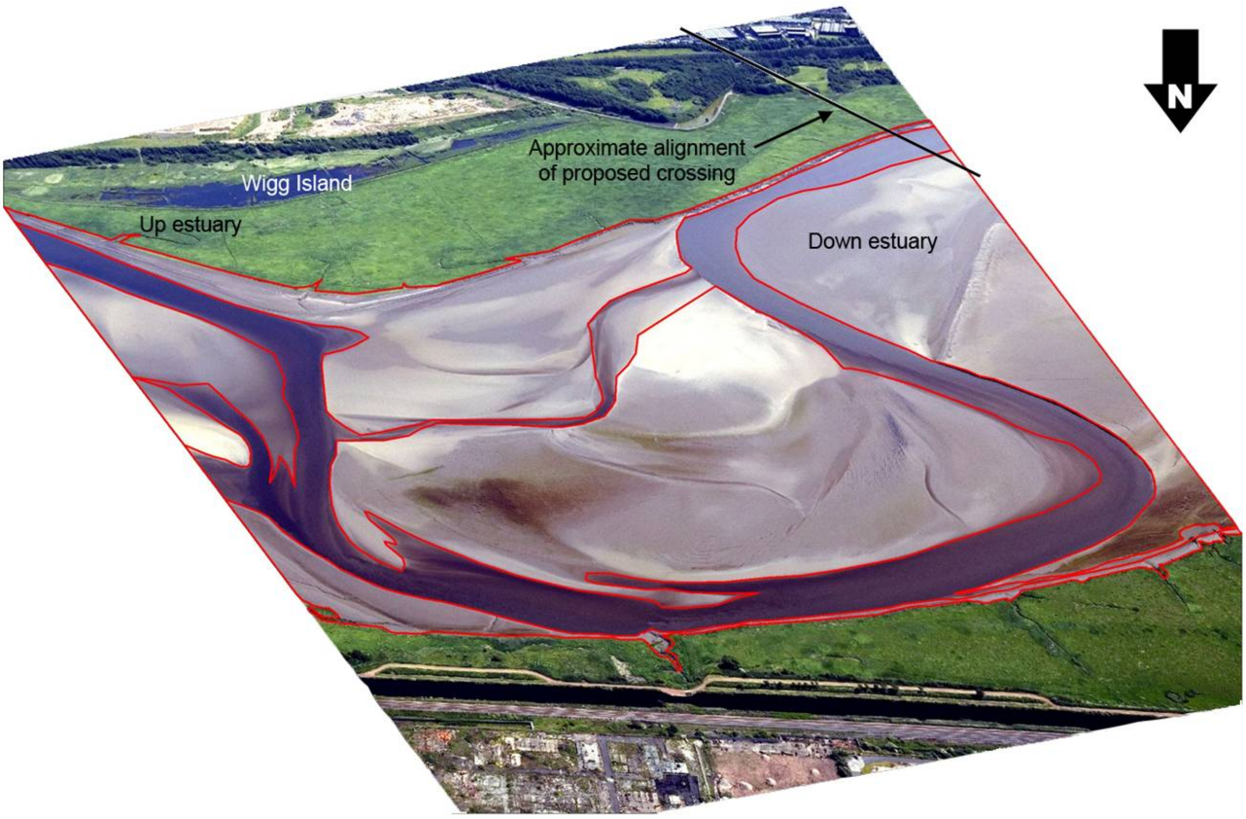


Figure 3.9 View 2 – S2 Wigg Island (downstream view)

Figure 3.10 View 3 – S2 Wigg Island (upstream view), Hempstones Point visible on the right

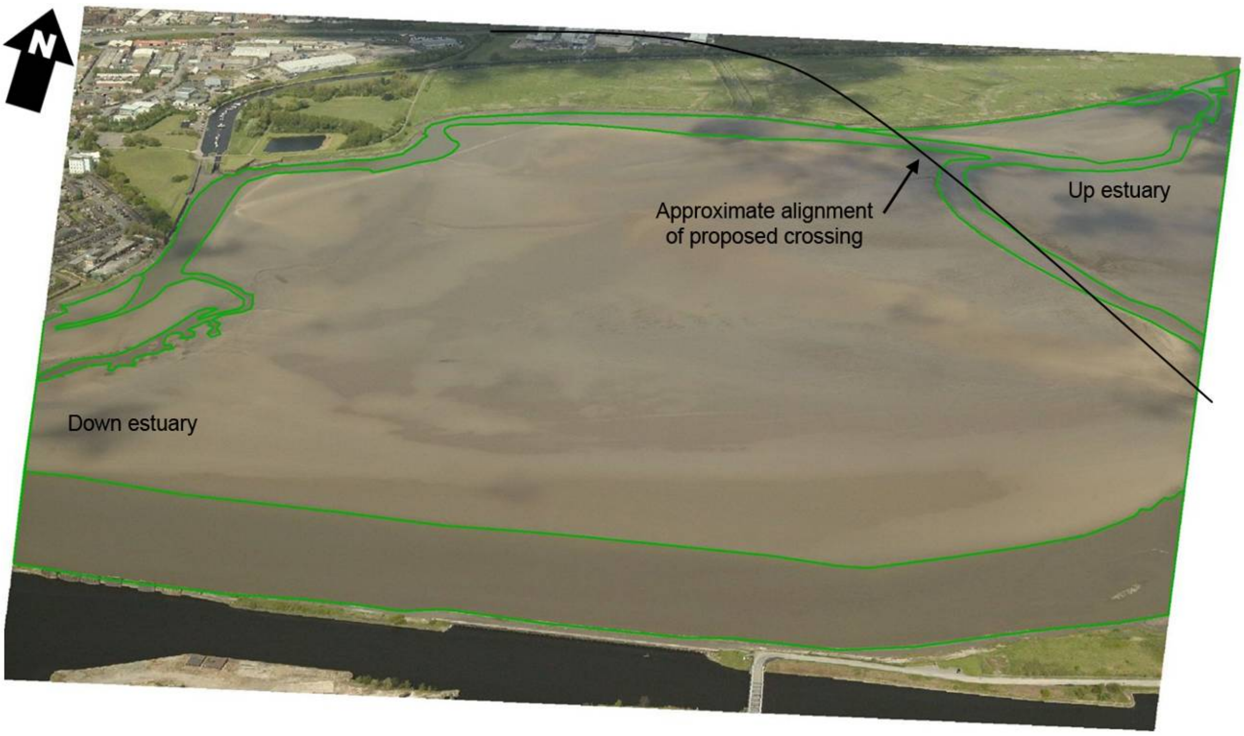


Figure 3.11 View 4 – S3 Runcorn Sands (the area up-estuary from the Silver Jubilee Bridge)

Figure 3.12 View 5 – S4 Silver Jubilee Bridge (the area down-estuary from the Silver Jubilee Bridge)

Image selection, rectification, digitizing and analysis

3.3.8 A system was established to quality assure the flight pictures and record all the incoming oblique aerial photos. Screening of the images was undertaken to select the best image - in terms of ground clarity, area covered, and angle – to be used for the analysis and monitoring the geomorphology of the Estuary.

3.3.9 The selected images were categorised into the four sections of the Study Area as shown in Figure 3.1.

3.3.10 A database was established to hold the oblique aerial photographic record. For each aerial photograph, the following details were logged into a database: date of the flight, description and location/orientation of the image, state of tide, altitude, weather conditions, wind speed, wind direction and the study area (S1; S2; S3 or S4 as detailed above).

3.3.11 The first flights provided several images of each Study Area. For each area the best image, in terms of ground clarity, area covered, and angle, was selected. This was used as a base image.

3.3.12 The images could not be rectified to a flat grid system, so the scale varies between each image. Since the images could not be rectified to a flat grid system, subsequent images were matched to the base image using ground control points that are clearly visible on both images - for example, a road junction or pylon. This approach allowed for qualitative comparison between images and permits an assessment to be made of both the mobility and sinuosity of the channel and sand bars.

3.3.13 The best images of the five views were selected from each subsequent flight, again based on ground clarity, area covered and angle. The outline of the ebb and flood channels, bars and saltmarsh were then traced digitally, in order to identify any changes in the position of the low water channels or other features within the estuary.

3.3.14 Successive selected images were rectified to the original base. The exercise allows comparison of images that were previously at different scales but does not permit distances between features to be measured accurately. Images were analysed for macro-scale morphological change. Where a change in the depositional/erosional processes or morphological characteristics was noted, the image was included in the detailed analysis.

3.3.15 The photographic data and channel outlines were overlain in chronological order using ArcGIS software to track channel movements and to identify change. Each photograph was digitised using a different colour to distinguish it from the others. The images were analysed for morphological change and process, and features of interest were documented and change described for each of the five viewpoints.

3.3.16 The results of this comparison for each of the key focus areas (S1- S4) are shown in the tables of analysis within Appendix 2.

3.3.17 The information collected in the database and analysed in Appendix 2 was used to identify the frequency and nature of observed morphological change. The database was also populated with details of the tidal cycle, high fluvial flow events and the wind climate between consecutive images to ascertain to what extent observed morphological change could be attributed to other controlling environmental parameters. It provides a summary of the key features present within each of the main view areas; around Wigg Island and Hempstones Point, Norton Marsh, Spike Island and downstream of the Silver Jubilee Bridge.

Accuracy and Precision in Analysis of Images

3.3.18 Morphological changes can only be confidently identified provided they are of a greater magnitude than any inaccuracies which may have resulted from image processing. Within the method employed for recording morphological change, four potential limitations of accuracy and precision can be identified:

a. Parallax error from oblique air photographs, where objects in the distance are distorted more than those close to the camera. This error varies spatially within an image;
b. Image rectification error. Images of the same study zone differ in the area covered due to the angle they are taken from, and, therefore, the images match each other with varying degrees of closeness;
c. Subjective (digitizing) variation is controlled by two main factors: (a) interpretation of the boundary between different morphological features; and (b) hand accuracy in tracing this boundary;
d. Tide-driven misconception. An area may appear different visually – even though no morphological changes have taken place - because the tide is at a different level.

3.3.19 The first of these limitations – parallax error – is controlled by rectifying images against each other, so that although an error is always present, it is constant between images and they can, therefore, be directly compared.

3.3.20 Rectification error is a result of variation the altitude of the aeroplane, the flight path, the field and angle of view together with the technical specification of the camera. The result is that the objects in the margin of the picture are more distorted than the centre. This makes the images difficult to rectify to the plane of the National Grid. Consequently the images were matched to each other using a false grid system to avoid the distortion which arises from stretching the images to fit into the National Grid. The matching method was based on using clear and visible Ground Control Points (GCPs). Rectification error was quantified by comparing how far apart ground control points (GCPs) were from one photograph to the next. A GCP is a fixed point on the ground that is used to match one image to the next. The error ranged between 0.046 – 0.320%, which is acceptably small.

3.3.21 Subjective (digitizing) variation was assessed by comparing the channel and bar polygons as digitized by three trained analysts. All operators had been trained by a specialist to follow the boundary between water and sediment, thereby discriminating channels and bars. A comparison based on the shape and perimeter of the variable digitised features was made, as shown in Figure 3.13. The figure shows the average cumulative Root Mean Square (RMS) variation achieved from both the interpretation of the geomorphological bars and the accuracy in hand tracing which varied from 1 to 17%.

3.3.22 The tide level would significantly influence the appearance and therefore the visual interpretation of the different morphological features. The presence or absence of a specific morphological feature might be determined only at low levels of tide. Consequently oblique images were taken only at low water.

3.3.23 Slight differences in the height of the tide at low water could still alter the visual interpretation of morphological features. Because the image processing method does not allow direct measurements, this error cannot be quantitatively investigated. However, in order to make a qualitative assessment, the tide height (as recorded at Old Quay Lock) was included in the table of changes (Appendix 2). This demonstrates that tide height shows very little difference between photographs in the observed area of the inundated Estuary.

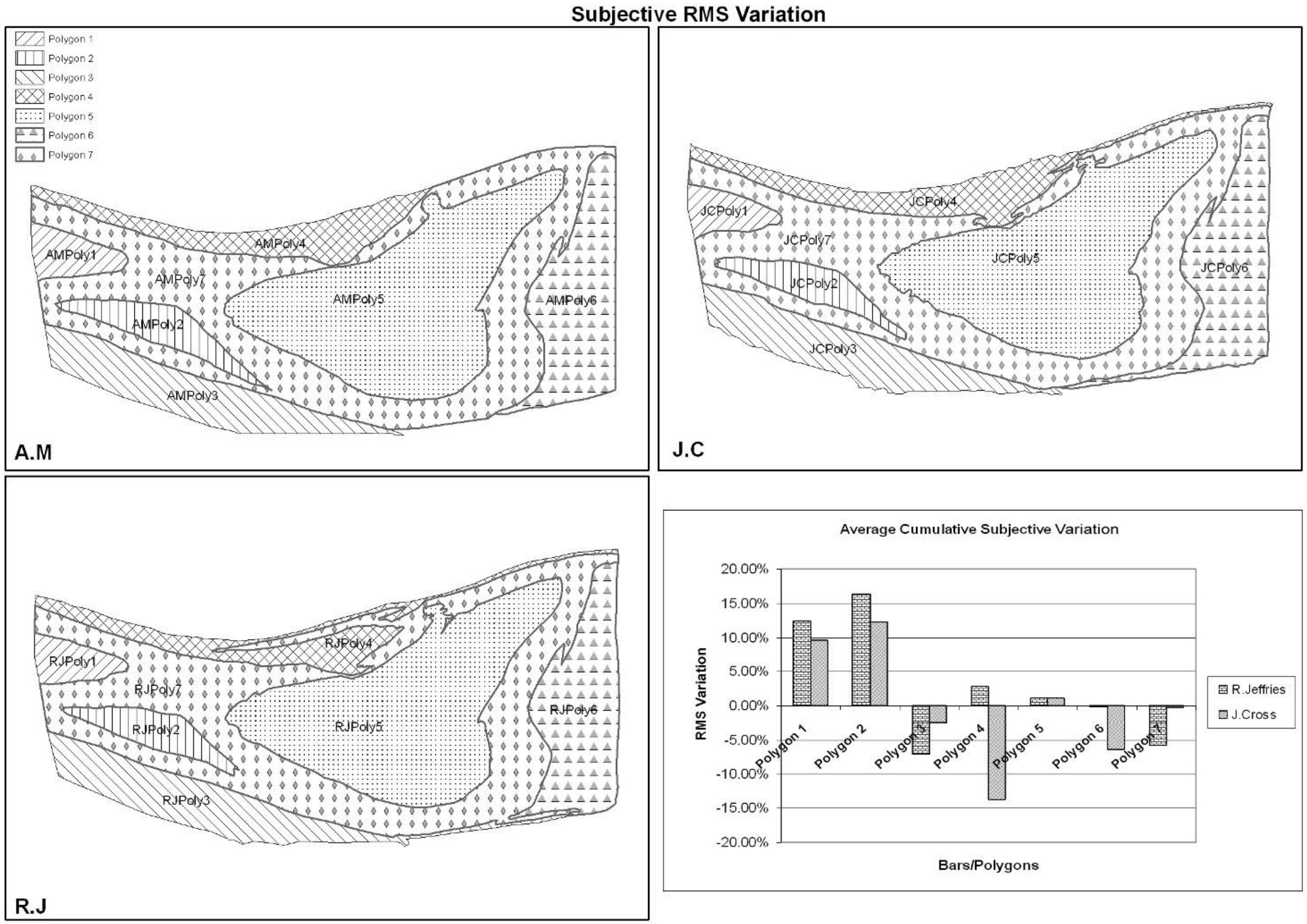


Figure 3.13 Example of the Oblique Aerial Photos Limitations - Digitising Error

3.4 Oblique aerial photographic visual analysis

S1 Norton Marsh

3.4.1 Visual analysis of the oblique aerial photographs is based on figures 3.16 to 3.20 which are displayed in subsequent pages.

3.4.2 At Norton Marsh a low flow channel is consistently visible along the north bank – this was stable during the study period. A large bar occupies the central part of the estuary, and again this was stable during the study period. However, secondary channels are sometimes visible on this bar. The dominant channel and central bar remained largely stable during the course of the study period, with minor changes occurring to the 'snout' of the bar that points downstream. A flood channel cuts into the bar. The only observed change visible in Figures 3.14 – 3.20 below regards the periodic development and decay/cut-off of secondary low flow channels located close to the south bank. Such changes were observed over the course of a week, month or longer. The morphology of Norton Marsh remained stable during the study period (Figures 3.14 – 3.20).

3.4.3 Average wind speed and direction at the time of photographing the Estuary was recorded to enable an understanding of the extent to which wind speed and direction influence the morphological changes of the Estuary to be gained. It was shown that wind speed and direction does not have a significant impact on the sinuosity of the channel or the changes of the sand bars, however there were minor changes in the secondary flood channel on 08/06/2005 (Figure 3.16) and on 06/11/2006 (Figure 3.19), which could be attributed to some extent to the wind.

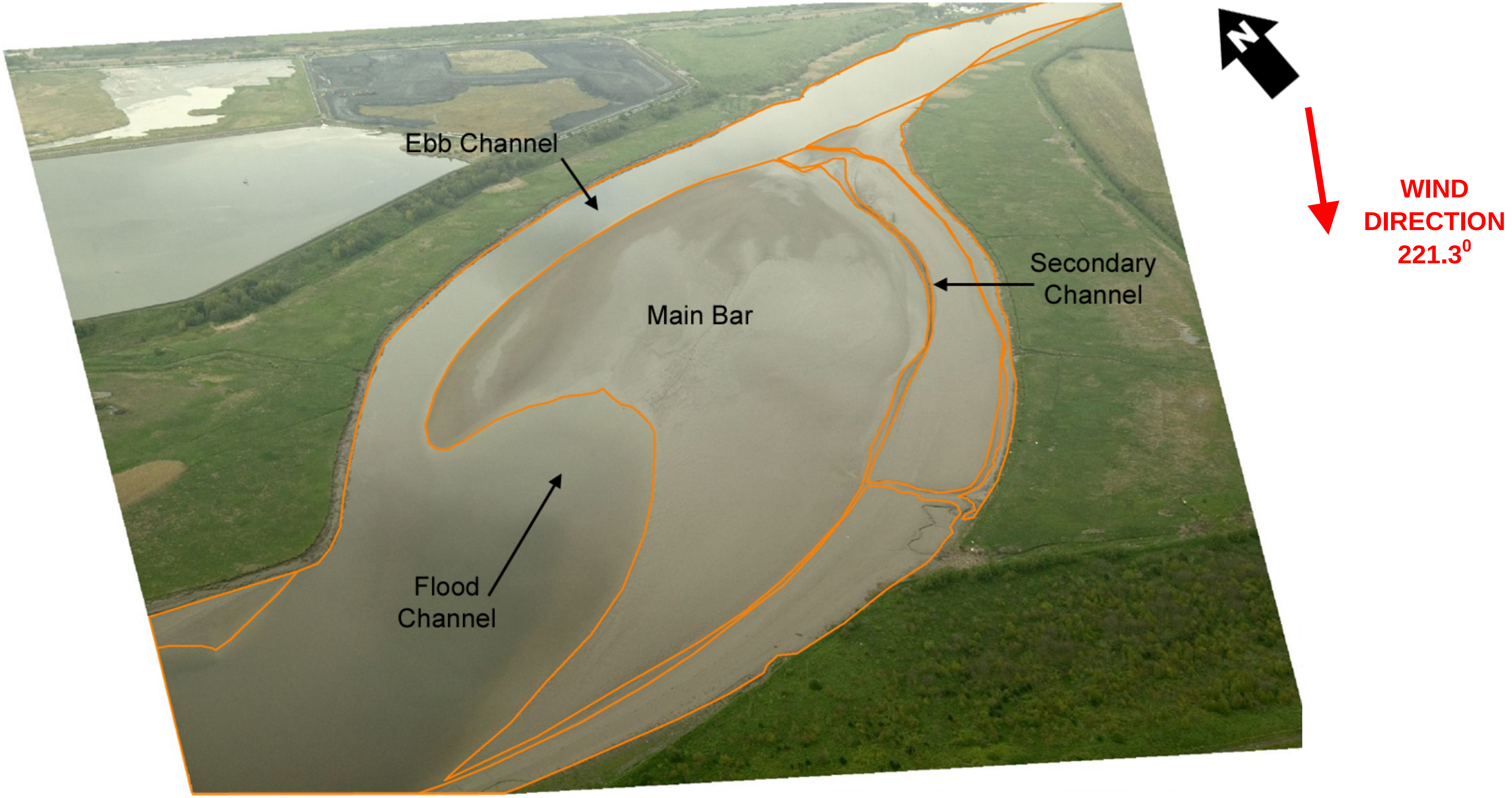


Figure 3.14 The location of the low water channels at S1 Norton Marsh - 30/04/2005

Image taken: 14:27 BST LW at time of image: 1.34m LW recorded at Old Quay Lock: 13:30 LW Height 1.06m

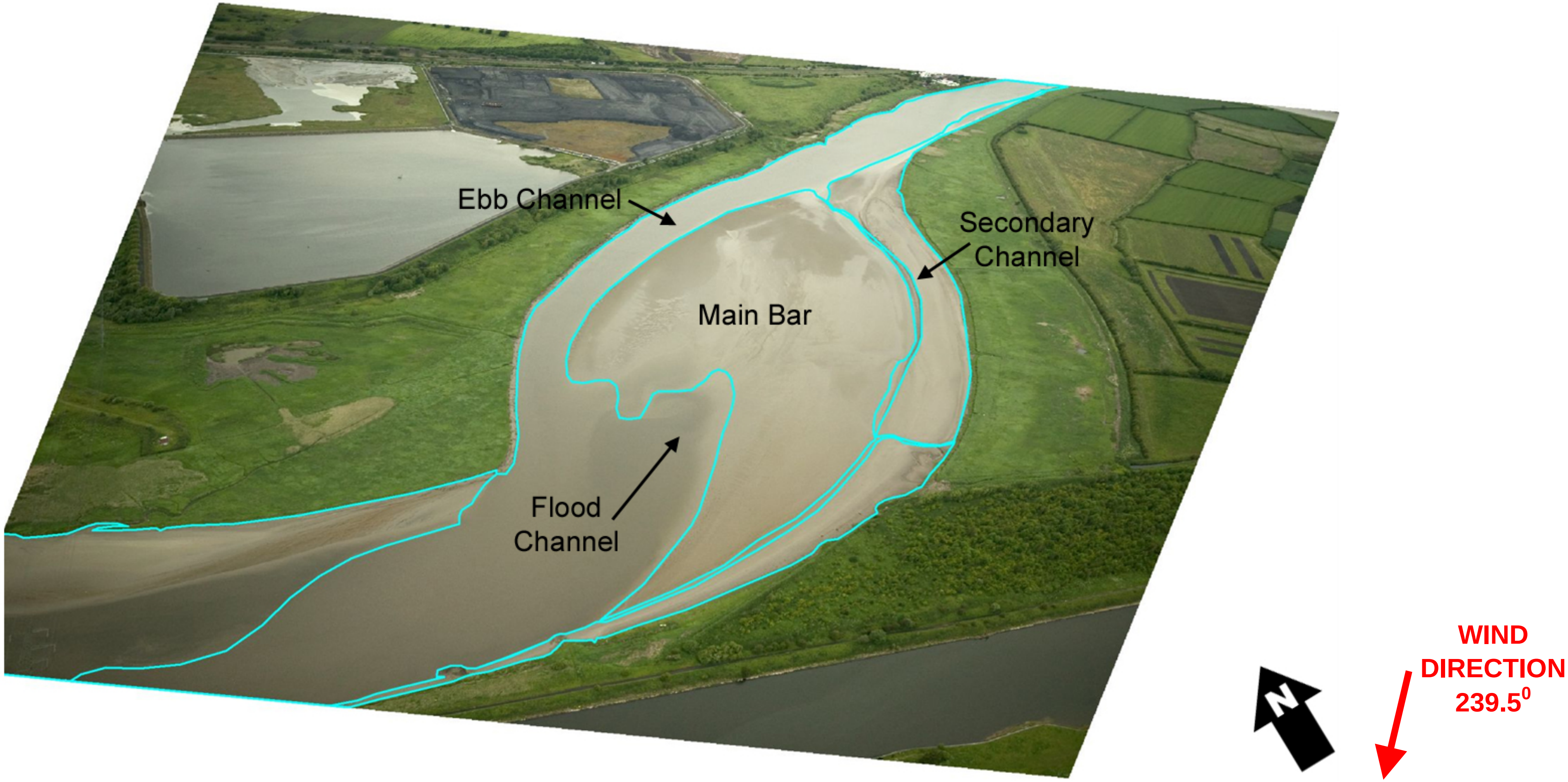


Figure 3.15 The location of the low water channels at S1 Norton Marsh - 01/06/2005 (one secondary channel)
Image taken: 18:07 BST LW at time of image: 1.27m LW recorded at Old Quay Lock: 17:30 LW Height 0.97m

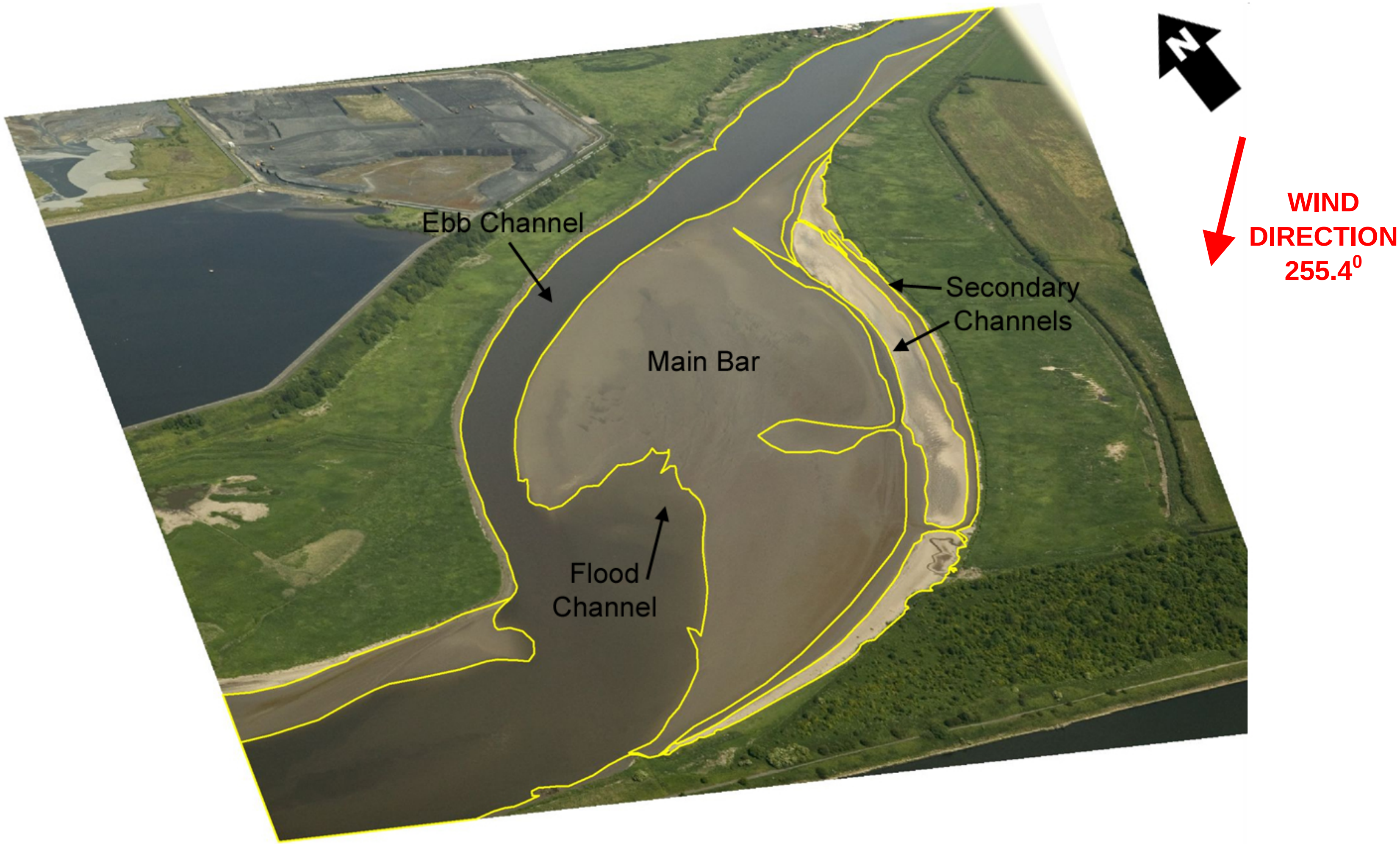


Figure 3.16 **The location of the low water channels at S1 Norton Marsh - 08/06/2005 (two secondary channels)**
Image taken: 11:09 BST LW at time of image: 1.86m LW recorded at Old Quay Lock: 10:45 LW Height 0.99m

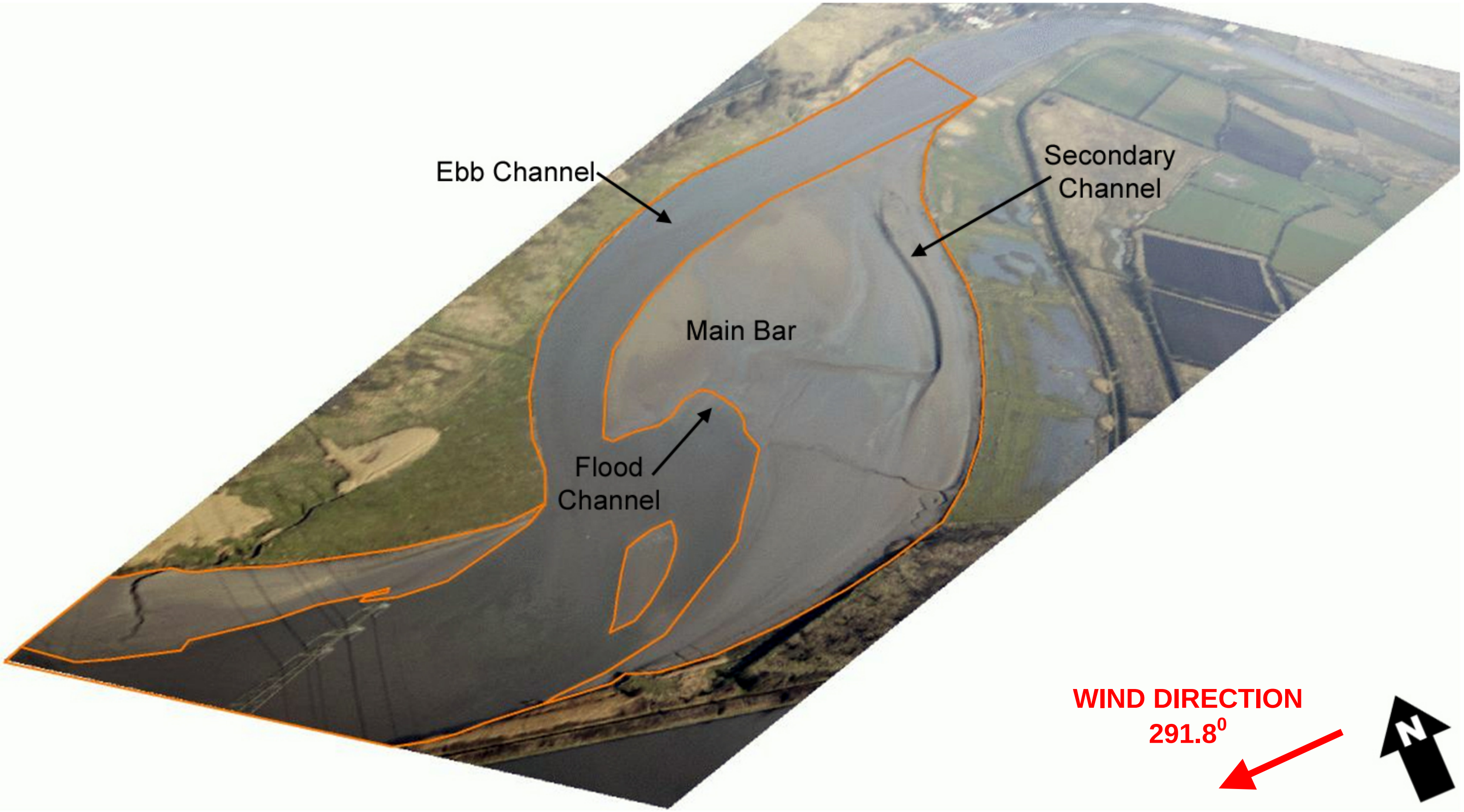


Figure 3.17 The location of the low water channels at S1 Norton Marsh – 14/04/2006

Image taken: 10:47 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 10:00 LW Height 1.23m

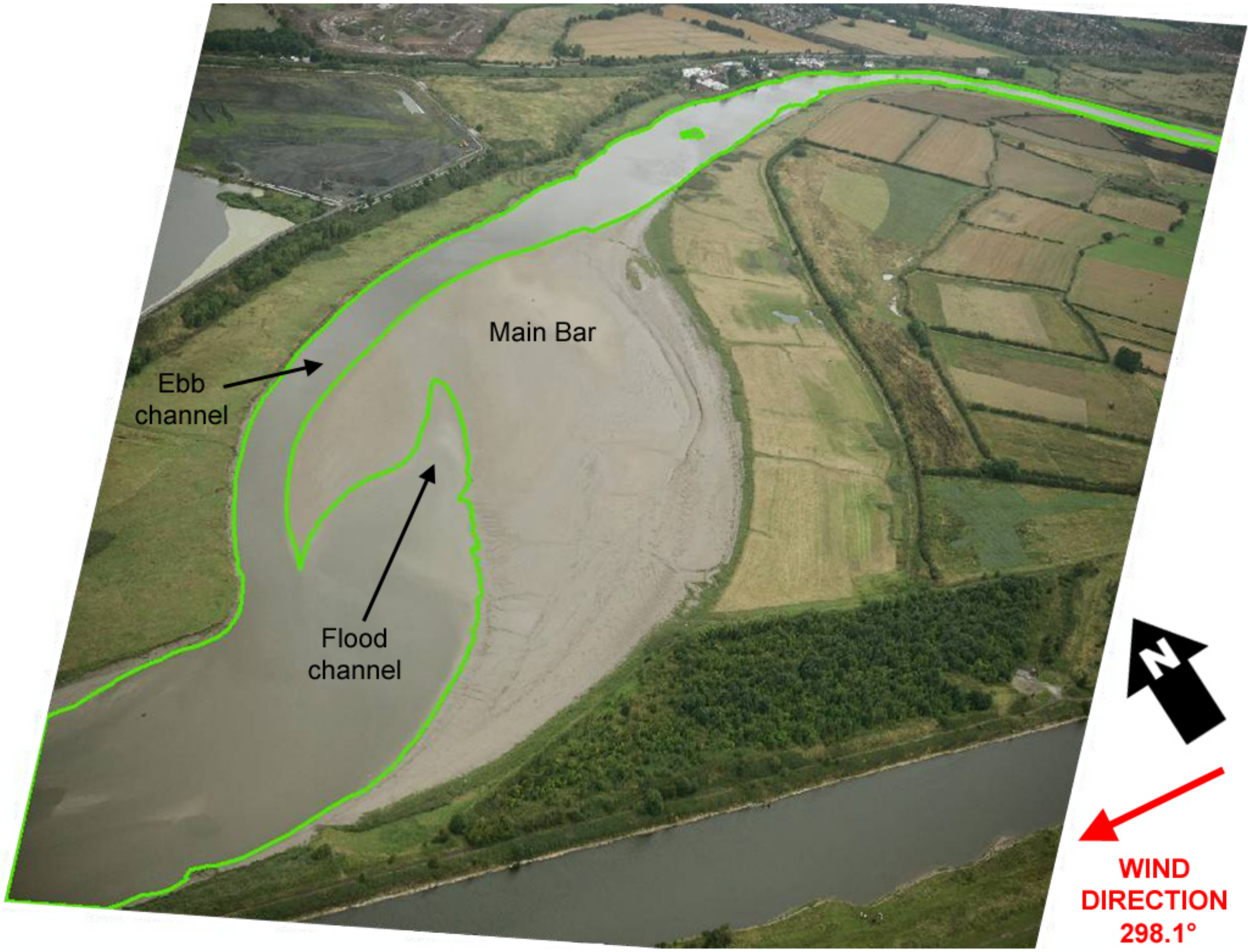


Figure 3.18 The location of low water channels at S1 Norton Marsh – 21/08/2006

Image taken: 10:47 BST LW at time of image: 3.13m. LW recorded at Old Quay Lock: 10:00 LW Height 1.23m

Figure 3.19 The location of the low water channels at S1 Norton Marsh – 06/11/2006

Image taken: 10:47 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 10:00 LW Height 1.23m

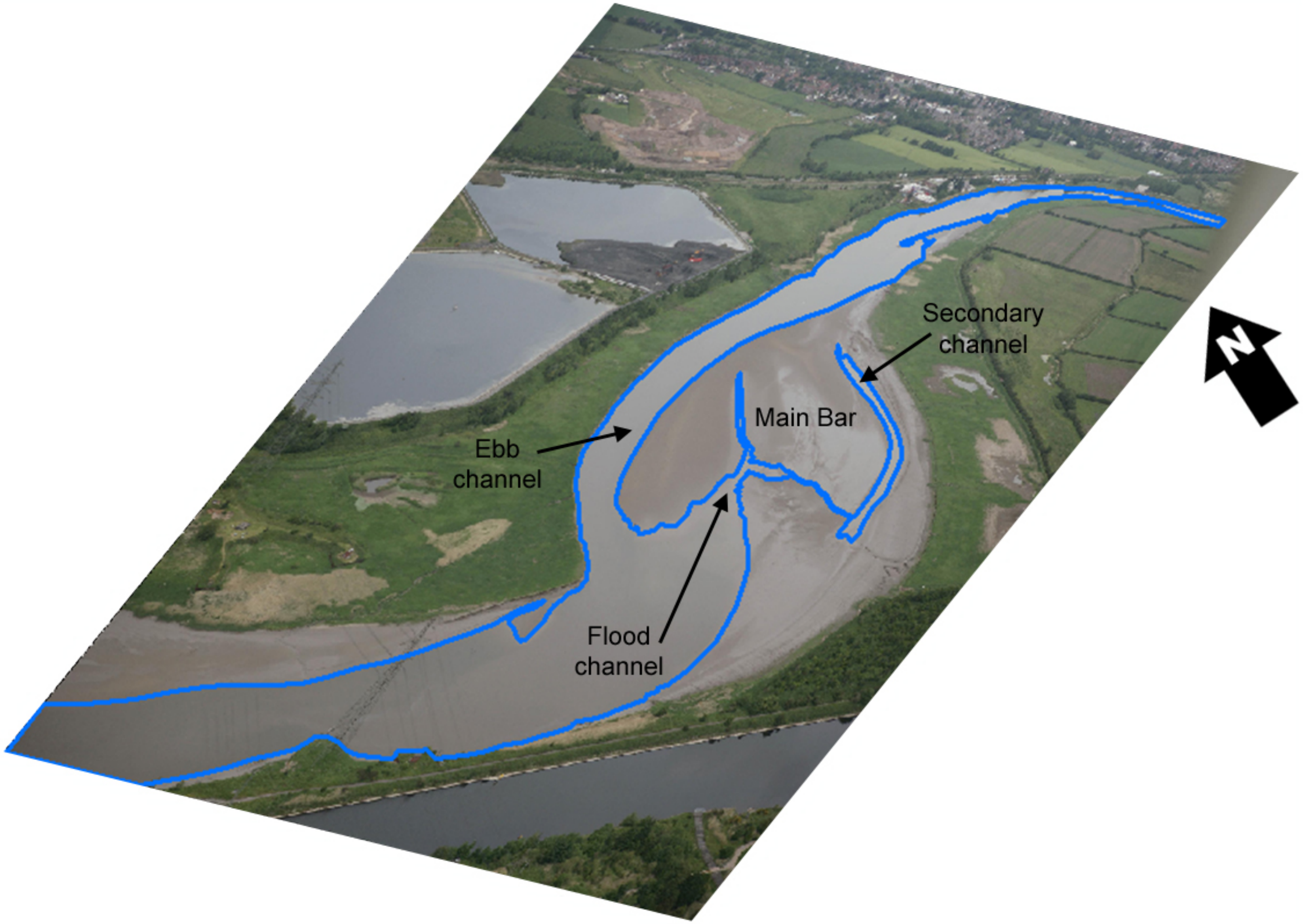


Figure 3.20 The location of the low water channels at S1 Norton Marsh – 21/05/2007

Image taken: 10:47 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 10:00 LW Height 1.23m

S2 Wigg Island (downstream view)

3.4.4 Visual analysis of the oblique aerial photographs is based on figures 3.21 to 3.27 which are displayed in subsequent pages.

3.4.5 Visual interpretation of the oblique aerial photos gives an understanding of the geomorphology of the Estuary. Figure 3.21 (12/05/2005) shows a dynamic ebb channel that is adjusting its boundary. Most flow is along the northern bank of the Estuary (bottom of image), where erosion is taking place along the outer bend of the meander. This erosion has several impacts: firstly it supplies a source of sediment to the channel. This sediment is then moved downstream and some is deposited as a bar in the lee of a small headland. Secondly, the erosion (and associated downstream deposition) changes the overall shape of the channel, causing it to lengthen. This reduces the bed gradient.

3.4.6 Most of the images (Figures 3.21 – 3.27) show the main bar in the centre of the image with an evidence of both flood and ebb flows. When the images were taken the ebb tide is draining through a secondary channel running across the bar and parallel to the southern bank of the estuary. Downstream flow along this channel is limited by a constriction in the centre of the bar. Upstream of the constriction the channel opens out into a funnel shape, the widest part oriented up the Estuary, and this is likely to be a flood delta formed when the flood tide flows rapidly up the Estuary. A second, smaller flood channel is visible on the opposite side of the main channel to the erosion described earlier.

3.4.7 Over the two weeks until 01/06/2005 (Figure 3.22), a progressive change in channel location and form has occurred. During this time the number of channels and bars within the area remain stable. But the main ebb channel is longer and a point bar has been deposited downstream of the erosion, leaving the former channel line – now a crevassed cliff – behind. The main bar in the centre of the image has grown downstream, and the smaller of the two flood channels is now clearly intruding into it. The secondary channel that runs across the bar neck appears to be wider. Erosion continues on the outside of the meander bend, and the bar downstream on the same side has also grown.

3.4.8 This process of channel lengthening continues for at least the next two weeks (Figure 3.23 taken on 15/06/2005), and then a major change occurs. The main ebb channel switches to a new location in the centre of the main bar, abandoning its former location next to the north bank. This process is shown progressing in Figure 3.24 (22/06/2005) where the secondary channel is split into three separate channels, likely to have been created by flood intrusions. By 20/07/2005 the main channel has switched to one of these channels (Figure 3.25).

3.4.9 This switching could be the result of a cycle of negative feedback. As the dominant channel adjusts its boundary it reduces its sediment transport capability, leading to sedimentation and causing the channel to switch to a new location, from which point it begins lengthening again. As erosion progressed during the previous 6-8 weeks, the dominant ebb channel lengthened, and its gradient reduced. This also reduces stream power, which is directly related to bed gradient. This channel would therefore become less competent at transporting sediment, and its bed would have accreted, reducing channel capacity, and forcing more water along the secondary channels that run across the neck of the main bar. This gradual increase in discharge would increase stream power and therefore competency to transport sediment, causing erosion of the channel boundary and the formation of a new channel, capable of transporting the majority of ebb flow. Once the majority of flow has been captured, the channel begins adjusting its boundary again, and the cycle recommences. Channel changes are related to sediment transport, which is a function of shear stress at the channel boundary. An increase in this energy increases the ability to erode sediment within the channel and thus change the morphology. Therefore, high energy conditions may relate to channel change. The greatest source of energy within the estuary is tidal influx. It is therefore conceptually possible that the switching could be caused by spring tides providing a large amount of energy for channel change. However, a large fluvial flow combined with a large tide could also provide the necessary energy.

3.4.10 This pattern of change continues for few months; however the overall pattern up to March 2007 is that the main channel maintained its route in the north bank with fluctuation of the minor flooding “secondary channel to be created in the south bank.

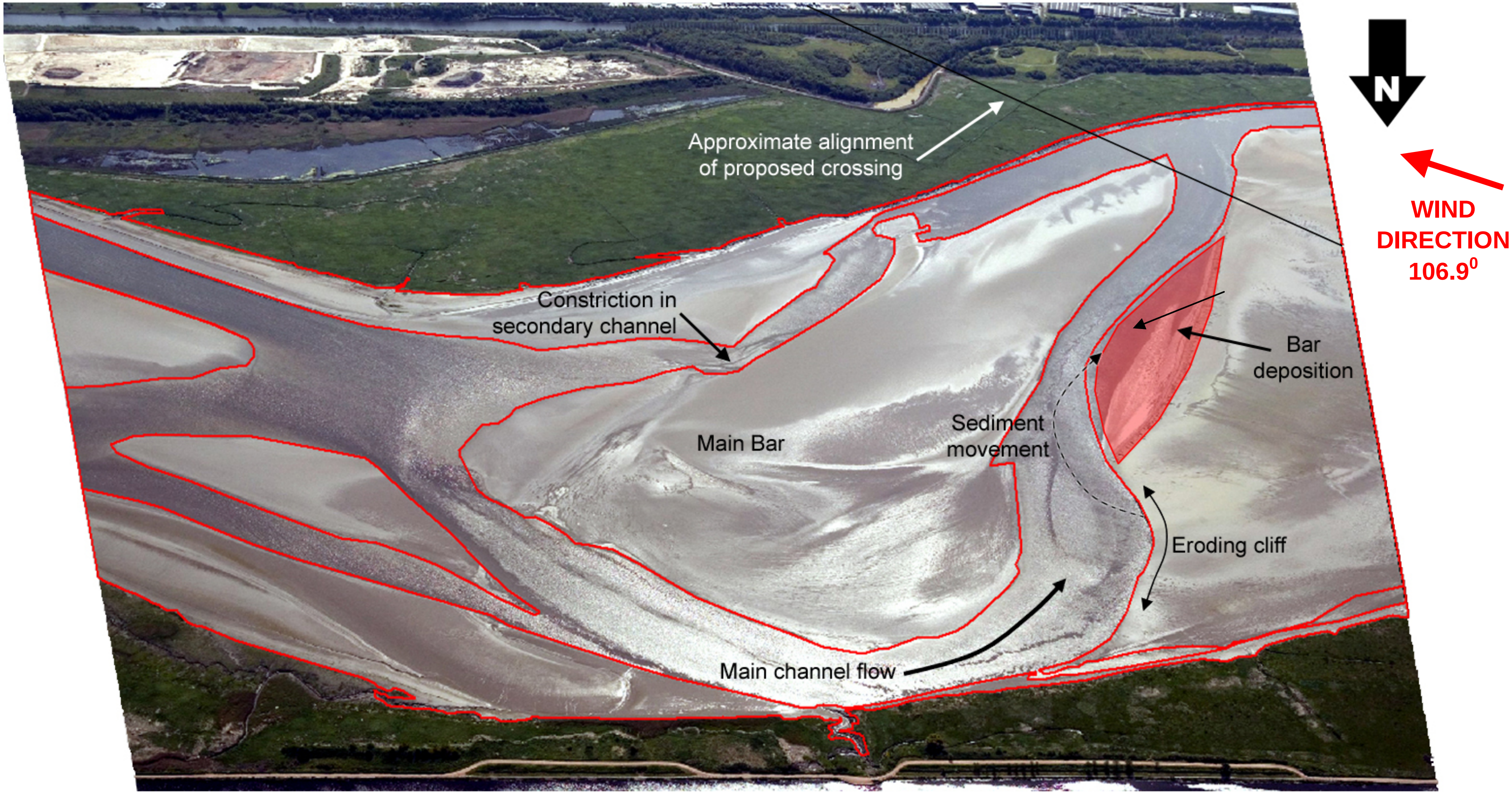


Figure 3.21 The location of low water channels at S2 Wigg Island (downstream view) - 12/05/2005

Image taken: 12:38 BST LW at time of image: 1.11m LW recorded at Old Quay Lock: 12:00 LW Height 0.98m

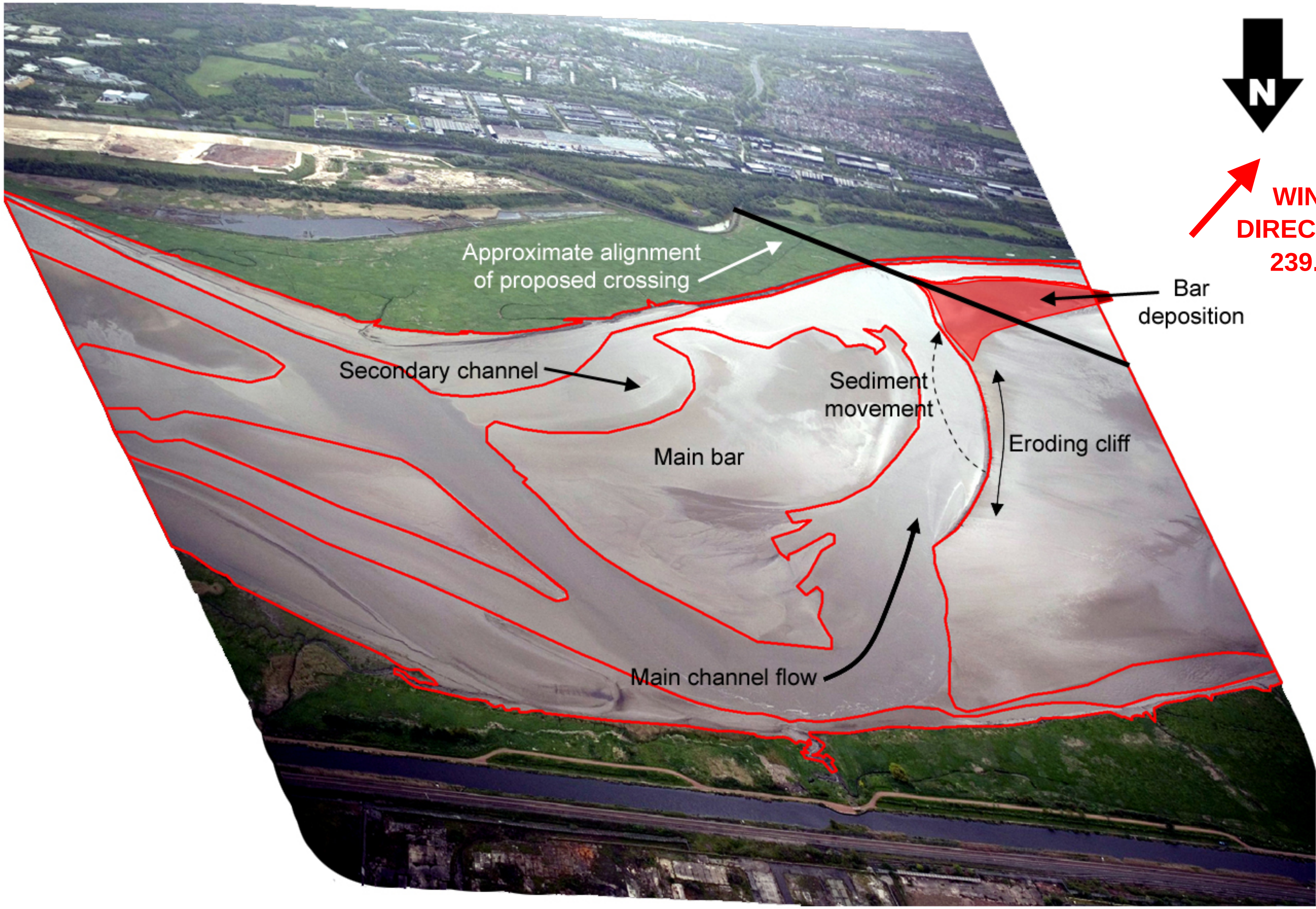


Figure 3.22 The location of the low water channels at S2 Wigg Island (downstream view) - 01/06/2005

Image taken: 18:07 BST LW at time of image: 1.27m LW recorded at Old Quay Lock: 17:30 LW Height 0.97m

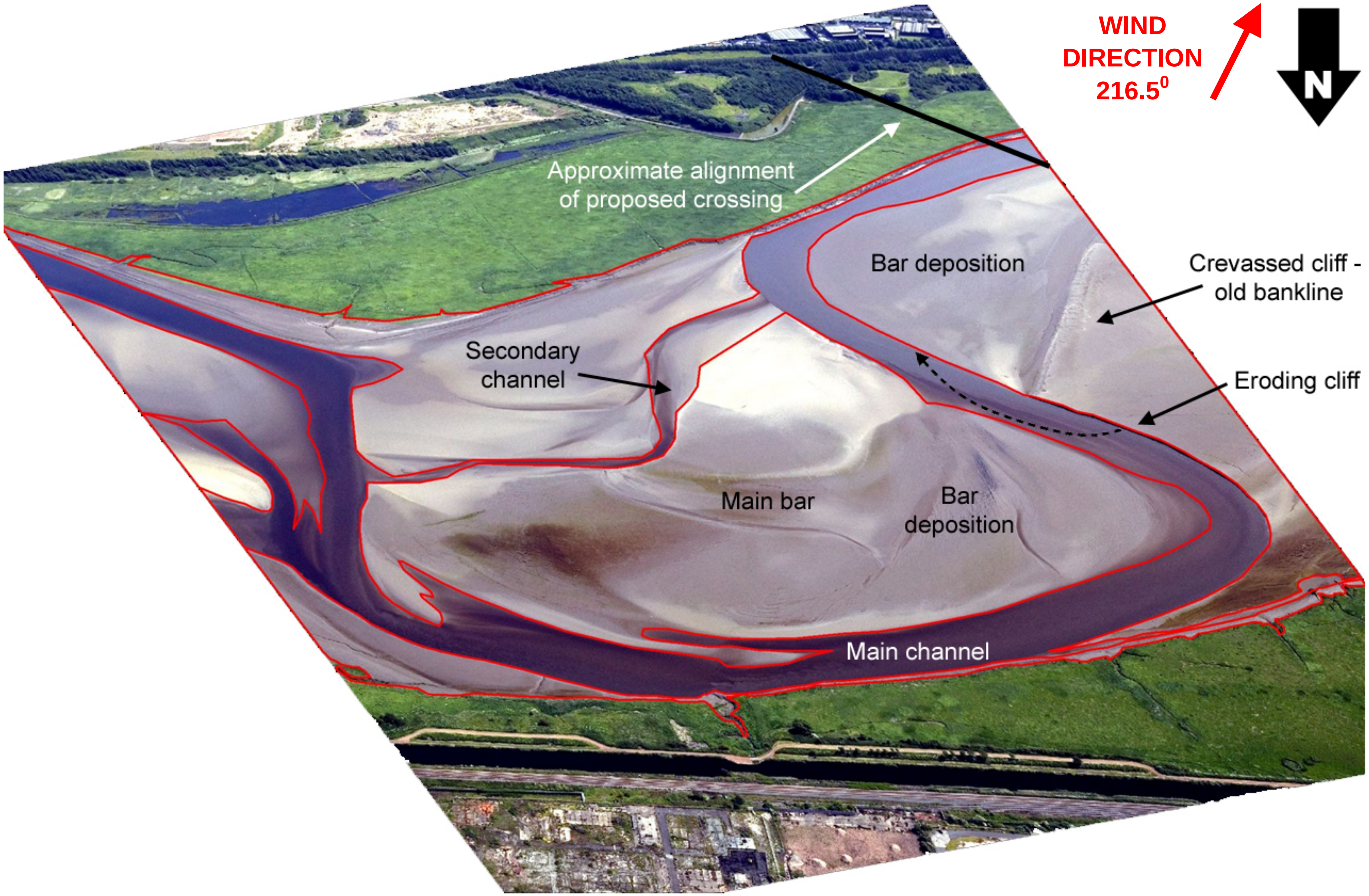


Figure 3.23 The location of the low water channels at S2 Wigg Island (downstream view) - 15/06/2005

Image taken: 16:12 BST LW at time of image: 1.4m LW recorded at Old Quay Lock: 15:45 LW Height 0.84m

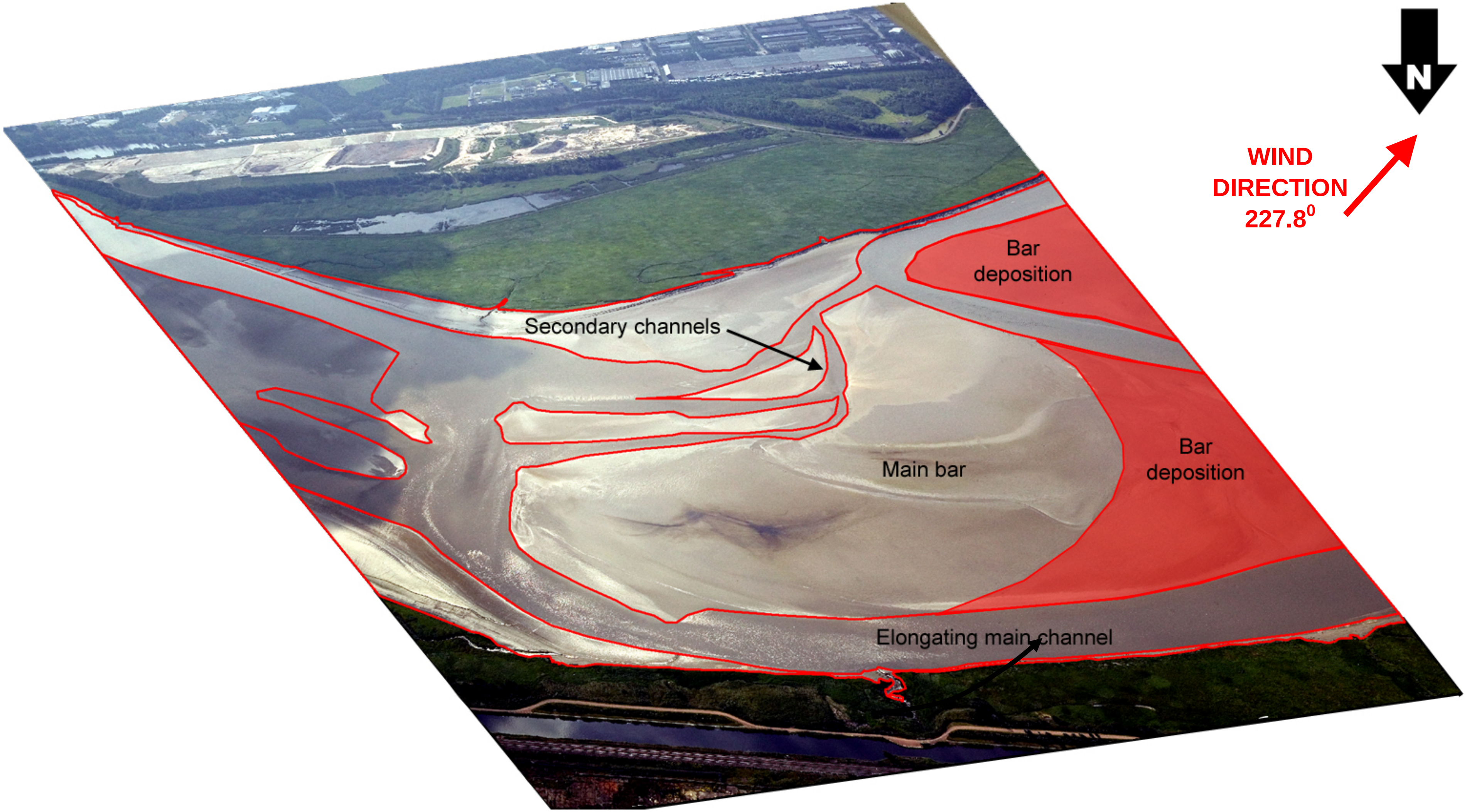


Figure 3.24 The location of the low water channels at S2 Wigg Island (downstream view) - 22/06/2005

Image taken: 10:11 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 09:15 LW Height 0.96m

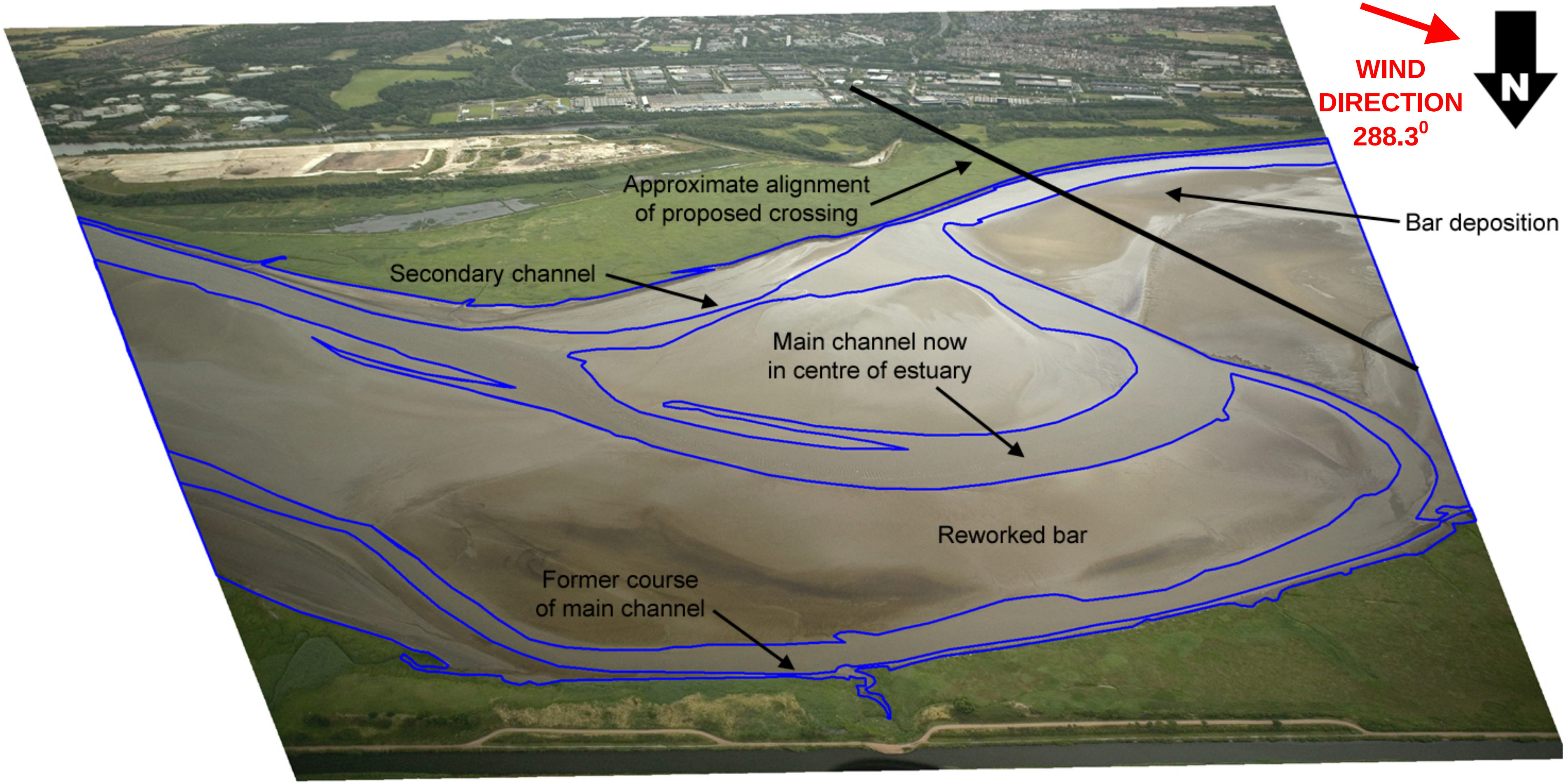


Figure 3.25 The location of the low water channels at S2 Wigg Island (downstream view) - 20/07/2005

Image taken: 09:06 BST LW at time of image: 2.3m LW recorded at Old Quay Lock: 08:30 LW Height 1.00m

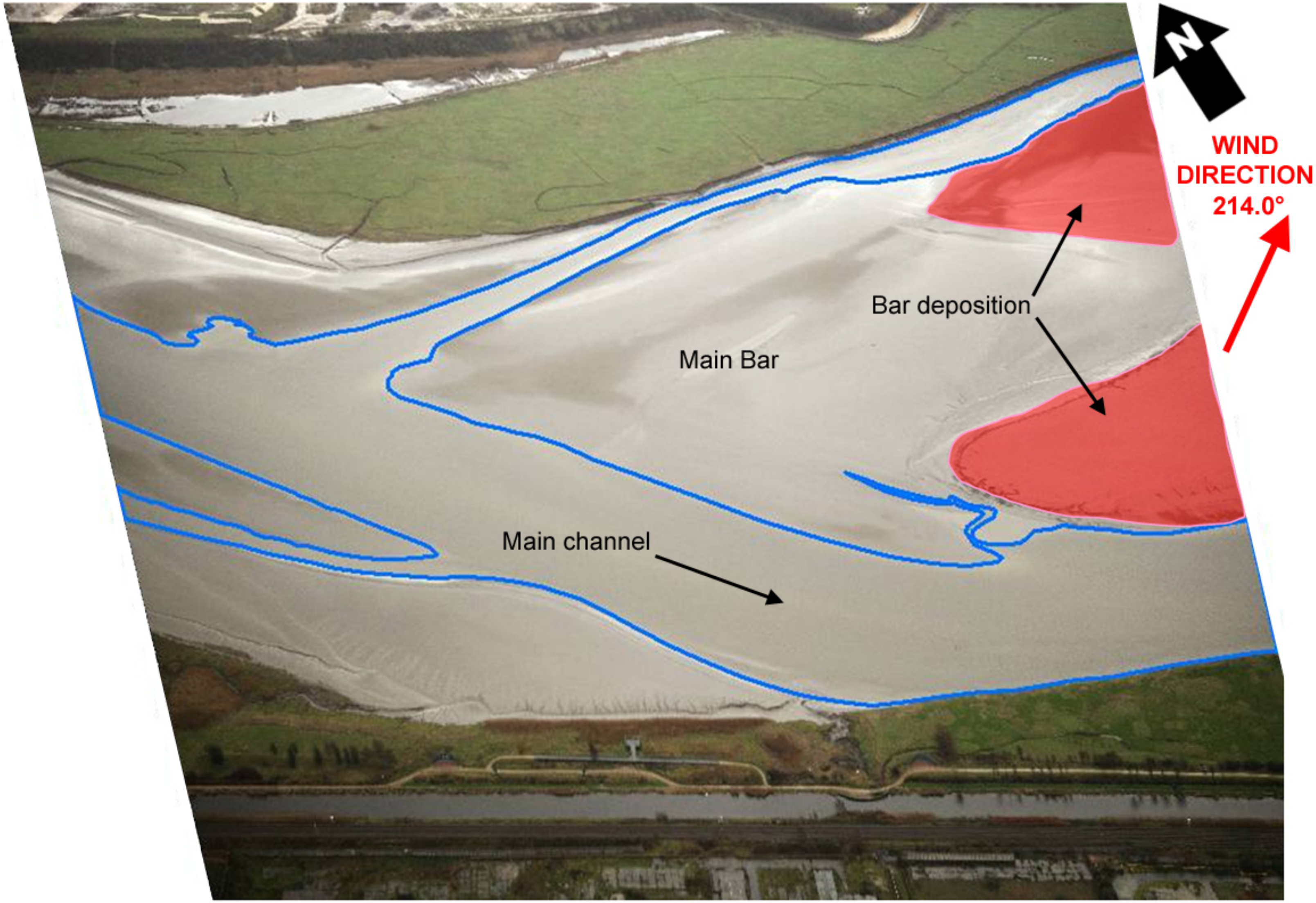


Figure 3.26 The location of the low water channels at S2 Wigg Island (downstream view) - 07/01/2007

Image taken: 11:37 BST LW at time of image: - LW recorded at Old Quay Lock: - LW Height -

"-" data were not available

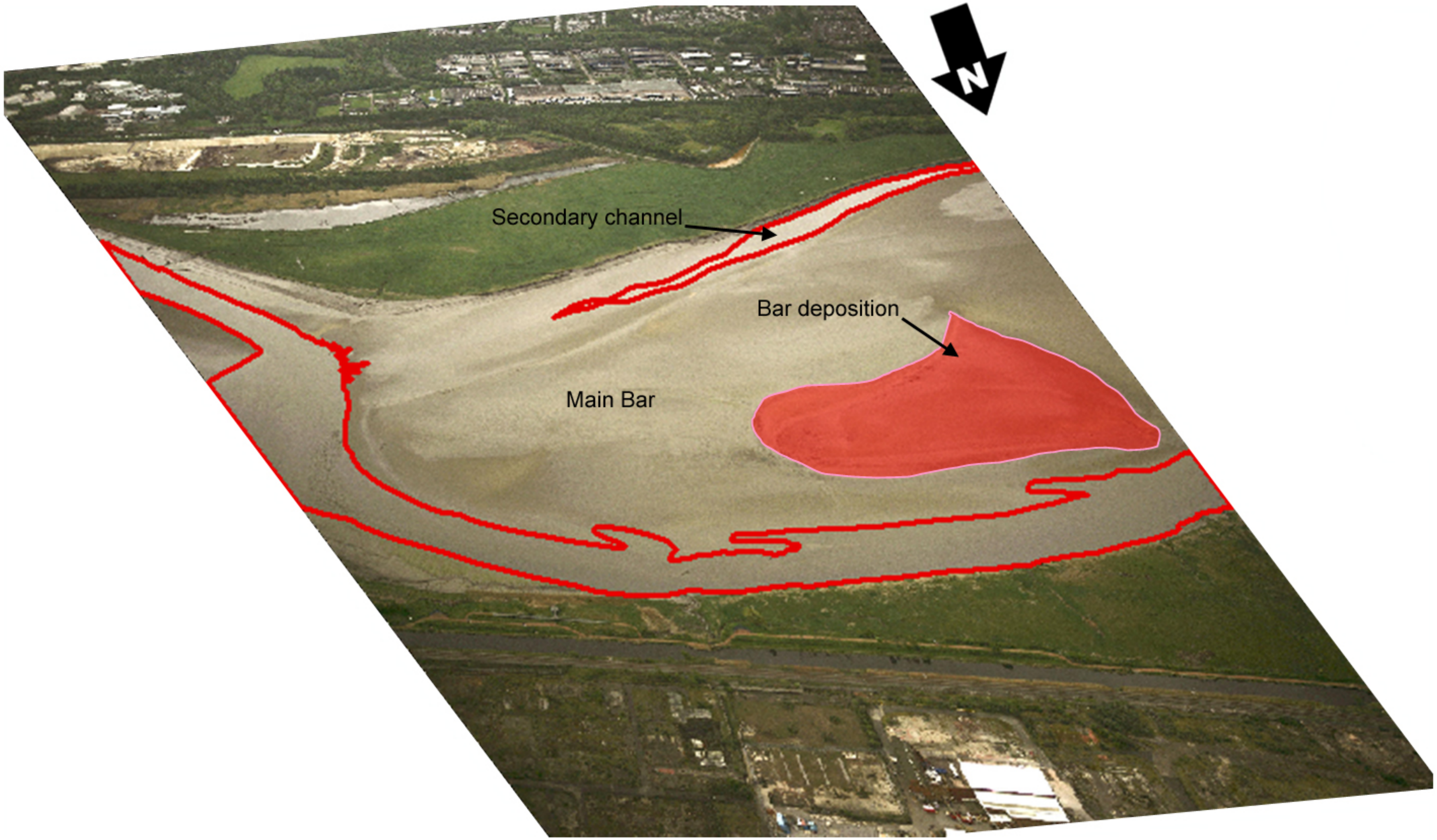


Figure 3.27 The location of the low water channels at S2 Wigg Island (downstream view) - 24/04/2007
Image taken: 15:51 BST LW at time of image: 0.4 m LW recorded at Old Quay Lock: 08:30 LW Height 1.00 m

S2 Wigg Island (upstream view)

3.4.11 Visual analysis of the oblique aerial photographs is based on figures 3.28 to 3.35 which are displayed in subsequent pages.

3.4.12 The channel lengthening and observed switching described above is also visible in Figures 3.28 (12/05/2005), 3.29 (08/06/2005) and 3.30 (13/07/2005). These figures also show clearly that the flood intrusion cutting across the bar to the south of the Estuary is an extension of the low flow channel that runs along the base of the images. This highlights that the broad shape of the Estuary – rather than the detail of the low flow channel – controls the direction of the flood tide, which apparently sweeps up the Estuary and across the bar.

3.4.13 Another abandoned channel runs across the large bar occupying the centre of this view (Figure 3.28, 12/05/2005). Ebb flow drains out of this abandoned channel and ends in a fan or delta that attaches to the main channel. A flood levee is visible on the western side of the main ebb channel as it crosses the body of the Estuary. Such levees have been reported elsewhere in marine environments (e.g., Hay et al., 1982, cited in Leeder, 1999) and result from the deposition of suspended material when the flow carrying it spills out of a high energy channel and onto a flatter plane (Pizzuto, 1987; James, 1992). Because they reflect a depositional process, one that only occurs at the transition between sediment-laden, high-energy flow and (relatively) sediment free flow, their distribution probably reflects the spatial limit of a given high-energy flood tide.

3.4.14 Between 12/05/2005 (Figure 3.28) and 16/09/2005 (Figure 3.31) a pattern of cyclical change emerges, with channel lengthening and subsequent cut-off within a spatially discrete zone of activity around Hempstones Point and Wigg Island. During this time, the area down-estuary appears to be relatively stable, and the large bar that occupies the centre of the Estuary is becoming vegetated.

3.4.15 Figure 3.31 (16/09/2005) shows a very distinct point bar with deltaic features forming where the ebb channel abuts the southern bank of the estuary. The volume of sediment moved highlights the dynamism of the channels in this area, especially compared with the relatively stable zone within the centre of the Estuary to the west.

3.4.16 However, by 25/11/2005, Figure 3.32 shows that the dynamic zone has moved down-estuary towards a previously stable area. The main ebb channel has once more moved to the north bank of the Estuary and now cuts obliquely across to the southern bank, whereas it previously abutted the bank perpendicularly. Figure 3.32 also shows a second abandoned channel or bank lying to the northwest of the main channel, in the centre of the Estuary, which indicates that the ebb channel had meandered across what had previously been a relatively stable bar. Furthermore, Figure 3.33, taken on 22/02/2006, shows reactivation of what had previously been a stable abandoned channel. By this date the zone of activity had moved down the Estuary. Subsequently, Figure 3.34, taken on 25/05/2005, shows a major shift in the position of the main channel towards the north bank and diagonally across what had previously been a stable area. Figure 3.35, taken on 19/06/2006 shows evolution of this channel concomitant with that observed within the active channel belt upstream: an increase in sinuosity and construction of inner meander bend point bar.

3.4.17 Clearly, the zone of greatest dynamism moves within the estuary, and although processes and cycles can be identified within this zone, the zone itself appears to move as a result of some other driving variable that was not documented by this photographic record. Nevertheless, the overall pattern of activity within the zone remains broadly similar, with the main ebb channel meandering, lengthening and reducing its gradient. Evidence for these features can be seen in all images.

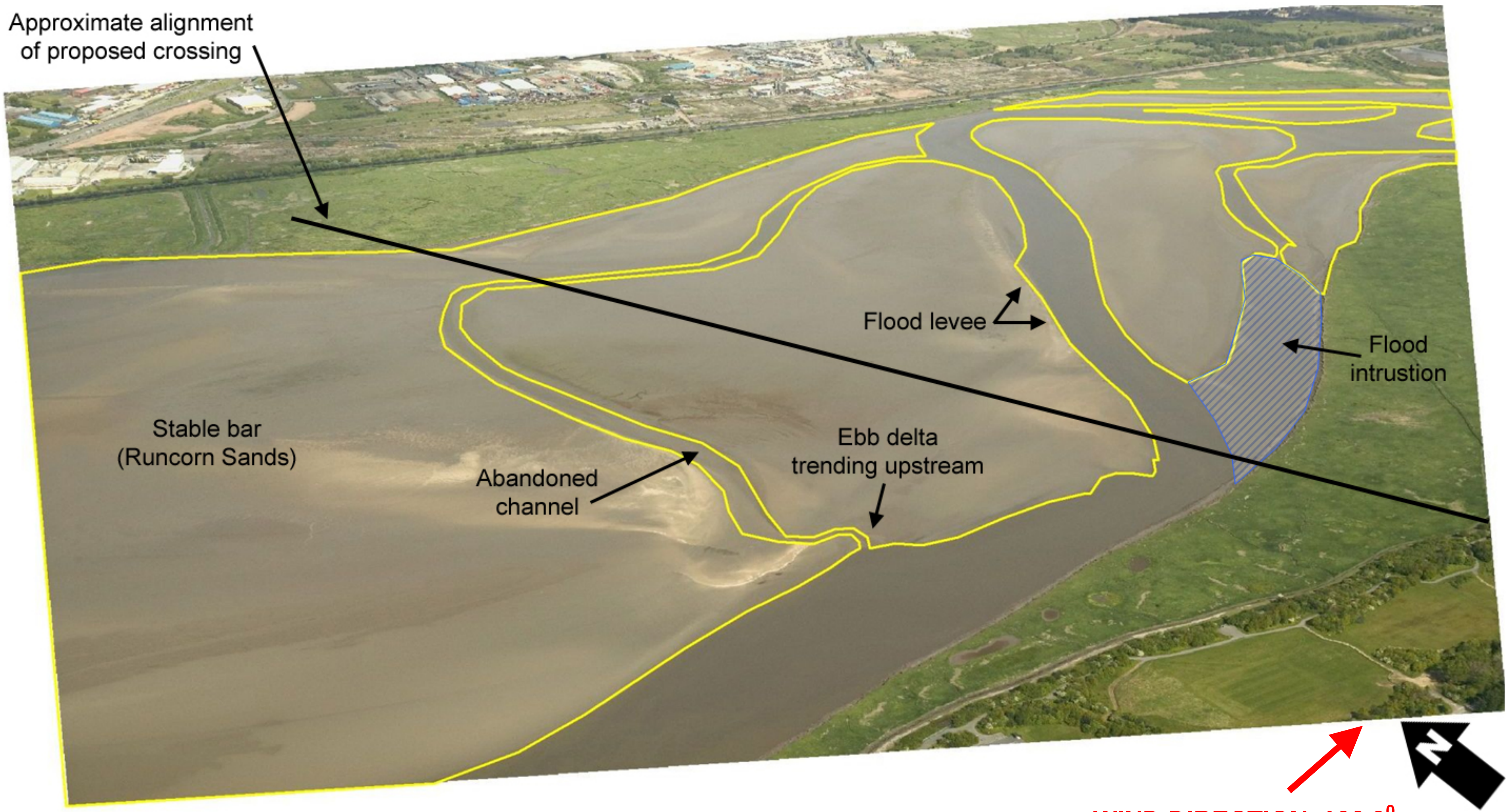


Figure 3.28 Low flow channels, S2 Wigg Island (upstream view) – 12/05/2005

Image taken: 12:38 BST LW at time of image: 1.11m LW recorded at Old Quay Lock: 12:00 LW Height 0.98m

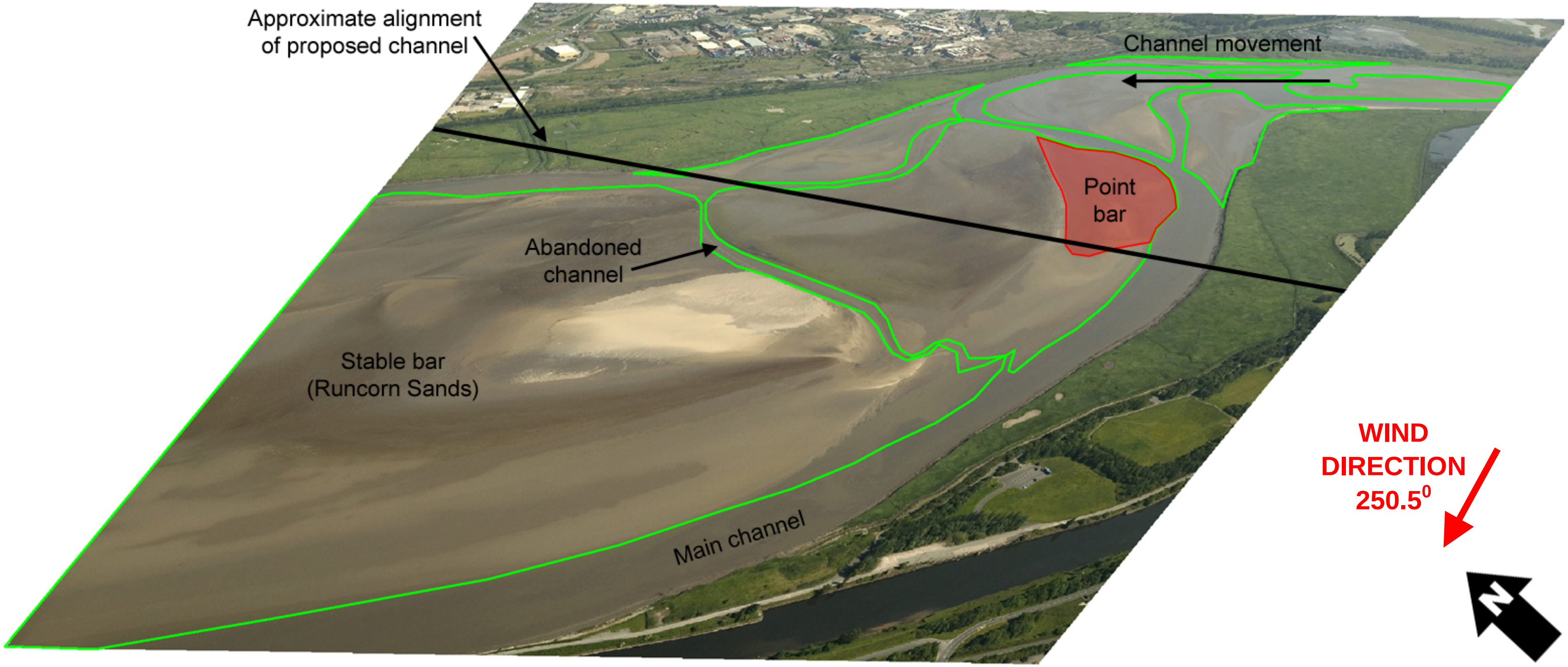


Figure 3.29 Low flow channel extension, Wigg Island (upstream view) – 08/06/2005
Image taken: 11:09 BST LW at time of image: 1.86m LW recorded at Old Quay Lock: 10:45 LW Height 0.99m

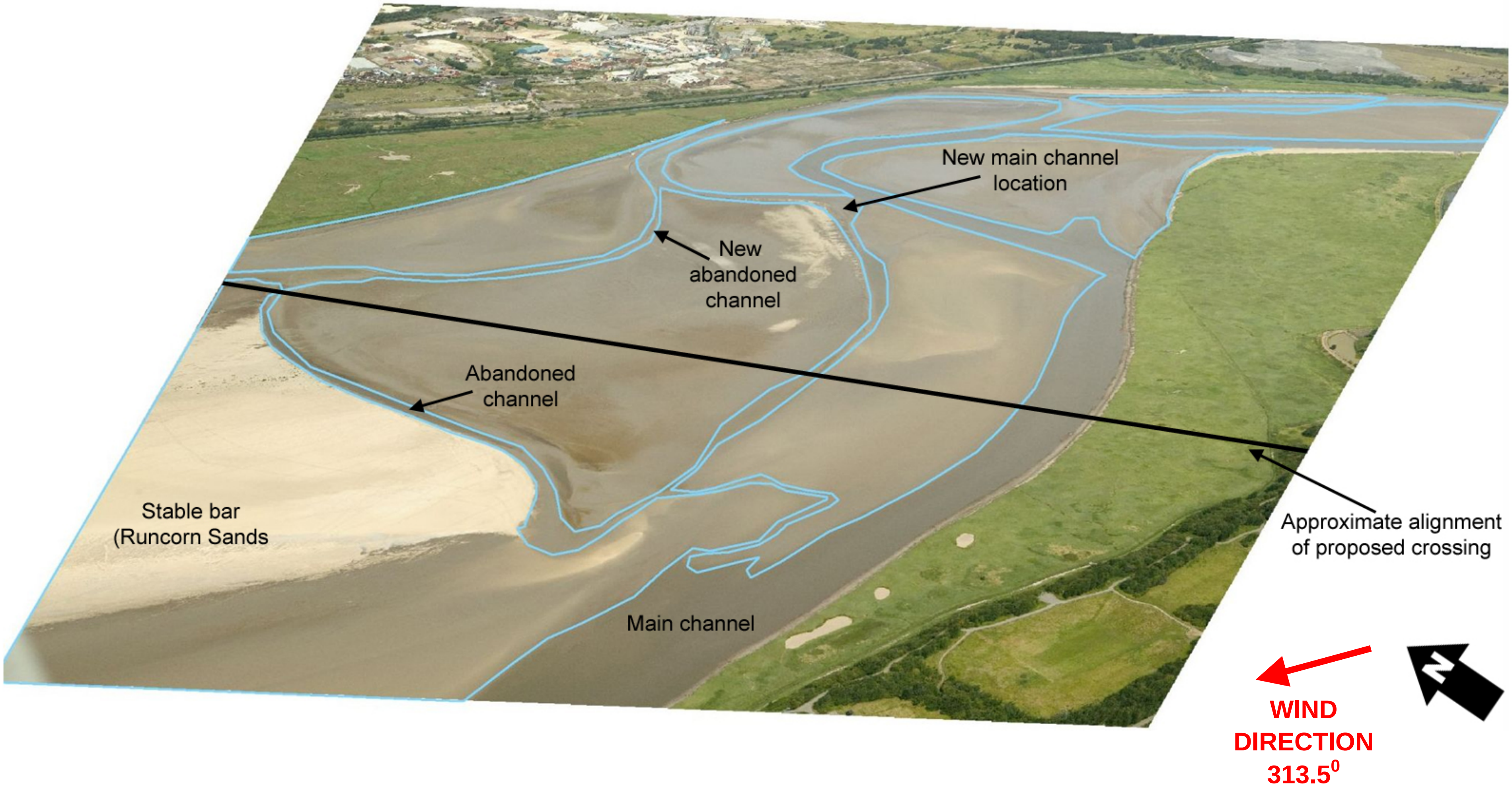


Figure 3.30 Low flow channel switching, Wigg Island (upstream view) – 13/07/2005

Image taken: 14:34 BST LW at time of image: 0.85m LW recorded at Old Quay Lock: 14:15 LW Height 0.78m

Figure 3.31 Low flow channels and ebb delta, Wigg Island (upstream view) – 16/09/2005

Image taken: 08:54 BST LW at time of image: 2.27m LW recorded at Old Quay Lock: 08:30 LW Height 0.88m

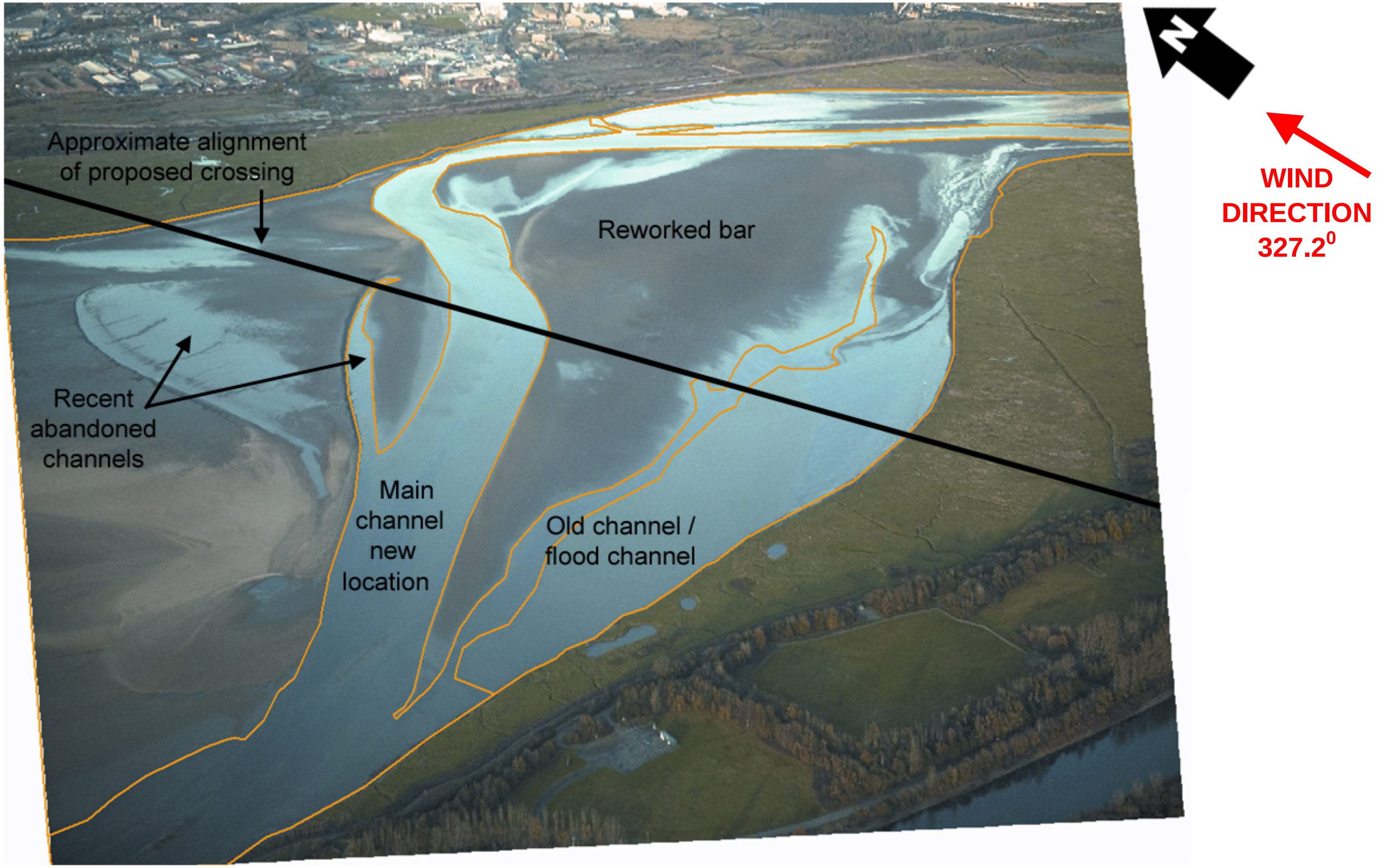


Figure 3.32 New ebb channel location, Wigg Island (upstream view) – 25/11/2005

Image taken: 15:00 BST LW at time of image: 1.09m LW recorded at Old Quay Lock: 16:30 LW Height 1.06m.

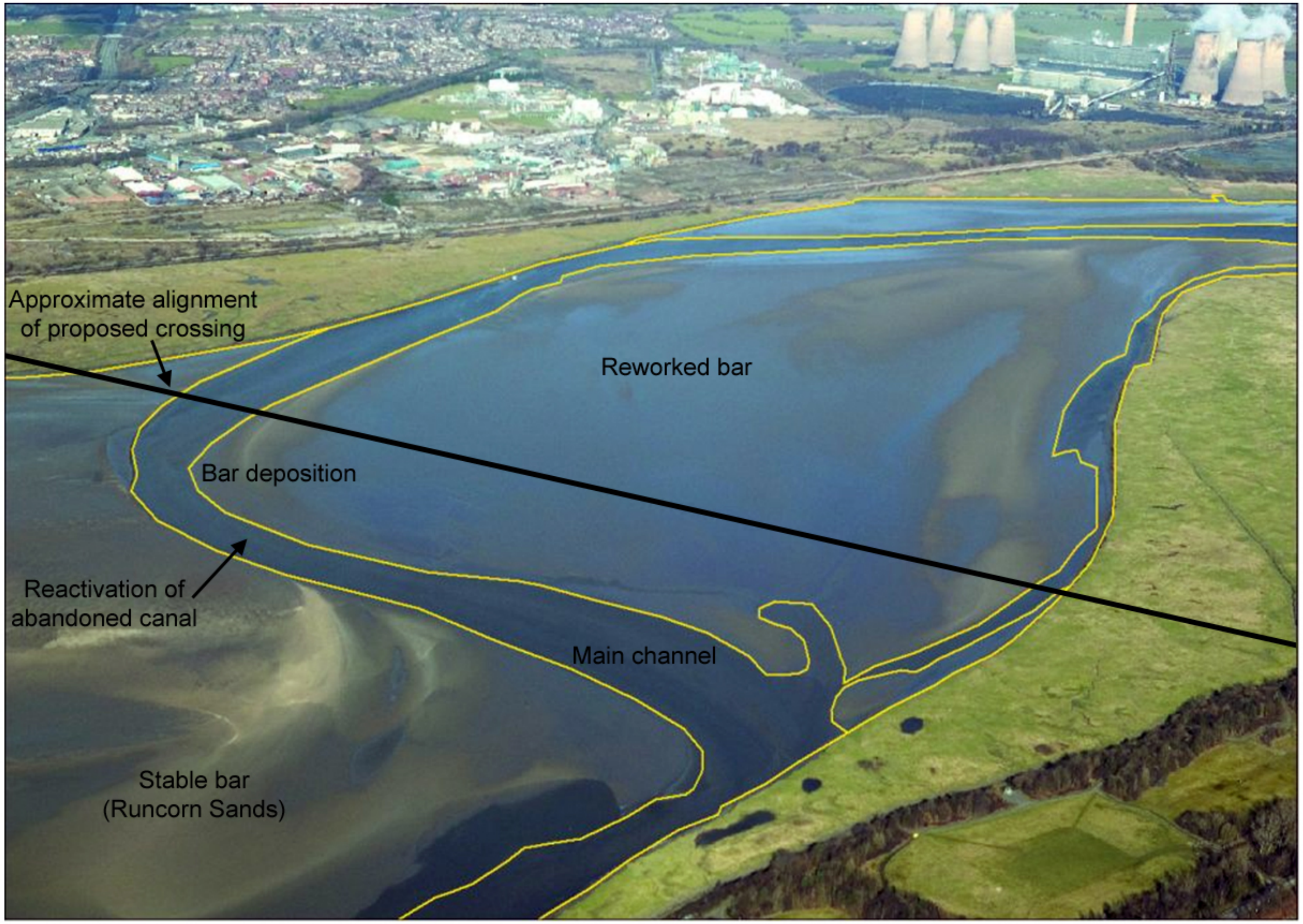


Figure 3.33 Downstream migration of main channel, Wigg Island (upstream view) – 20/02/2006

Image taken: 13:18 BST LW at time of image: 0.9m LW recorded at Old Quay Lock: 14:00 LW Height 0.88m

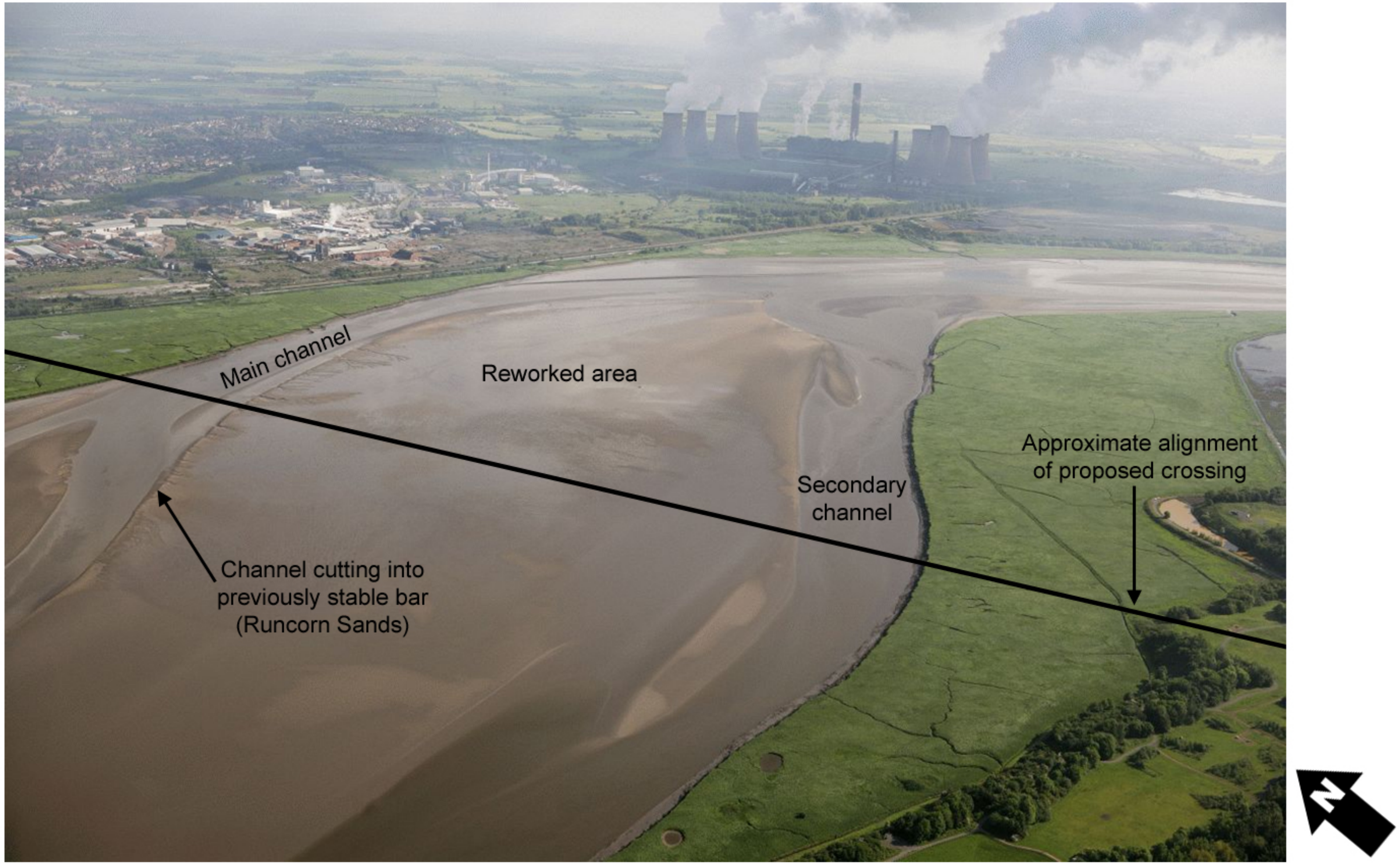


Figure 3.34 Downstream migration of main channel, Wigg Island (upstream view) – 25/05/2006. Unrectified / untraced image.

Image taken: 08:43 BST LW at time of image: - LW recorded at Old Quay Lock: - LW Height -

"-" data were not available

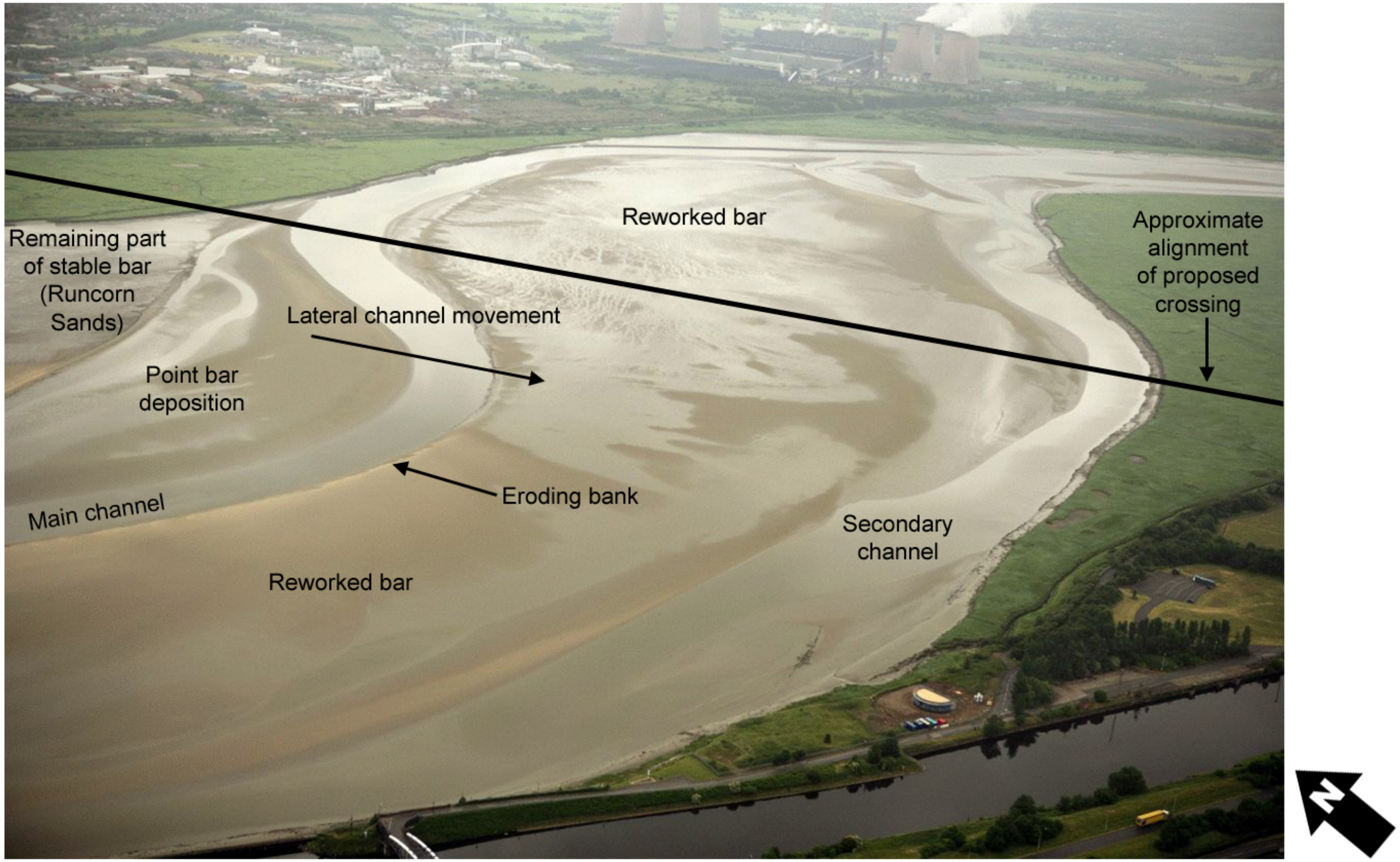


Figure 3.35 Downstream migration of main channel, Wigg Island (upstream view) – 19/06/2006. Unrectified / untraced image.

Image taken: 16:29 BST LW at time of image: - LW recorded at Old Quay Lock: - LW Height -

"-" data were not available

S3 Runcorn Sands

3.4.18 Visual analysis of the oblique aerial photographs is based on figures 3.36 to 3.43 which are displayed in subsequent pages.

3.4.19 The oblique overall pattern that emerges from this area is one of medium-term (annual) stability, followed by a sudden change in ebb channel location (see figures 3.36-3.43). The most common condition from the aerial photographic record is of a large and relatively stable bar occupying the centre of the Estuary, flanked to the south by the main channel and to the north by a secondary channel (Figure 3.36- 29/04/2005). Both of these carry flood flow and ebb flow. To the east lies an abandoned channel that shows evidence of slight reactivation.

3.4.20 Figure 3.36 (29/04/2005) shows a large stable bar occupying the centre of the estuary. To the west a secondary channel runs up to the lock and along the northern bank. Figures 3.36 to 3.44 show that the same area over the next 5 months varies only slightly. A distinct tide line is visible on the main bar in Figure 3.37 (20/07/2005), showing that this bar does not always become inundated. Flood levees are visible on Figure 3.38 (21/09/2005). An ebb flow delta is clearly visible in Figure 3.39 (25/11/2005), and this delta moves downstream (Figure 3.40; 14/03/2006).

3.4.21 However, Figures 3.41 to 3.43, taken between 14/04/2006 to 19/06/2006, show a major change in position of the main channel towards the west. This underlines that the dynamic channel belt can appear to be stable over several months, and then switch in a short period of time to a previously dormant zone.

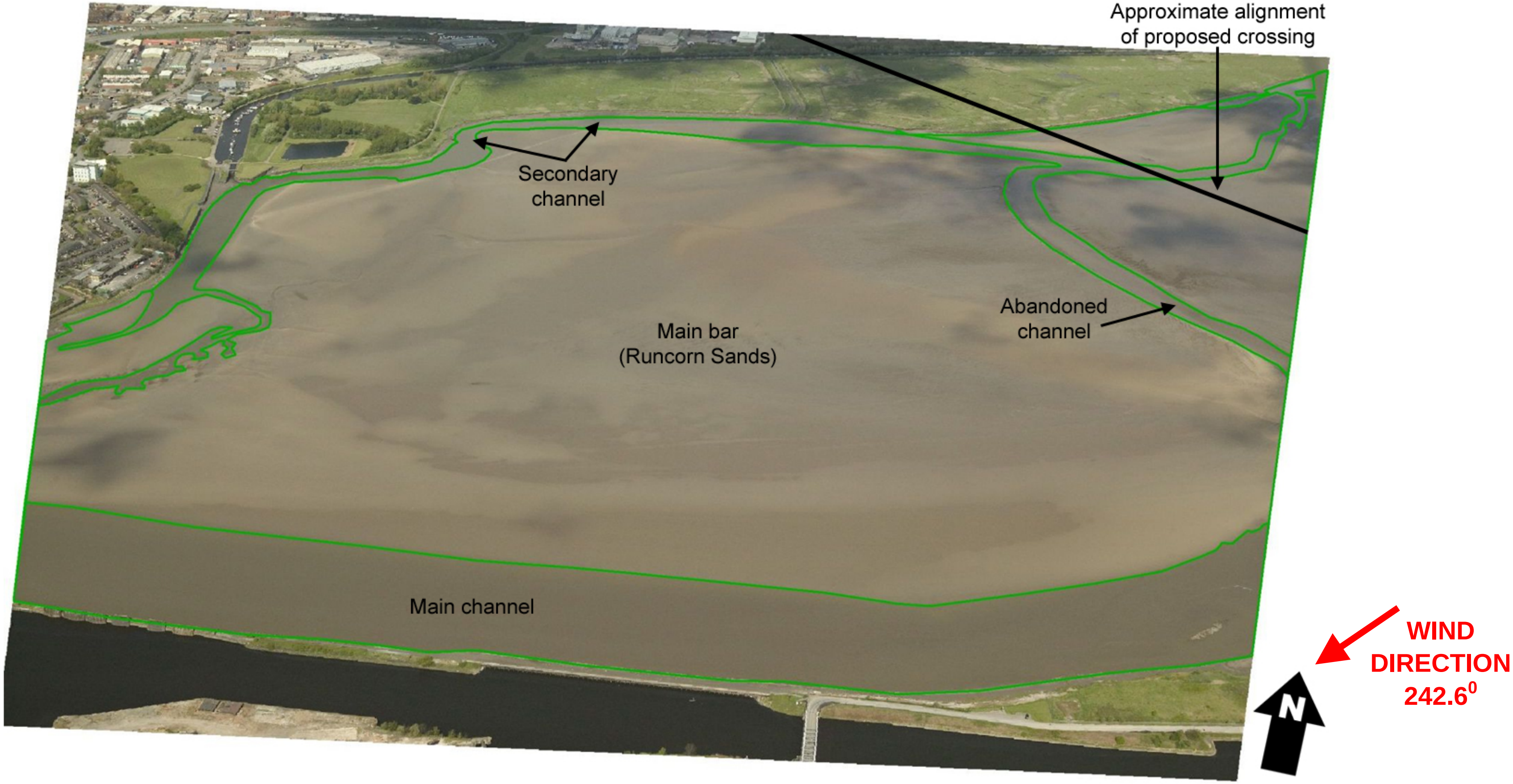


Figure 3.36 S3 upstream of Silver Jubilee Bridge on 29/04/2005 bedforms visible. Stable bar. Main channel on southern side. Secondary channel on northern side. Abandoned channel on right.

Image taken: 13:31 BST LW at time of image: 1.47. LW recorded at Old Quay Lock: 13:00 LW Height 1.07m

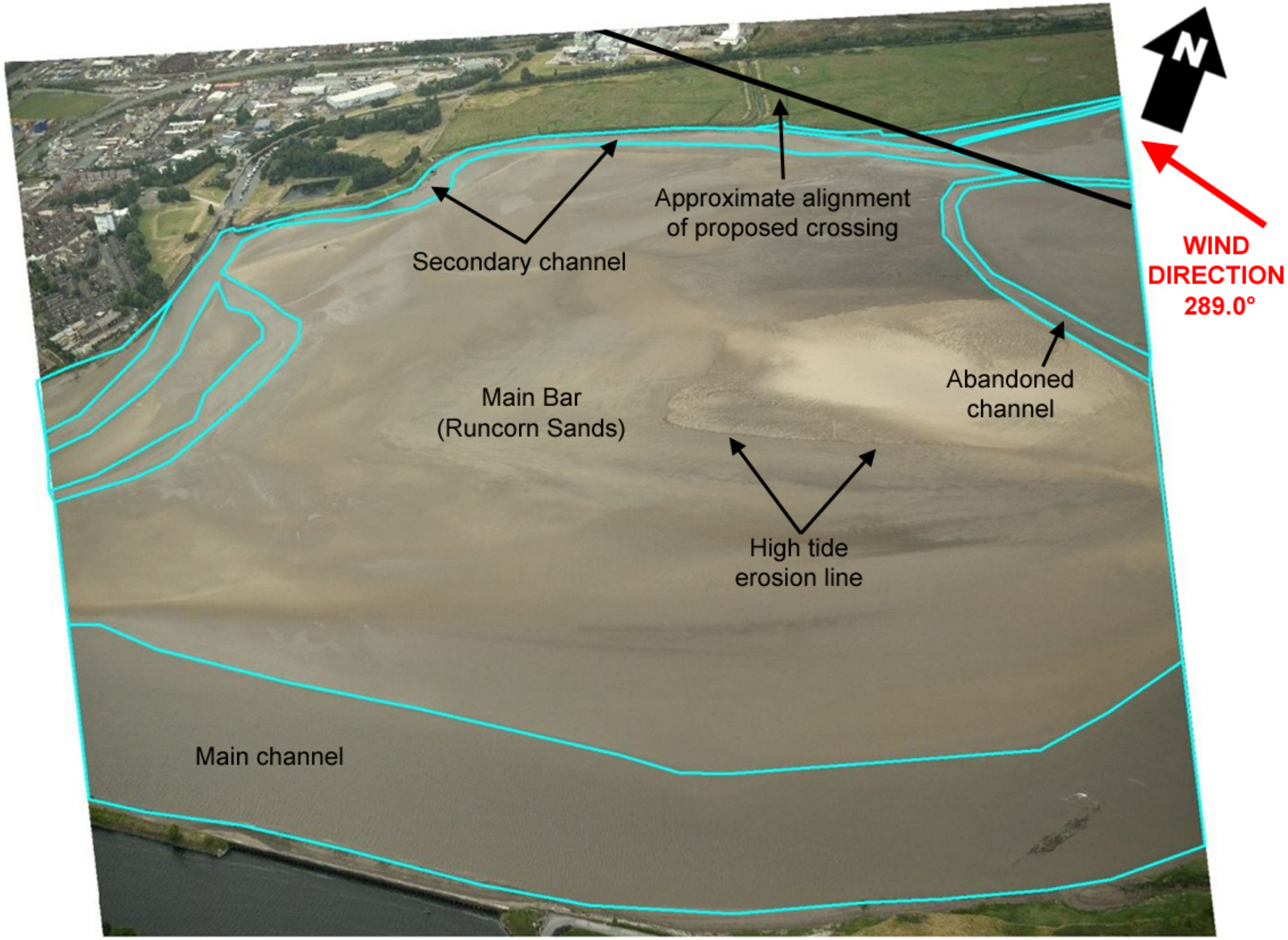


Figure 3.37 S3 upstream of Silver Jubilee Bridge on 20/07/2005 as before but with distinct erosion line visible on main bar.

Image taken: 09:06 BST LW at time of image: 2.3m LW recorded at Old Quay Lock: 08:30 LW Height 1.00m

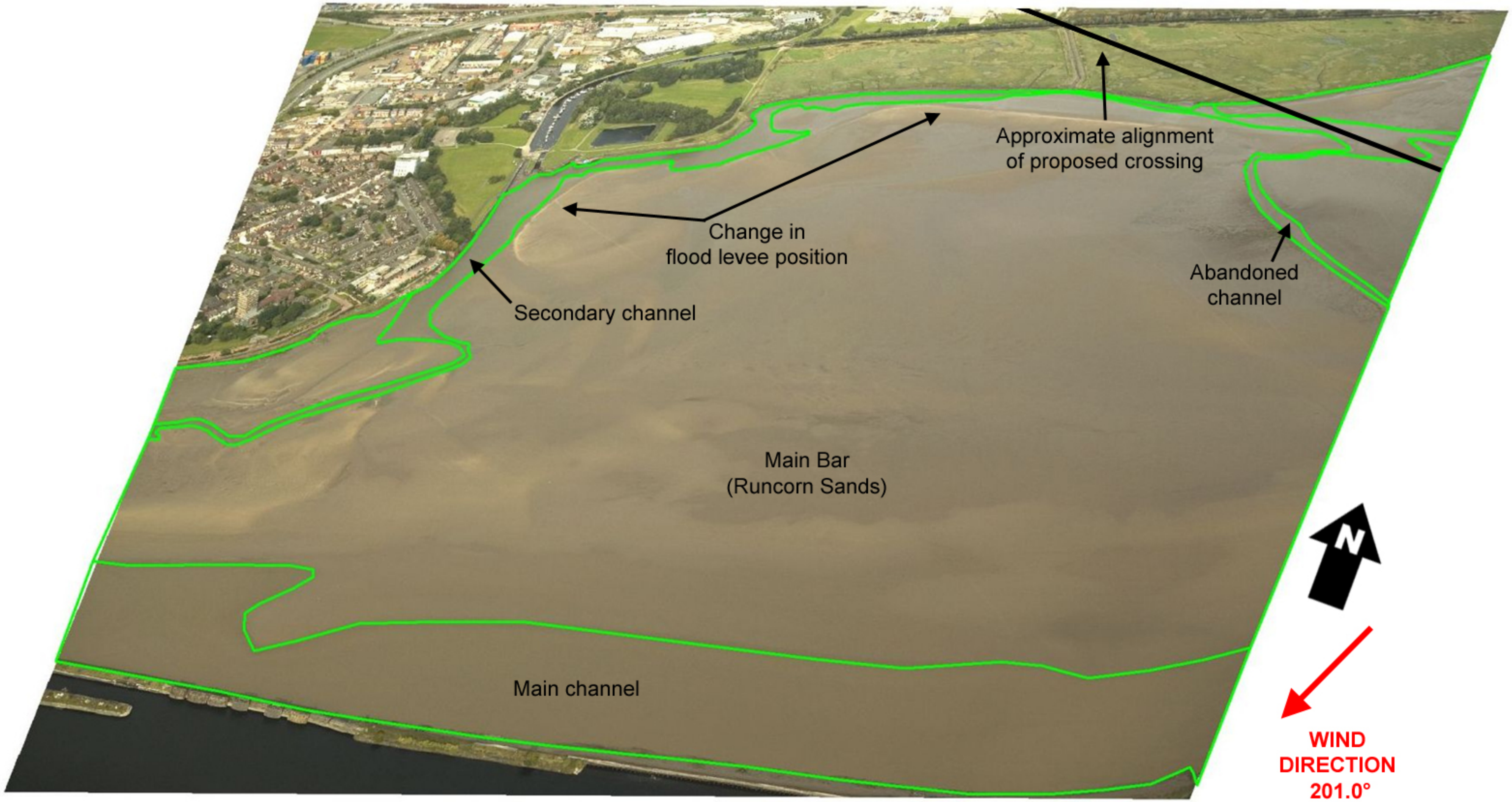


Figure 3.38 S3 upstream of Silver Jubilee Bridge on 21/09/2005 as before but with visible flood levee running parallel to secondary channel on north bank

Image taken: 12:25 BST LW at time of image: 3.52 LW recorded at Old Quay Lock: 11:45 LW Height 0.98m

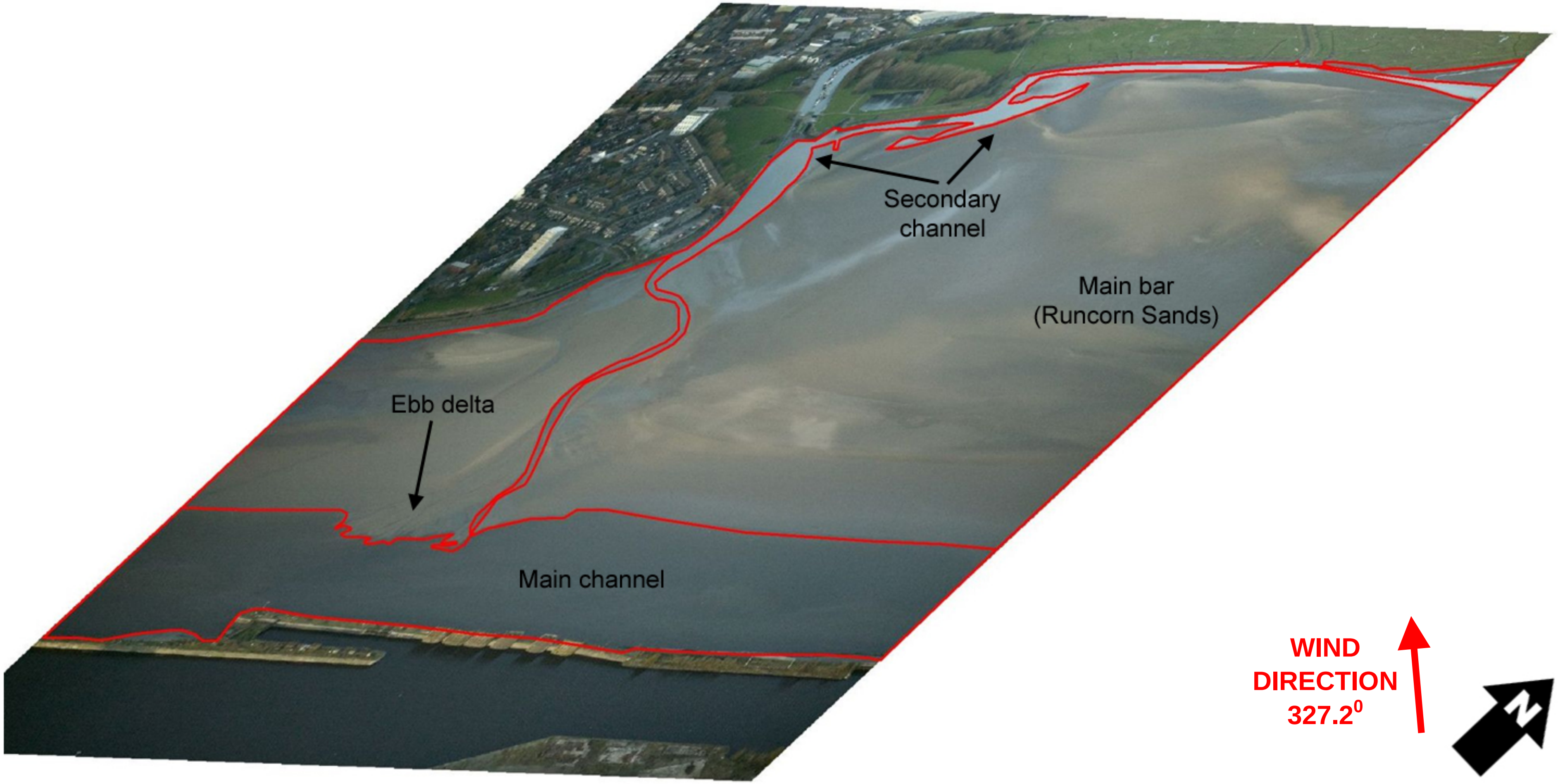


Figure 3.39 S3 upstream of Silver Jubilee Bridge on 25/11/2005 secondary channel ebb delta filling into main ebb channel

Image taken: 15:00 BST LW at time of image: 1.09m LW recorded at Old Quay Lock: 16:30 LW Height 1.06m

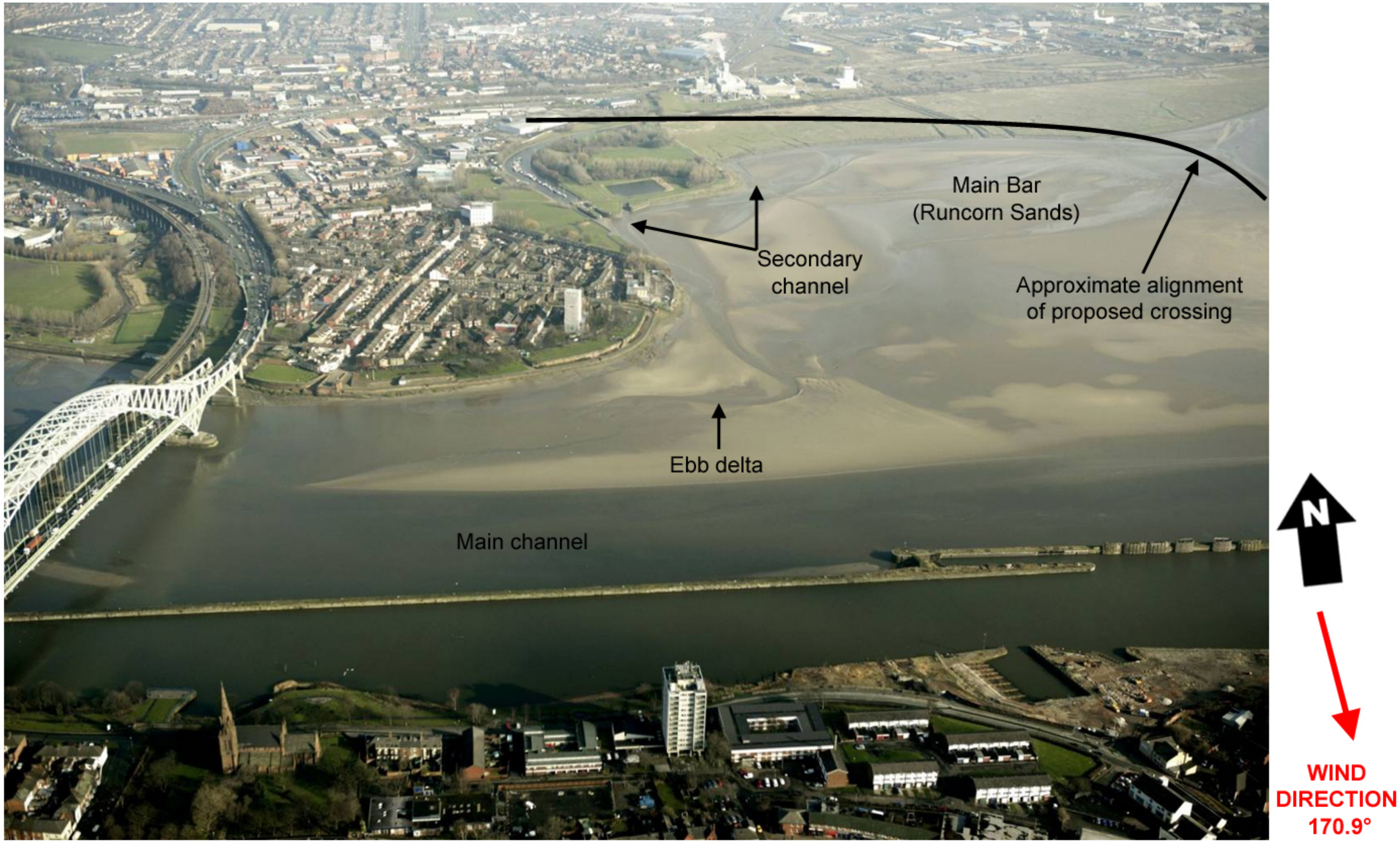


Figure 3.40 Untraced / unrectified image showing change in ebb delta location. S3 upstream of Silver Jubilee Bridge from V4 on 14/03/2006

Image taken: 09:24 BST LW at time of image: 1.16m LW recorded at Old Quay Lock: 09:00 LW Height 1.16m

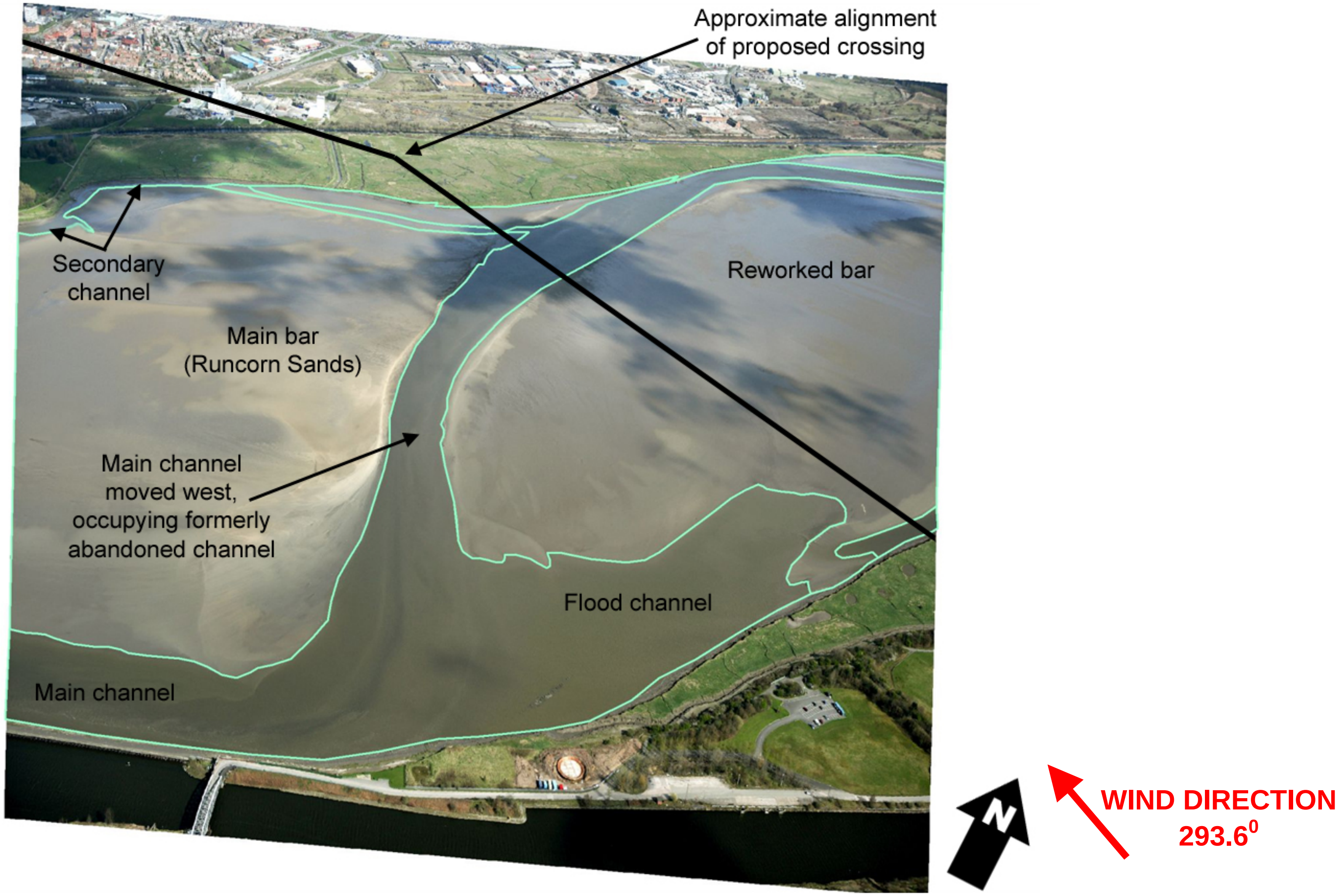
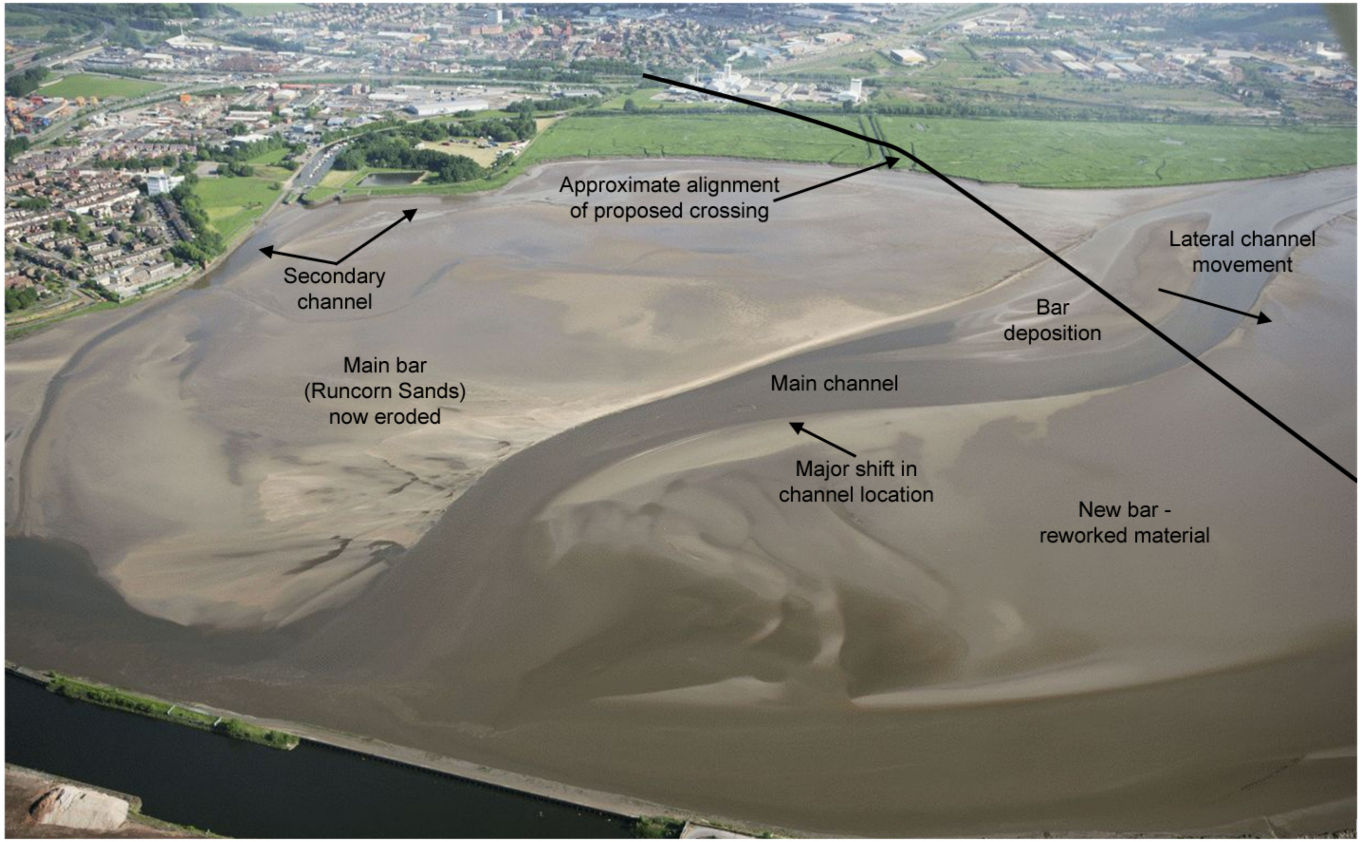


Figure 3.41 S3 upstream of Silver Jubilee Bridge from S4 on 14/04/2006 main channel now moved significantly down estuary

Image taken: 10:47 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 10:00 LW Height 1.23m



WIND DIRECTION 259.9^{0}

Figure 3.42 Unrectified and undigitized image from S3 upstream of Silver Jubilee Bridge from S4 on 25/05/2006

Image taken: 08:43 BST. LW at time of image: - LW recorded at Old Quay Lock: - LW Height -

"-" data were not available

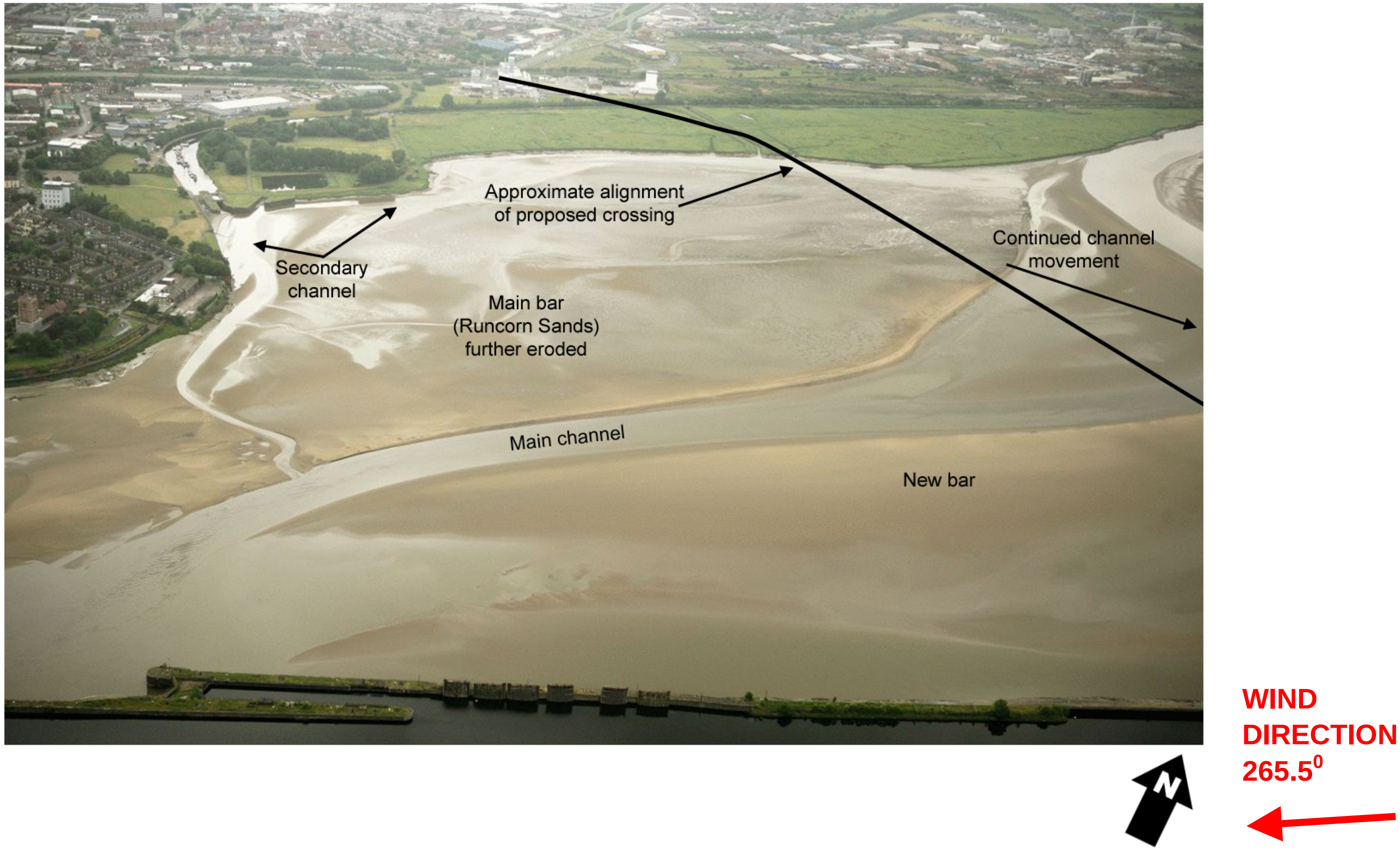


Figure 3.43 Unrectified and undigitized image from S3 upstream of Silver Jubilee Bridge from S4 on 19/06/2006

Image taken: 16:29 BST LW at time of image: - LW recorded at Old Quay Lock: - LW Height -

"-" data were not available

S4 Silver Jubilee Bridge

3.4.22 Visual analysis of the oblique aerial photographs is based on figures 3.44 to 3.50 which are displayed in subsequent pages.

3.4.23 Throughout the sequence of images available, the geomorphology of S4 is consistent and, when compared with other areas of the Upper Estuary (especially S2), the majority of the area is relatively stable (Figures 3.44 to 3.50). A dynamic zone exists under the Silver Jubilee Bridge, where multiple channels shift location at irregular intervals.

3.4.24 The main area of activity lies within Runcorn Gap itself, underneath the existing bridges. Three geomorphological processes occur within and just downstream of the Gap:

(i) splitting and migration of the dominant channel;
(ii) shifting of a mid-channel bar present beneath the Silver Jubilee Bridge and Railway Bridge; and
(iii) movement of the flood levee on the main bar.

3.4.25 Channel splitting occurs at irregular intervals, with a change in state (from single to multiple channel or vice versa) ranging between 4 -16 weeks (Table 3.2). The channel splits immediately downstream of the Silver Jubilee Bridge. Whether a single or multiple channel is present, an eroding face is usually present on whichever bank is furthest down-estuary. Thus, the channel is unstable and continually adjusts its boundary. When multiple channels occur, a mid-channel bar is formed that separates the channels and this often shows evidence of recent flow, suggesting it is a transitory feature, being lost and created at different times.

3.4.26 Downstream of the bridge these channels invariably coalesce – the exact location varies over time – to form a large, fairly stable ebb channel that flows along the north bank of the Estuary (Figure 3.44).

3.4.27 In the centre of the Estuary lies a large bar separated from the ebb channel by a flood levee. The shape and position of this flood levee changes over time, from a linear form close to the channel in 01/06/2005 (Figure 3.45), to a sinuous shape set back from the main channel in 13/07/2005 (Figure 3.46). By 19/09/2005 (Figure 3.47), the flood levee has moved to the south. This possibly represents a change in dominance of the flood and ebb flows. The flood levee continues to vary in position, with channel switching between 14/04/2006 (Figure 3.48) and 25/05/2006 (Figure 3.49).

3.4.28 On the down-estuary part of the bar is a wide and shallow flood channel. This flood channel splits, with one part flowing west and into the main ebb channel leaving a depression in the flood levee; and a second part spreading across the bar and shallowing the estuary. Some of the flood flow creates a narrow breach in the flood levee, transporting sediment into the main channel and forming a small delta.

Table 3.2 Change from single to multiple channel state in Runcorn Gap

Date	Activity	Single	Multiple
29/04/2005	Single channel		
04/05/2005	Single channel with eroding downstream bank		
12/05/2005	Single channel being partly avulsed onto the large bar		
01/06/2005	Little observable change to previous image	6 weeks	
15/06/2005	Split of main channel into three branches: a dominant north branch, a secondary southern branch, and a split in the southern branch before it rejoins the main channel.		
13/07/2005	Main channel split into two branches: a dominant northern and a secondary southern branch, with aggradation of a bar in the centre of Runcorn Gap immediately down-estuary of the bridges.		
15/08/2005	Very similar pattern to 20/07/2005		16 weeks
19/09/2005	Single main channel: secondary south channel now cut off and mid-channel bar removed.		
03/10/2005	Similar pattern to 19/09/2005	12 weeks	
25/11/2005	Split of main channel, this time into dominant southern channel and secondary northern channel, split by a new mid-channel bar		
21/12/2005	Downstream migration of the dominant channel with obvious eroding cliff. Extension of mid-channel bar		
20/02/2006	Unclear image of bridge. Possible relocation of main channel upstream towards the bridge.		
28/02/2006.	Unclear image		15 Weeks
14/03/2006	Single main channel flowing under the centre of the bridge. No bar apparent.	4 weeks	
14/04/2006	Split of main channel, with dominant north channel and large south channel separated by a bar. The bar shows clear evidence of recent down-estuary flow, with downstream sediment transport being split. A flood intrusion is present on the downstream edge.		6 weeks
25/05/2006	Single main channel flowing obliquely from the centre of the bridge obliquely across to the north bank	N/A	

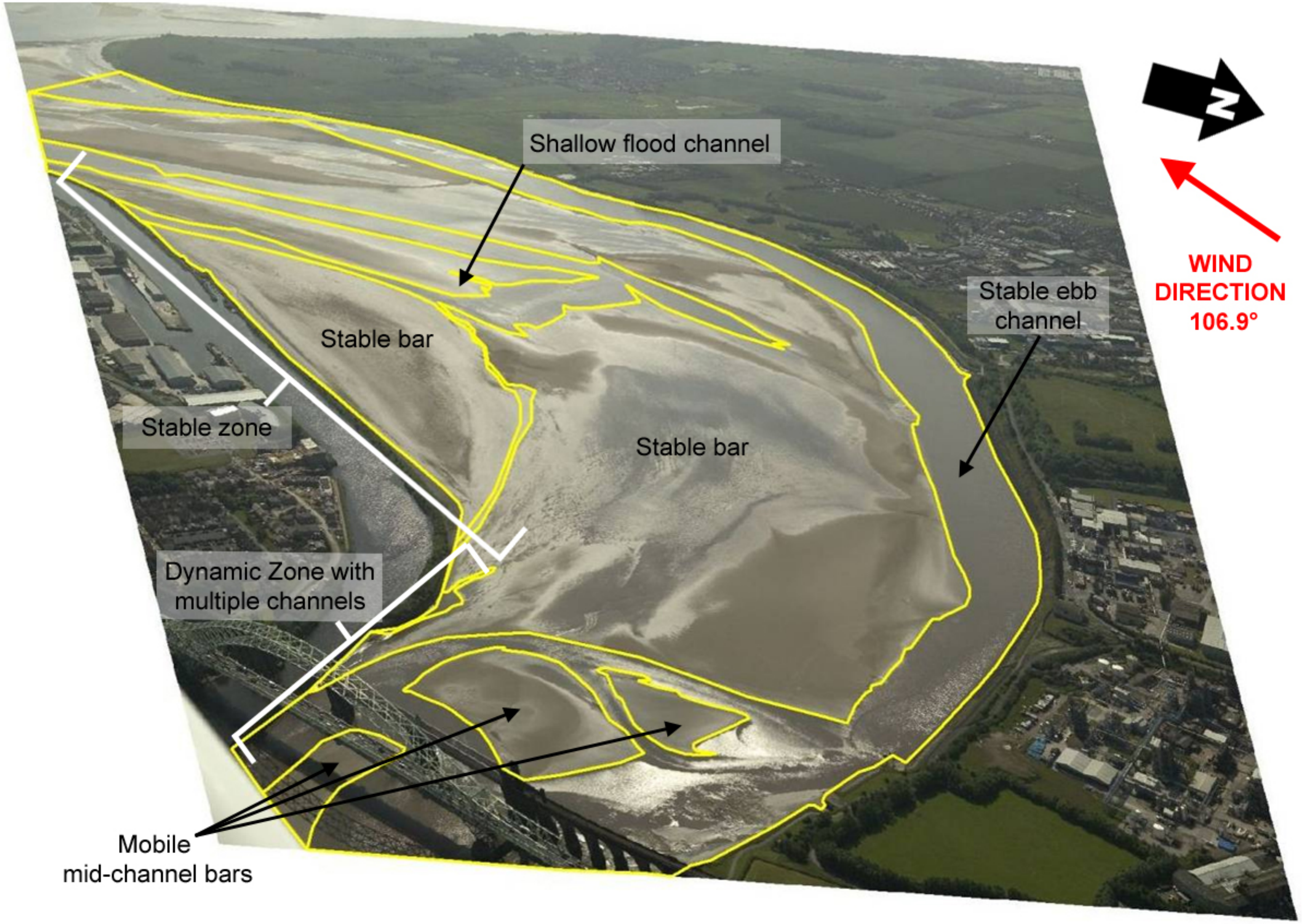


Figure 3.44 Channel locations at S4 Downstream of Runcorn Gap 12/05/2005

Image taken: 12:38 BST LW at time of image: 1.11m LW recorded at Old Quay Lock: 12:00 LW Height 0.98m

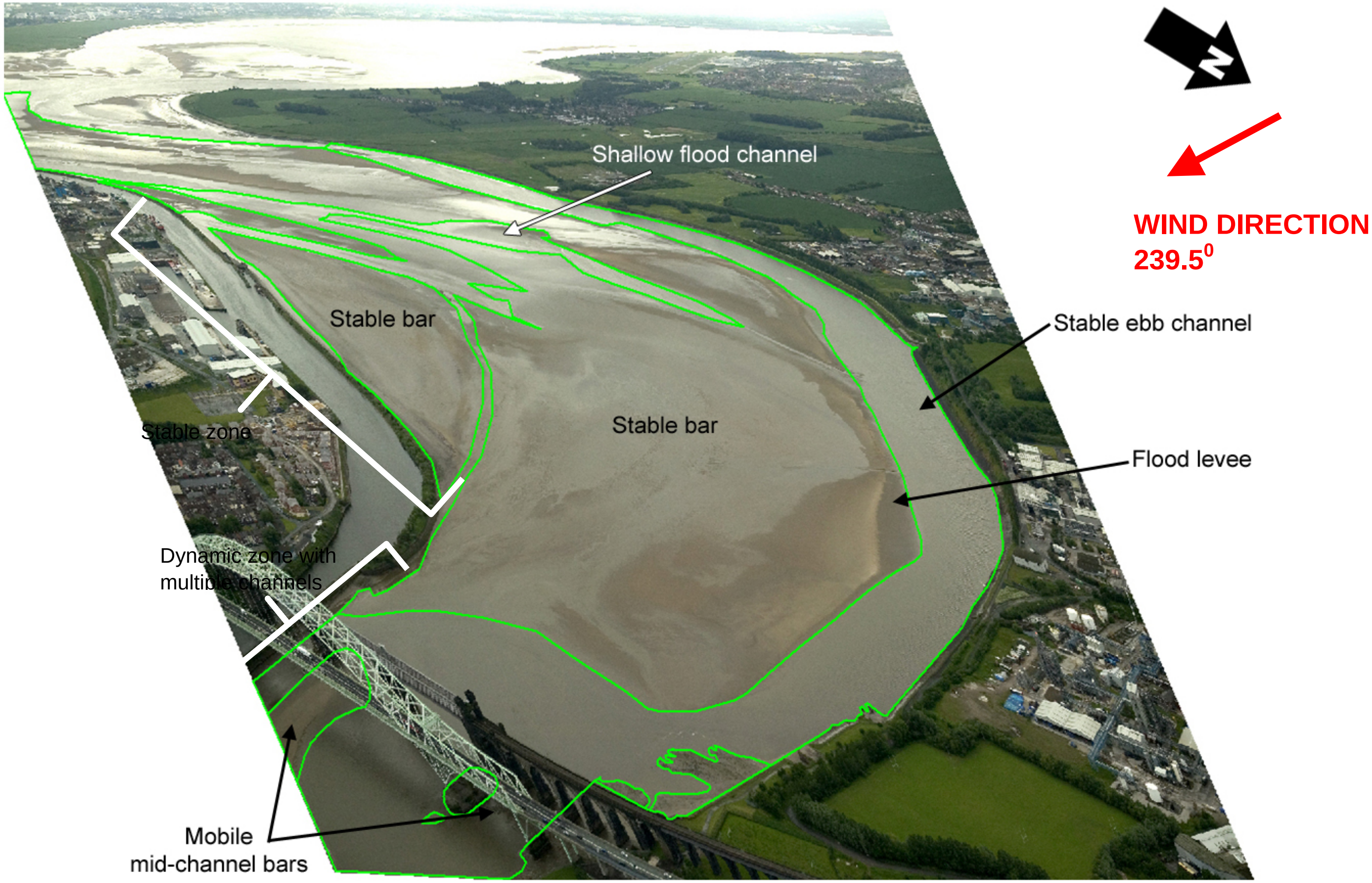


Figure 3.45 Channel locations at S4 Downstream of Runcorn Gap 01/06/2005

Image taken: 18:07 BST LW at time of image: 1.27m LW recorded at Old Quay Lock: 17:30 LW Height 0.97m

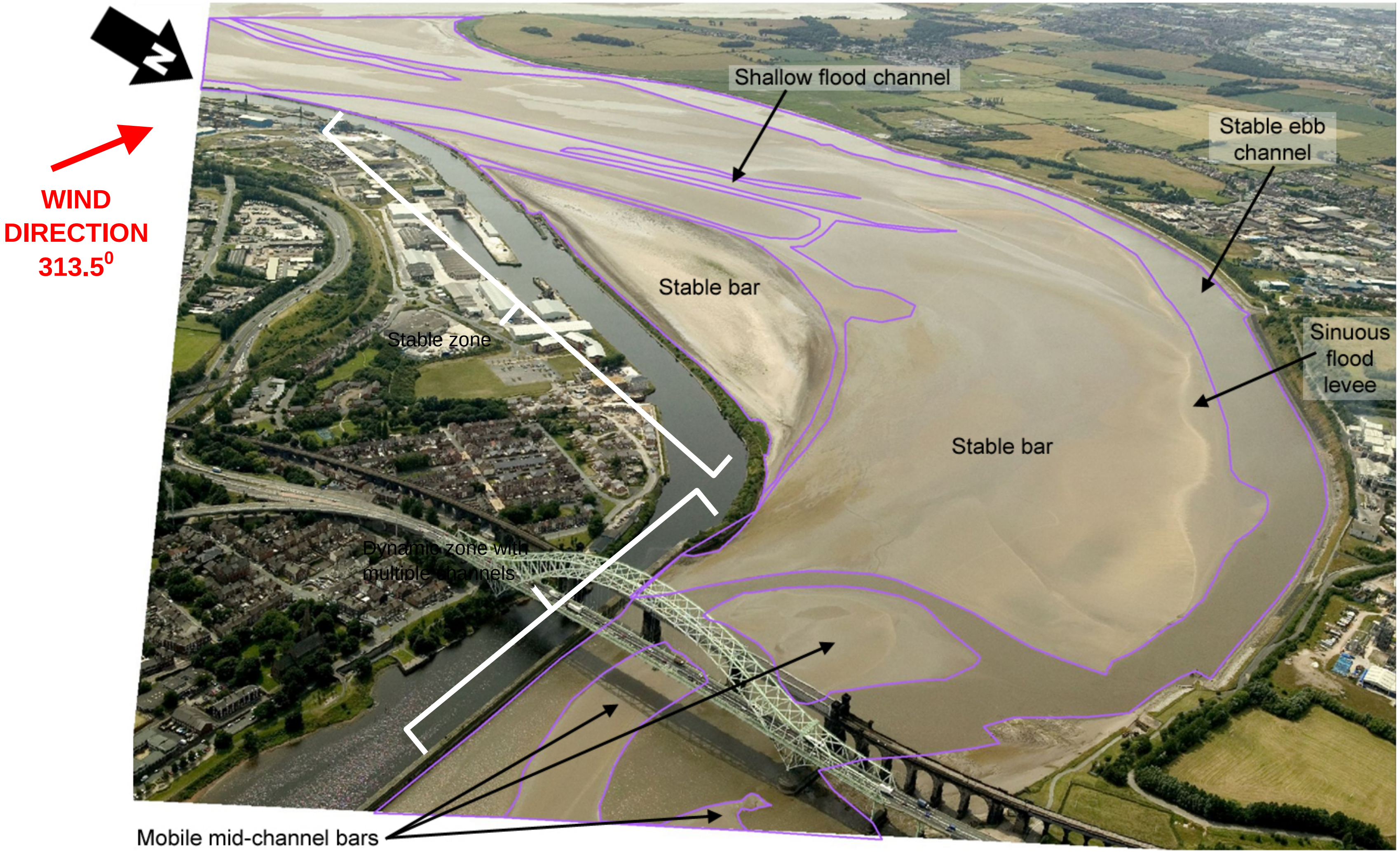


Figure 3.46 Channel locations at S4 Downstream of Runcorn Gap 13/07/2005

Image taken: 14:34 BST LW at time of image: 0.85m LW recorded at Old Quay Lock: 14:15 LW Height 0.78m

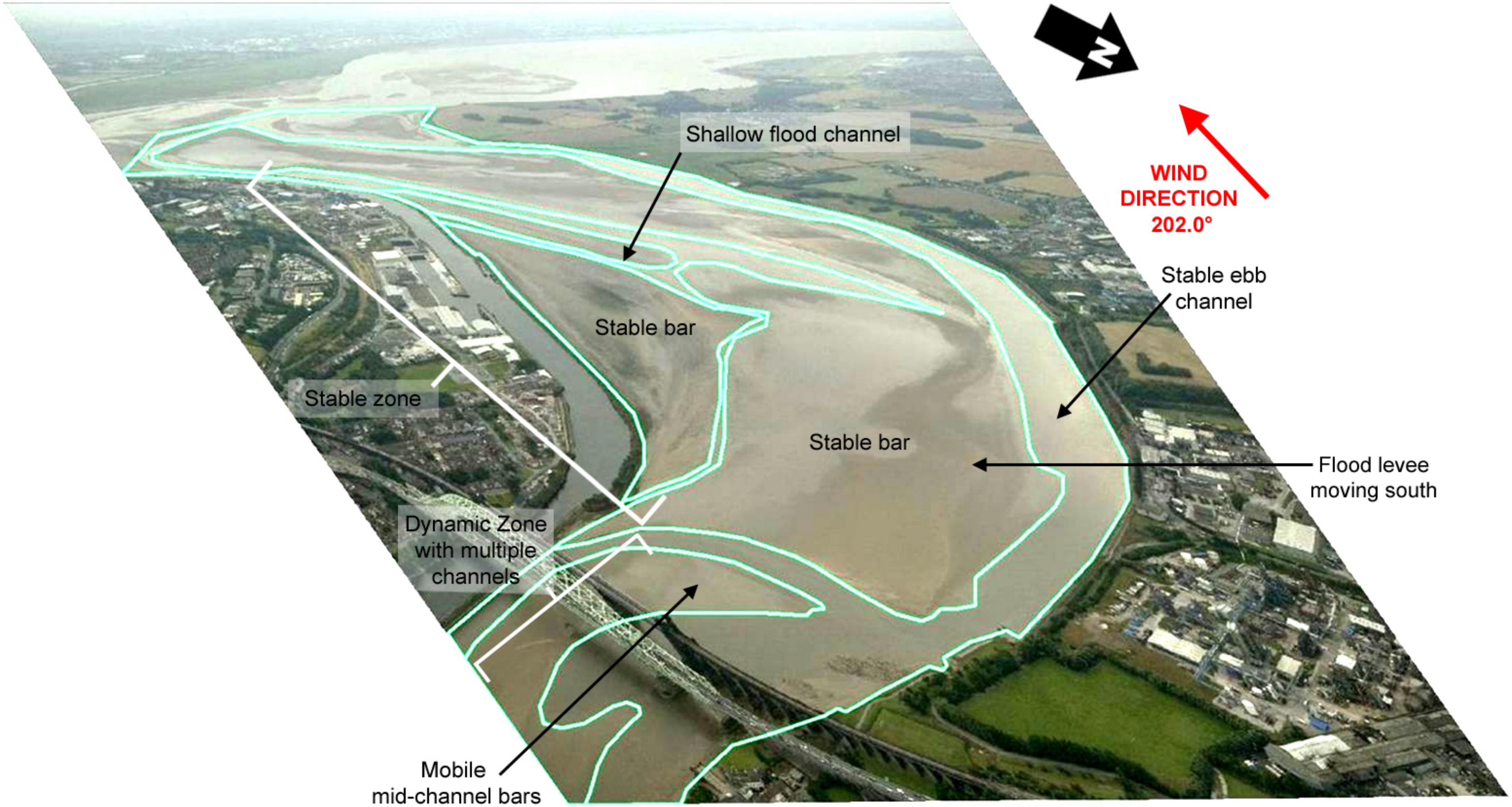


Figure 3.47 Channel locations at S4 Downstream of Runcorn Gap 19/09/2005

Image taken: 11:08 BST LW at time of image: 3.99m LW recorded at Old Quay Lock: 10:30 LW Height 0.97m

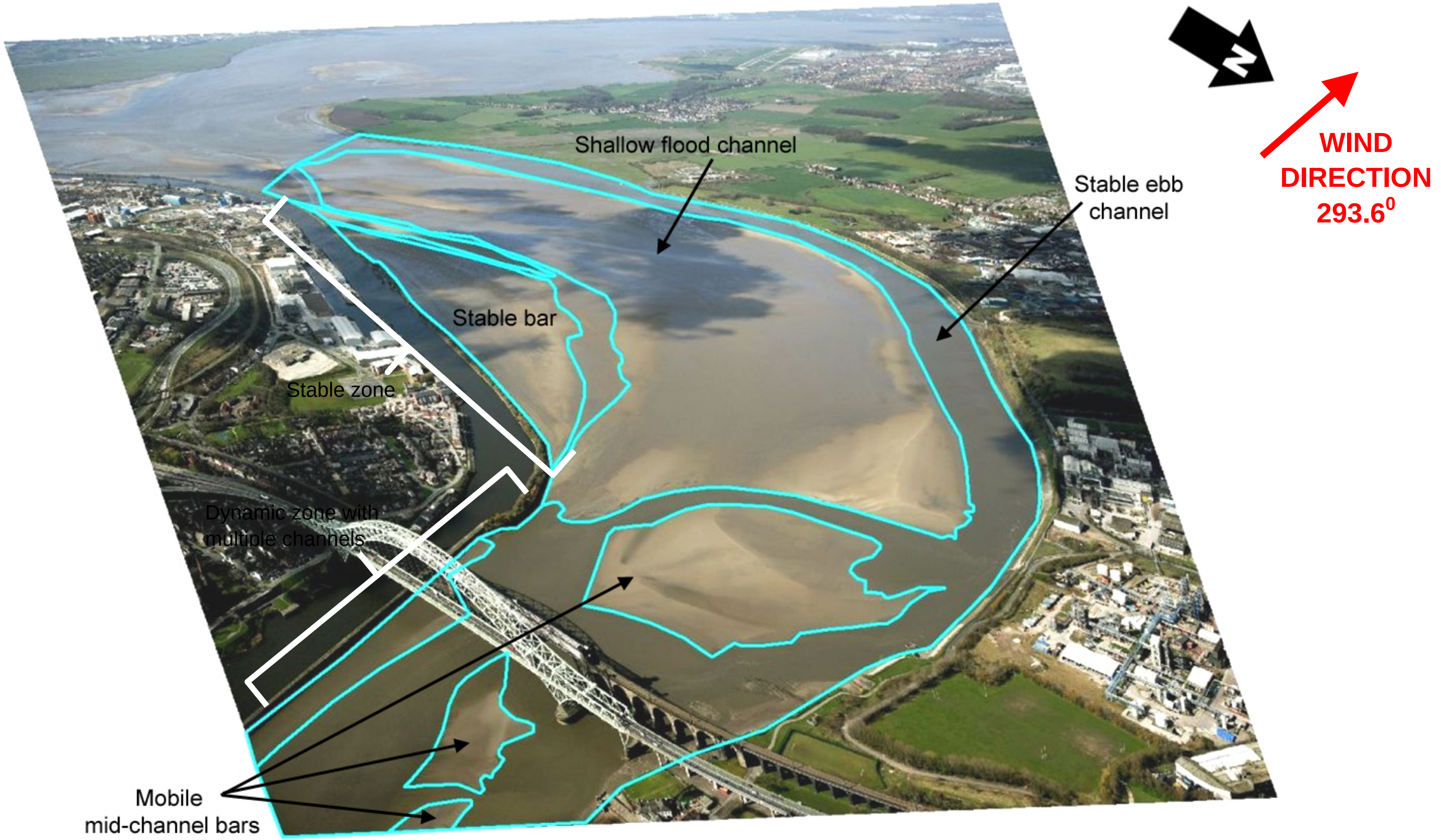


Figure 3.48 Channel locations at S4 Downstream of Runcorn Gap 14/04/2006

Image taken: 10:47 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 10:00 LW Height 1.23m

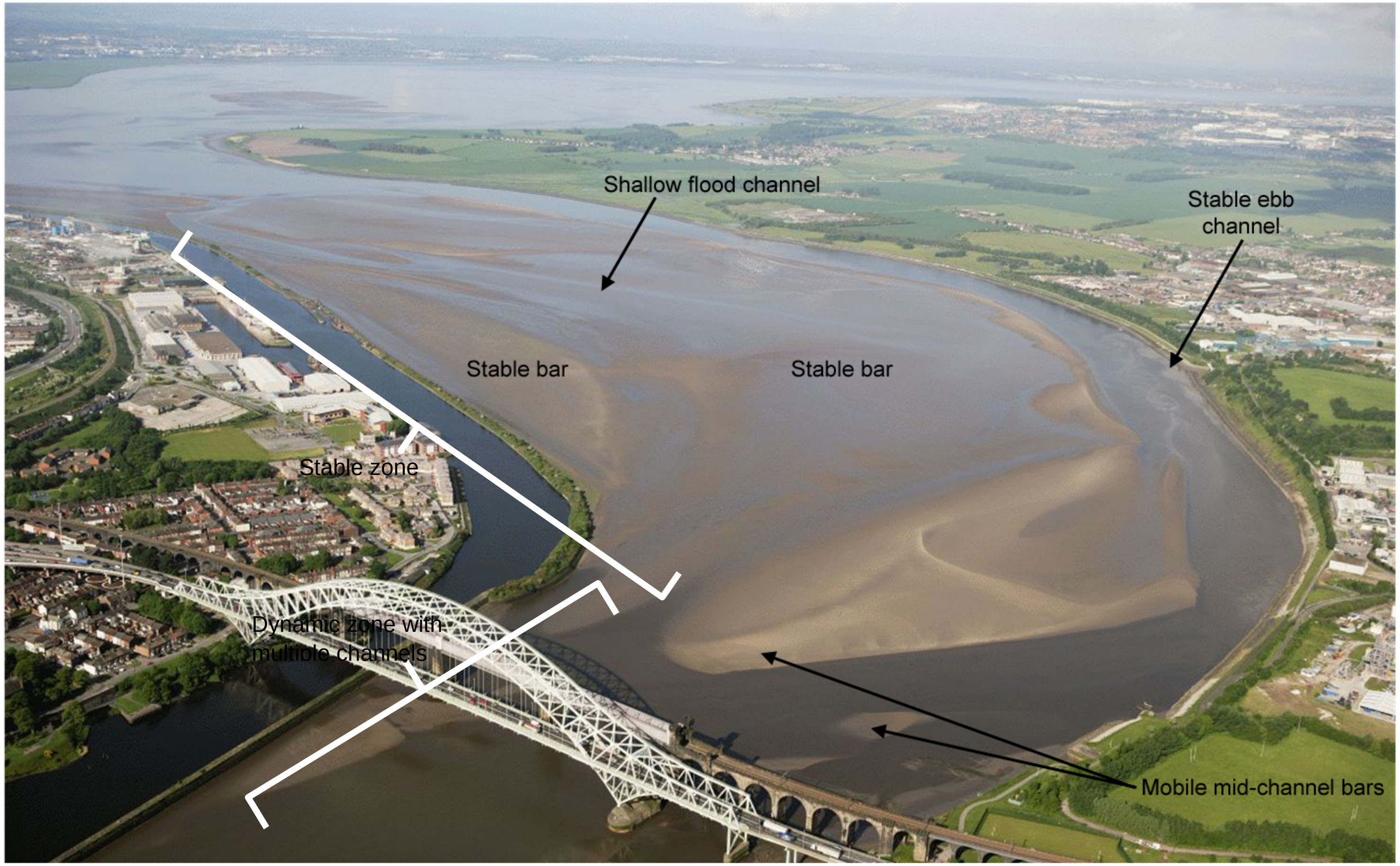


Figure 3.49 Channel locations at S4 Downstream of Runcorn Gap 25/05/2006 (unrectified / undigitized image)

Image taken: 10:47 BST LW at time of image: 3.13m LW recorded at Old Quay Lock: 10:00 LW Height 1.23m

Figure 3.50 S4 downstream of Silver Jubilee Bridge on 21/05/2007.

Image taken: 13:38 BST. LW at time of image: - LW recorded at Old Quay Lock: - LW Height -

"-" data were not available

3.5 Oblique aerial photographic mobility model

Introduction and Method

3.5.1 A GIS model was developed to map the channel boundaries using the series of the oblique aerial photos from each viewpoint of the Study Area sections. This was the same model as was used for analysis of the UMNC charts but the rectified oblique aerial photographs were used as the basis of the analysis. The aim of the model was to assess whether the main channel is mobile and if so, its degree of mobility, particularly where the bridge towers are proposed.

3.5.2 The model used the channel boundary as a polygon (i.e. the boundary between the water and sediment "sand bars"). Channel locations were derived from the digitised channel boundaries from the matched oblique aerial photos taken throughout the aerial photographic survey.

3.5.3 The model overlaid these polygons and weighted the intersections between these polygons; the higher the intersected areas the higher the weight and vice versa. The higher the weight means that the channel occupies this location relatively frequently. This result was then shown as a channel mobility map overlain on the best rectified photograph of that section. Each polygon identified was then coloured according to the frequency at which a channel was located in that location. This exposed geomorphological changes and the mobility of the main channel.

3.5.4 The model was applied to each section of the Study Area for each of the four sections identified above for a period of one year from April 2006 to May 2007. This is a subset of the images used in the oblique aerial photographic visual analysis and was chosen as this period is well covered by aerial photographs from all view points.

Accuracy and Precision in Analysis of Images

3.5.5 The mobility model analysis is subject to the same limitations as the oblique aerial photograph visual analysis (see section 3.3).

Results

S1 Norton Marsh

3.5.6 Figure 3.51 shows categories the Estuary into zones ranging from very high frequency of channel occupation where the channel frequently uses the same route shown in green, to very low frequency of occupation (i.e. highly the channel is highly mobile – such as the flood channel) which is shown in the different degrees of red. This could also be taken as an indicator of stability; areas of high frequency of occupation are relatively stable.

3.5.7 This section is upstream of the proposed alignment and channel locations are relatively unstable.

3.5.8 The factors controlling the channel mobility range from the high energy of incoming flow, the current, wind speed and direction, and the tide level. Despite the variability of these factors, and based on the available data it seems that the main channel in this section is likely to be stable. It should be noted that the zone of stability not absolute, and areas of very high frequency of channel occupation may be subject to some degree of change.

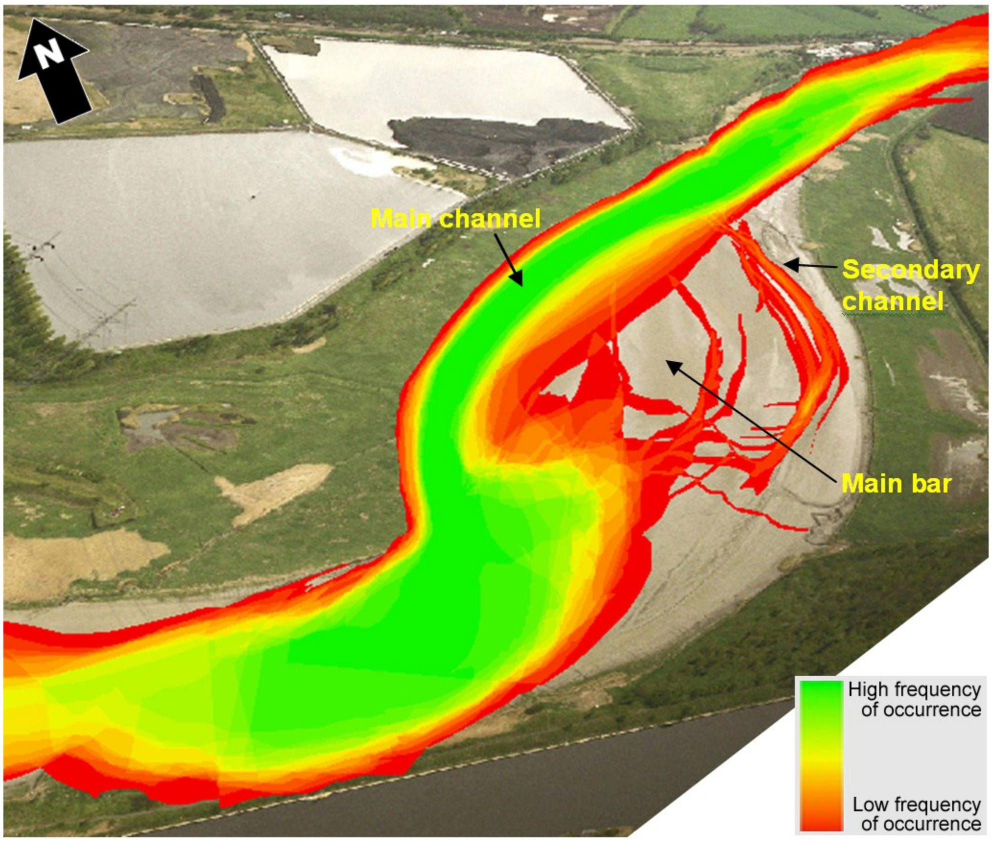


Figure 3.51 Channel mobility and sinuosity from April 2006 to May 2007 at S1 Norton Marsh

S2 Wigg Island

3.5.9 The aim of the model was to assess whether the main channel is mobile, and if so, its degree of mobility, particularly in this section where the bridge towers are proposed.

3.5.10 Figure 3.52 shows the result of this model for the downstream view, and figure 3.53 shows the upstream view. The estuary is marked with coloured zones of channel routes ranging from very high frequency of channel occupation where the channel frequently uses the same route shown in green, to very low frequency of occupation (i.e. the channel is highly mobile – such as the flood channel) which is shown in the different degrees of red. This could also be taken as an indicator of stability; areas of high frequency of occupation are relatively stable.

3.5.11 Both figures show the alignment to be across a relatively stable section of the estuary. The central tower would be located in a stable sand bar and the north and south towers near to the relatively stable ebb channels which run close to the north and south banks.

3.2.12 The factors controlling the channel mobility range from the high energy of incoming flow, the current and wind speed and direction, and the tide level. Despite the variability of these factors, and based on the available data it seems that the main channel is likely to be stable matching with most of the visual interpretation shown in figures 3.30 – 3.37 [should be 3.23-3.37?]. It should be noted that the zone stability is not absolute, and areas of very high frequency of channel occupation may be subject to some degree of change.

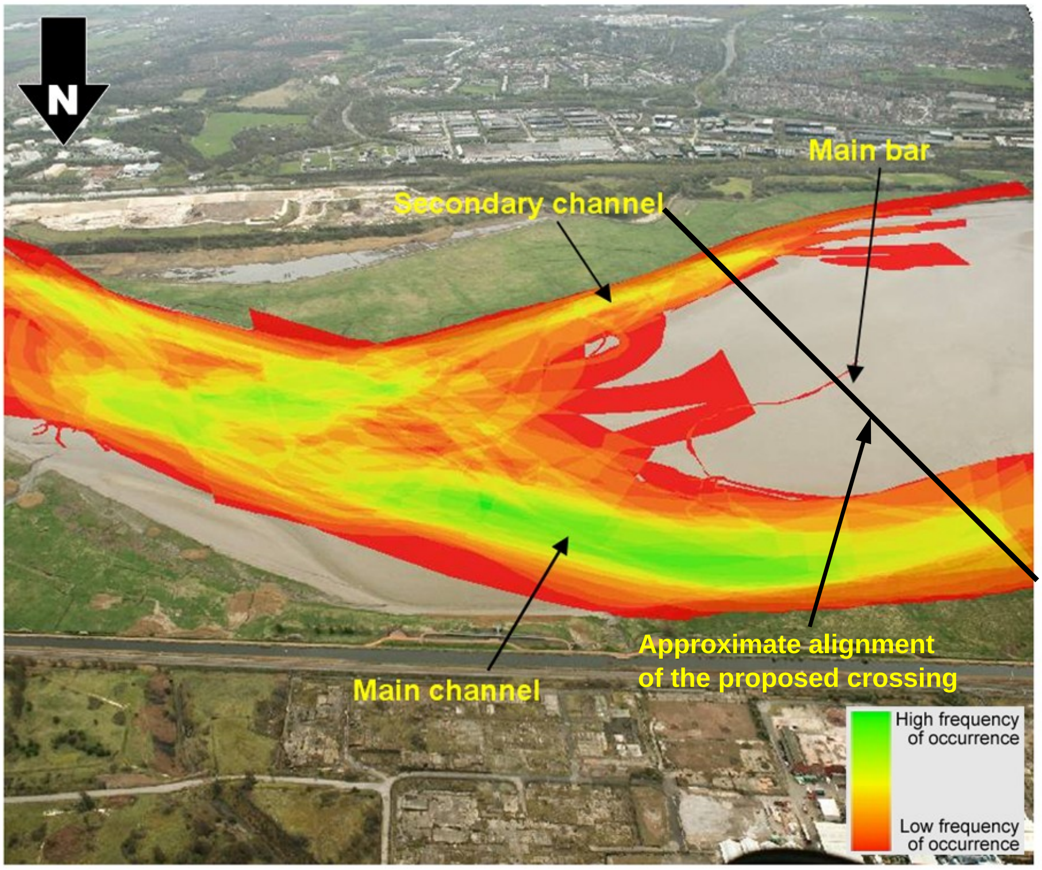


Figure 3.52 Channel mobility and sinuosity from April 2006 to May 2007 at S2 Wigg Island (downstream)

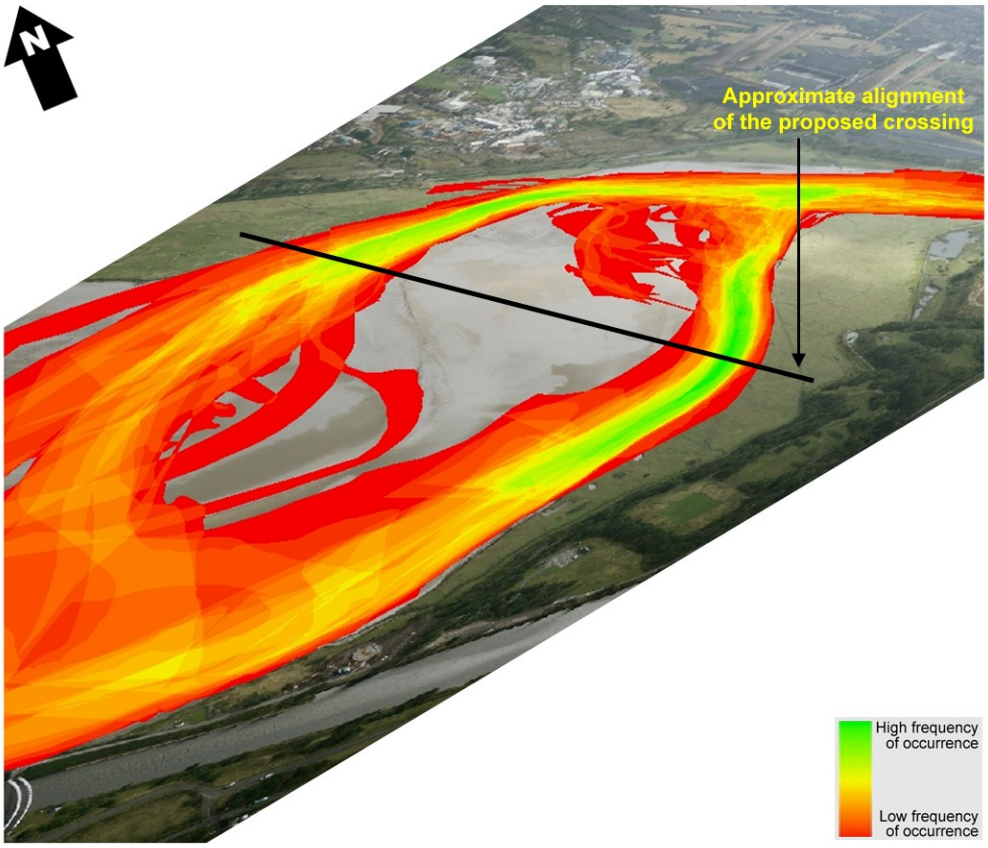


Figure 3.53 Channel mobility and sinuosity from April 2006 to May 2007 at S2 Wigg Island (upstream)

<u>S3 – Runcorn Sands</u>

3.5.13 Figure 3.54 shows categories the Estuary into zones ranging from very high frequency of channel occupation where the channel frequently uses the same route shown in green, to very low frequency of occupation (i.e. highly the channel is highly mobile – such as the flood channel) which is shown in the different degrees of red. This could also be taken as an indicator of stability; areas of high frequency of occupation are relatively stable.

3.5.14 This section is downstream of the proposed bridge alignment and is highly mobile with the exception of a relatively stable sand bar.

3.5.15 The factors controlling the channel mobility range from the high energy of incoming flow, the current, wind speed and direction, and the tide level. Despite the variability of these factors, and based on the available data it seems that the main channel in this section is likely to be relatively stable in the vicinity of the proposed crossing. It should be noted that the stability not absolute, and areas of very high frequency of channel occupation are subject to change.

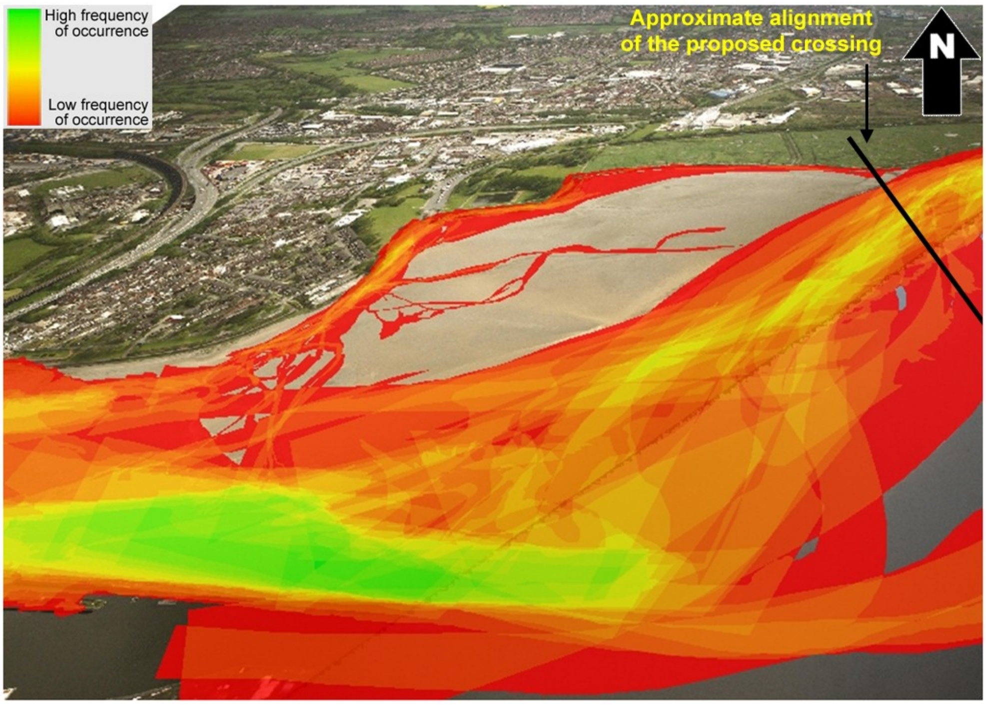


Figure 3.54 Channel mobility and sinuosity from April 2006 to May 2007 at S3 Runcorn Sands

S4 – Silver Jubilee Bridge

3.5.16 Figure 3.55 shows categories the Estuary into zones ranging from very high frequency of channel occupation where the channel frequently uses the same route shown in green, to very low frequency of occupation (i.e. highly the channel is highly mobile – such as the flood channel) which is shown in the different degrees of red. This could also be taken as an indicator of stability; areas of high frequency of occupation are relatively stable.

3.5.17 This section shows the highly dynamic area around the Silver Jubilee Bridge, downstream of the proposed crossing.

3.5.18 The model result agreed with historical and contemporary data which shows high dynamicity and multiple ebb channels in the area under Silver Jubilee Bridge. However, a more stable zone is located where the proposed alignment would be installed. The factors controlling the channel mobility range from the high energy of incoming flow, the current, wind speed and direction, and the tide level. Despite the variability of these factors, and based on the available data it seems that the main channel in this section is likely to be relatively stable in the vicinity of the proposed crossing. It should be noted that the stability not absolute, and areas of very high frequency of channel occupation are subject to change.

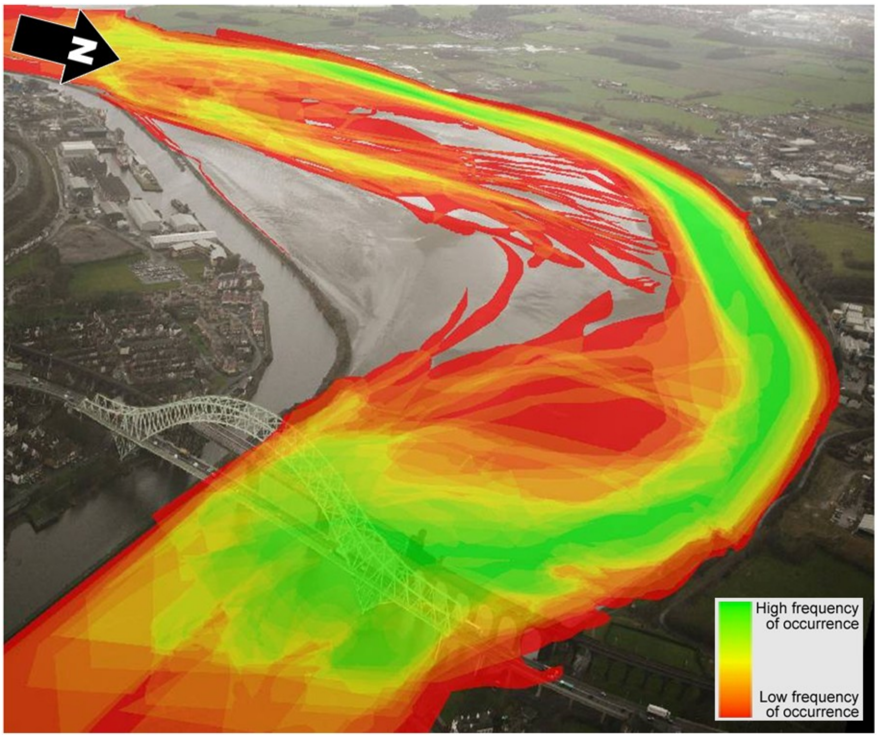


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Figure 3.55 Channel mobility and sinuosity from April 2006 to May 2007 at S4 Silver Jubilee Bridge

3.6 Relationship between channel change and tidal heights

3.6.1 It is logical to hypothesise that energy which drives morphological changes is derived from the tide. If this were the case the greatest morphological changes would be expected when tidal variations are at their greatest.

3.6.2 Channel change can only be evaluated qualitatively from photographic images whereas tidal data is quantitative. Qualitative and quantitative data cannot be directly compared using statistical methods. Consequently a qualitative analysis was conducted to explore the relationship between the tidal cycle and channel change.

3.6.3 The photographic images were interrogated to pick out sequences of images which displayed significant morphological change and the tidal regime experienced between the dates of the images was noted. The images taken around Wigg Island were used for such purposes given that this region has been identified as being one of the most morphologically active regions in the study area.

3.6.4 Based on the assumption that the energy which drives morphological changes is derived from the tide, the greatest morphological changes would be expected when tidal variations are at their greatest. Consequently, the tidal record was also interrogated around the dates of the new and full moon phases (when spring tides occur) and following the spring and autumn equinoxes (21 March and 23 September). At Old Quay Lock the largest spring tide varies from 0.9 to 6.4m (range 5.3m); the smallest neap tide varies from 0.9m to 2.5m (range 1.4m).

3.6.5 Table 4.1 lists morphological change which occurred over a year at Wigg Island where a high degree of morphological change was noted (near to the proposed crossing). In general, visibly significant morphological changes at Wigg Island occur over the course of 2,3 or 4 spring tides.

However, significant morphological change was noted between 15/06/2005 and 22/06/2005 with only the influence of a neap tide between these dates.

Table 3.3 Example of Short-Term Morphological changes at Wigg Island and spring tides, 15/06/2005 to 21/05/2007

Dates	Nature of morphological change	Height of preceding spring tide (m)	Date of tide
15/06/2005 – 22/06/2005	Development of three meander cut-off channels	3.14	17/06/2005 Neap tide: no spring tides between images.
22/06/2005 – 13/07/2005	Decay of dominant channel and migration of secondary channel	5.32 4.33	24/06/2005 08/07/2005
20/07/2005 – 15/08/2005	Sequence of cut-off and migration	5.6 No data	23/07/2005 07/08/2005
03/10/2005* – 25/11/2005	Migration of secondary channel and development as a dominant channel	4.95 5.80 5.60 4.87	05/10/2005 19/10/2005 04/11/2005 18/11/2005
14/03/2006 – 14/04/2006	Migration of dominant channel to occupy formerly abandoned channel	4.65 6.42 4.99	16/03/2006 31/03/2006 15/04/2006
24/03/2007 - 21/05/2007	Migration of dominant channel and development of secondary channel	4.6 4.3	24/03/2007 21/05/2007

3.6.6 The highest tidal events were recorded on 31/03/2006 and 20/09/2005 (around the spring and autumn equinox). It is interesting to note that visibly significant morphological change was noted around the time of the spring equinox. Some morphological change was also noted during the September equinox. However, this was not recorded as one of the most obvious examples of channel change from the photographic record and is probably attributable to the fact that low water channels at Wigg Island are in a constant state of dynamism and that over a period of 16 days, some degree of channel change at this location is highly probable.

3.6.7 Whilst it is logical to relate high tides with morphological change, and there are some instances of morphological change occurring at key tidal dates, correlation does not necessarily mean the two are significantly related. This is suggested by the fact that obvious channel change was seen to occur when there were no especially high tides. This, in combination with the fact that no quantitative assessment can be made, means that it is impossible to confirm whether channel change is determined solely by changes in tides. In reality, the process is complex and influenced by many factors, possibly including the antecedent condition of the estuary. Observations have suggested a gradual progression of change, which can then in move rapidly, over two or three tides, into a substantially different form.

3.7 Relationship between channel change and meteorological effects

3.7.1 As with the relationship between channel change and astronomically-driven tides, qualitative and quantitative data cannot be directly compared to determine whether any relationship exists between meteorological effects and observed channel change.

3.7.2 This approach is made more complex with the inclusion of several additional variables. Whereas the astronomically-driven tide can be identified as a singular hydrological variable, meteorological effects may comprise of several different elements such as wind, precipitation and low atmospheric pressure. In addition to these ‘primary’ meteorological variables, secondary variables can also be expected, including high fluvial flows generated by precipitation or raised sea levels caused by low atmospheric pressure.

3.7.3 The pattern, influence and timing of these variables make distinguishing any relationship complex, and extremely difficult to identify which (if any) of the meteorological variables may have caused any changes in channel morphology. It is also clear that changes in channel morphology occur both in the short and long-term, which may not collate with historical meteorological events. It is also likely that any meteorologically-related change in channel morphology may also be disguised by the energy caused by the incoming and outgoing tide.

3.7.4 As such, determining any clear relationship (either from singular events or using long-term trends) between channel change and meteorological effects from the qualitative photographic images and quantitative datasets (e.g. wind speed and direction) proved to be a complex task outside of the scope and practical capability of this report. Further research could be undertaken to establish the inter-variable relationship using historical datasets as well as the qualitative photographic images, although it is thought unlikely that any clear relationship between meteorological effects and observed channel change could be identified.

4. GEOMORPHOLOGICAL PROCESSES

4.1.1 S1 Norton Marsh was seen as being relatively stable in the short term aerial photographs and no channel switching occurred. However anecdotal evidence and historical data both show that the dominant low flow channel does switch from one bank to the other. This change, and the mechanism that causes it, has not been observed during the timescale of this study, and it is therefore not possible to identify causal mechanisms or their timescales. Nevertheless, photographs taken with a 20 year interval do show changes (Figure 4.1). This suggests that changes should be expected to occur at least over the decadal timespan.

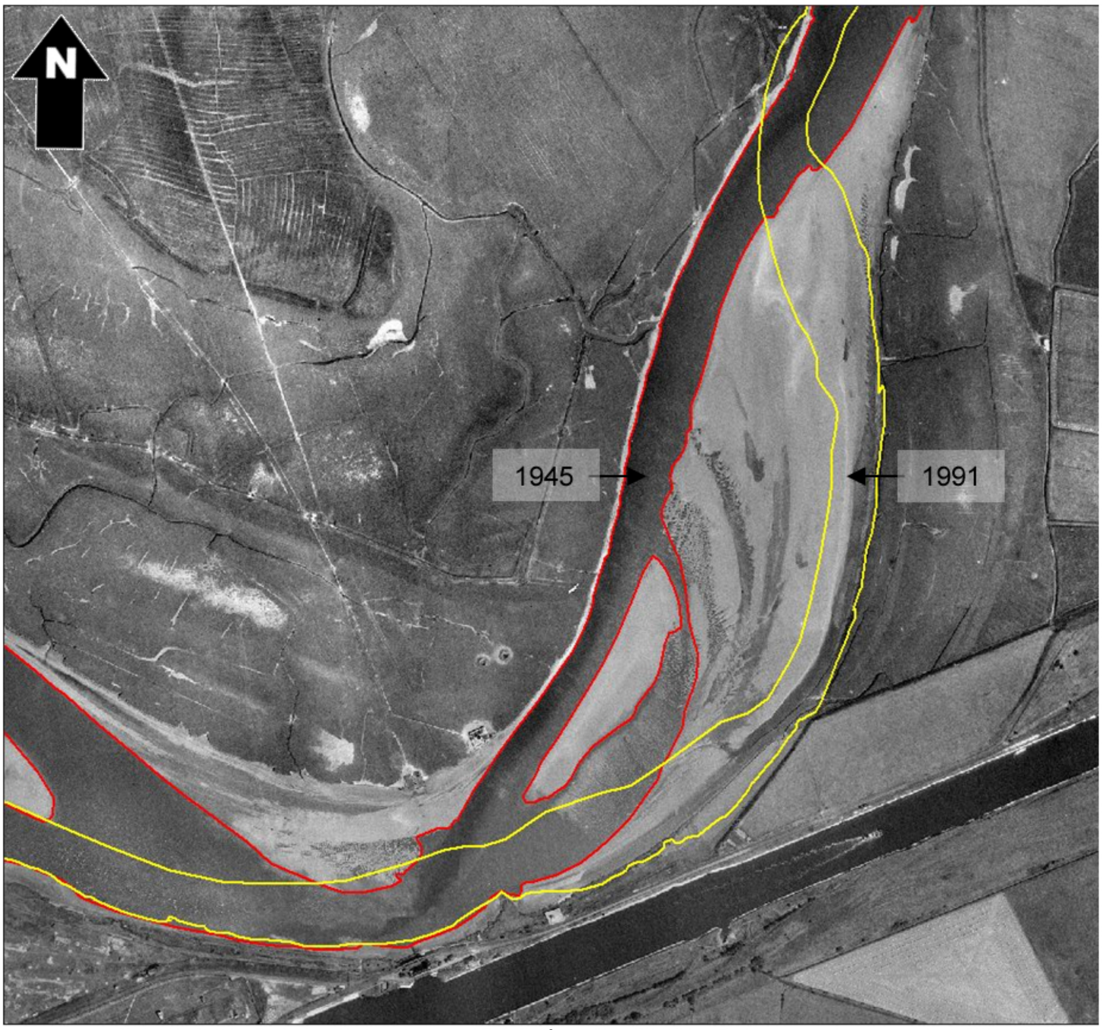

Figure 4.1 1945 aerial photograph of S1 – Norton Marsh showing the 1945 channel (red), and the 1991 channel (yellow) lying to the east. Note the similarity between the generic form observed in 1945 and the present situation (Figure 4.1)

4.1.2 S2 Wigg Island is currently characterised by a zone of dynamic channel change emanating from Hempstones Point. The dominant features are a) an ebb channel that is never completely static; b) flood channels, and c) channel boundaries of unconsolidated, easily eroded sediment.

4.1.3 Between S1 and S2 the Estuary is oriented northwest (a relict valley shape), and this orientates flow towards the northwest. It is possible to illustrate the series of process that have been seen to operate in this section (Figure 4.2). Entering S2, ebb flow is forced west either by the banks of the estuary or by the existing channel layout. This turn creates the start of a meandering channel pattern, and flow begins to erode the outer bank of the channel. This process is illustrated in Figure 4.2. This erosion supplies sediment to the channel as bedload, which is then transported downstream and deposited as a point bar or ebb delta where gradient lessens or velocity decreases (Figure 4.2). The erosion and deposition have the combined effect that they increase channel length and thereby reduce channel gradient, stream power and ability to transport sediment. The process of outer bank erosion and inner bank deposition, a classic feature of river channels (Leopold and Wolman, 1957), continues through several tidal cycles. The hypothetical endpoint of this process is that the main channel lengthens, which reduces its average gradient and it then becomes unable to carry the incoming flow or bedload, and flow switches to a new route with a lower overall roughness. The switch is aided by the naturally-occurring presence of flood channels (Figure 4.2). This sequence of processes was observed regardless of where the main ebb channel was located within the estuary, and is a generic model of evolution for these channels.

4.1.4 The flood tide moves up the estuary and is deflected out of the ebb channel by a roughness effect where the two flows interact (van Veen, 1950, Robinson, 1960). The flows are deflected away from each other most easily at the downstream part of a meander loop, and the flood tide therefore pushes upstream and across the meander loop to create a blind-ended flood channel (Figure 4.2). Under some circumstances such flood channels may subsequently become the most efficient route for ebb flow, and will then tend to capture flow from the dominant ebb channel.

4.1.5 The majority of the photographic evidence analysed demonstrates the validity of the conceptual model developed above. However, capture of ebb flow by flood channels does not always occur, and the ebb channel may shift to a new location. The cause for this change is unknown and requires further investigation.

4.1.6 The historical patterns of channel change (Figures 4.3, 4.4) show a qualitatively similar pattern to those observed during the short term study, with movement of the main ebb channel either to the north or south bank, and with the zone of greatest geomorphological dynamism around Hempstone Point. Further monitoring is needed to observe the patterns of these major changes, specifically what patterns and processes trigger them, and how they then evolve.

4.1.7 During this study the area in S3 has, in comparison with the dynamism observed elsewhere, often remained relatively stable. This stable area in S3 is at the edge of the proposed bridge crossing which is mostly in S2. Recent photographs (Figures 3.36-3.43) show that the ebb channel does migrate across this area and the southern parts of Runcorn Sands are reworked by this channel movement. The historic data also shows evidence of channel movement across the sands (Figures 4.3, 4.5). However, the main ebb channel flows across Runcorn Sands infrequently, and this area can, therefore, be classified as less dynamic than the zone upstream around Hempstones point.

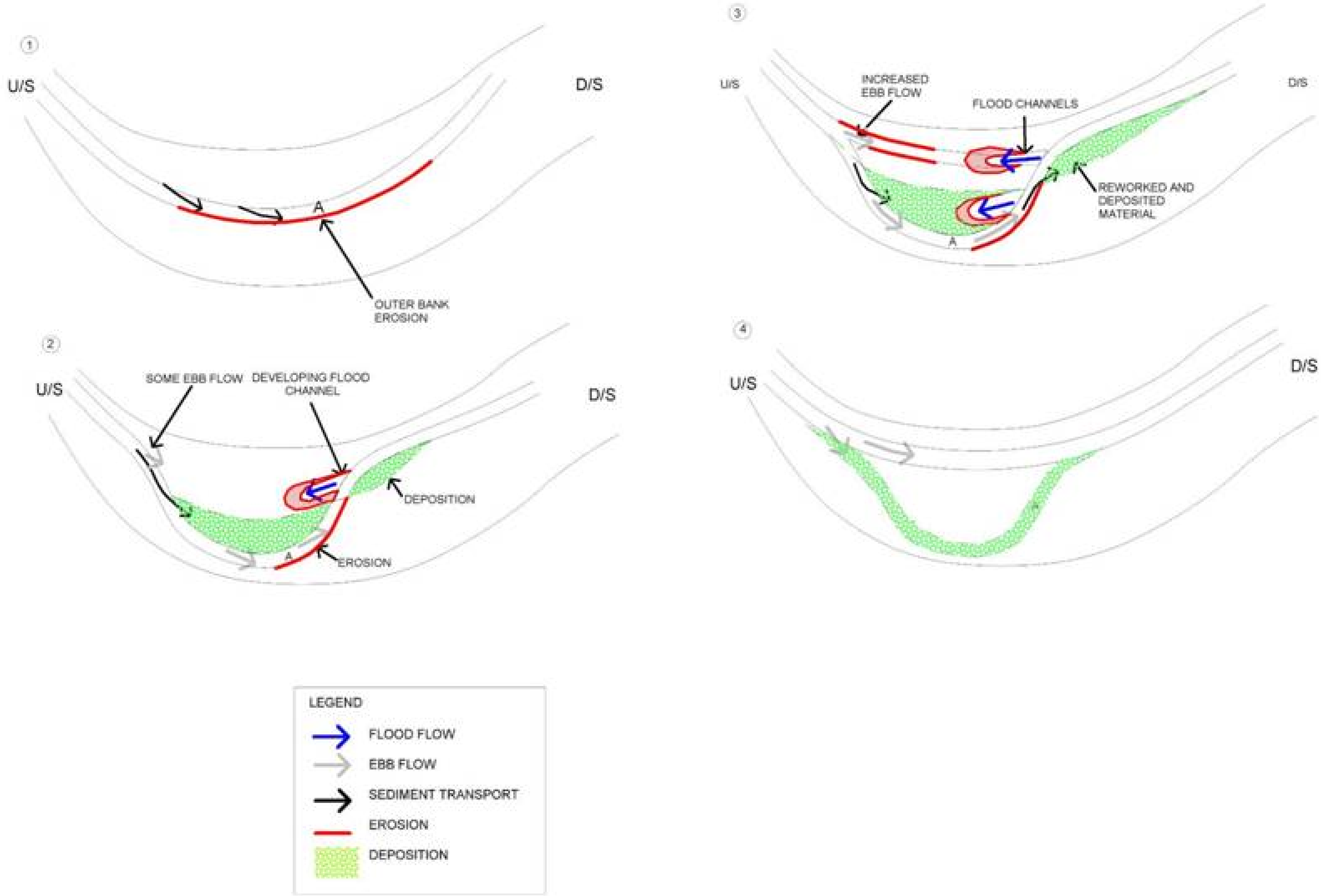

Figure 4.2 Possible processes operating within S2 – Wigg Island and Hempstones Point

4.1.8 A moderate degree of activity has been observed over the study period around the Silver Jubilee Bridge. The cycle of growth and decay of secondary and sometimes tertiary channels follows an irregular temporal pattern, but the spatial limits of this change, and the processes that occur within it, are clear: a very dynamic zone exists around Runcorn Gap (Figure 4.4), and downstream of this area lies a stable large bar and ebb channel that have changed relatively little during the study period.

4.1.9 Historic records do show some morphological changes, with the loss of stable bars and creation of secondary channels (Figure 4.5). In particular, the development and subsequent decay of a secondary channel over this bar illustrates a level of dynamism not observed during this study. This underlines the fact that significant geomorphological changes can occur downstream of the Silver Jubilee Bridge, but that such change is relatively less likely to occur frequently than in most other study areas.

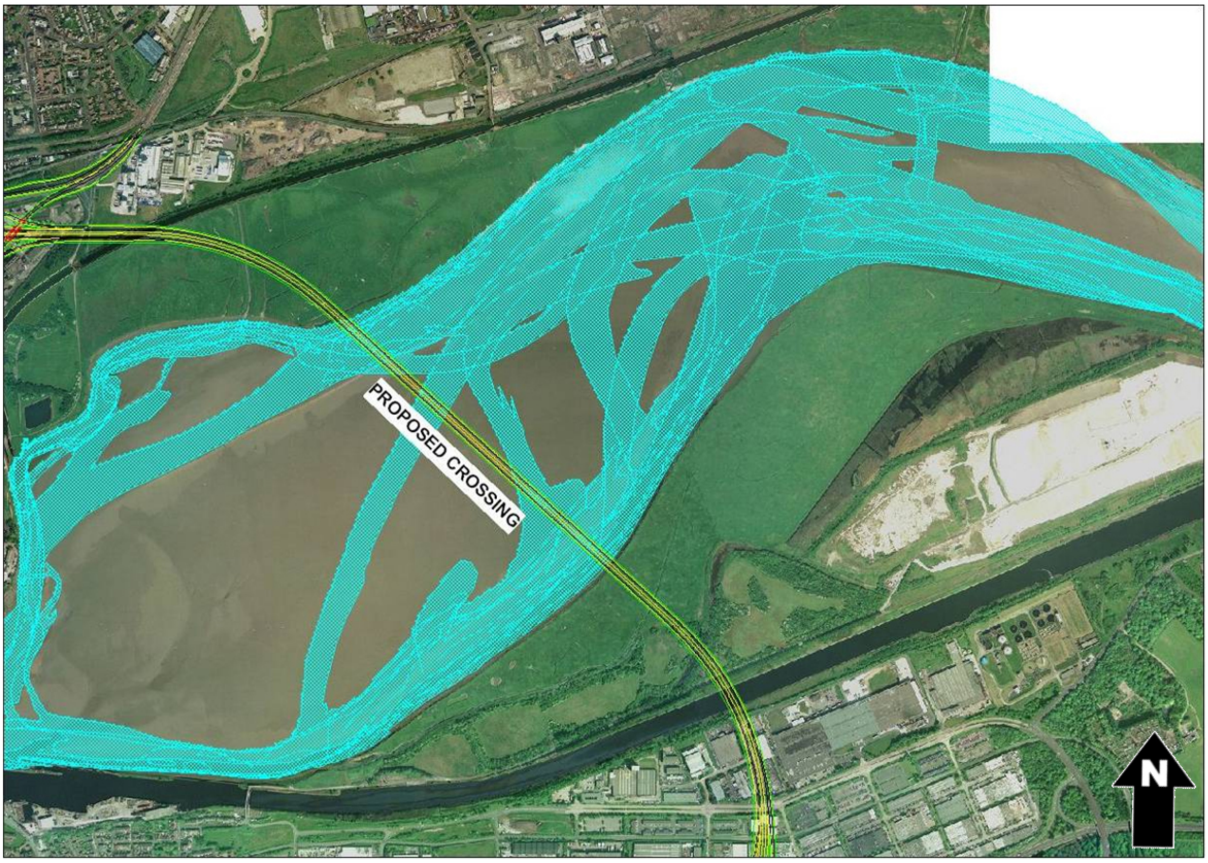

Figure 4.3 S2 and S3 historical locations of the dominant ebb channel between 1945 and 2000 in comparison to the location of the proposed crossing.

Figure 4.4 S4 historical locations of the dominant ebb channel between 1945 and 2000

Figure 4.5 Air photos of S4 in 1975 and 1991, showing the loss of a bar and creation of channel

5. DISCUSSION

5.1 Implications for the proposed Mersey Gateway

5.1.1 The Mersey Estuary is a unique estuary environment with high levels of tide dynamicity. To understand the geomorphology of the Estuary as part of the hydrodynamics and environmental impacts of a new crossing, sources of information which varied on both spatial and temporal scales were used. Historical and contemporary data were used to understand long-term and short-term morphological changes of the Estuary.

5.1.2 For historic information on channel movement 940 navigation charts (each representing a month), out of a possible 1209 months, dated from July 1971, were analysed to give an overview of the Estuary in the last century. These had a wide spatial coverage of the whole estuary. Although the original aim of these charts was to locate the navigation channel, they gave an understanding of the dynamicity and sinuosity of the main navigable channel in the last century. The Manchester Ship Canal was completed in 1894 and surprisingly, the dynamism of the navigable channels downstream of Runcorn Gap has reduced significantly with almost no change after August 1896.

5.1.3 Screening of the 940 charts with regard to the proposed bridge alignment showed that only 22 charts showed the main channel coinciding with the location of the proposed towers. This gives a 0.02 probability that the channel might return to the bridge towers in 100 years. However, the accuracy of locating the bridge towers on the UMNC charts is low. If this probability is doubled to allow for the inaccuracies accrued through the rectification of these charts and locating the bridge towers, the probability is still only 0.04, or 4 years out of every hundred.

5.1.4 A replicate GIS model of the channel mobility and sinuosity was applied on ten years interval; one including most of the 22 charts where the channel coincided with the proposed locations of the bridge towers that matched with the alignment and the other with a set that was not selected specifically to coincide with the towers. The result of the GIS model showed that the main channel has maintained its route to the south bank with the development of secondary channels along the Estuary. The model also showed the un-stable, highly dynamic area of multiple channels under the Silver Jubilee Bridge.

5.1.5 This research and analyses on long term data strengthens the argument that where the proposed alignment would be installed the main channel is likely to be stable and less mobile.

5.1.6 Short-term study relied on two different sources of information: Eight topographic surveys undertaken from December 2004 to March 2007 gave an understanding of the topography and levelling of the estuary. Analysis of oblique aerial photographs both visually and using the mobility model contributed further evidence.

5.1.7 The topographic survey showed that the area of the sand bars downstream of the Silver Jubilee Bridge is very dynamic and changeable; however this area is further downstream than the proposed location of the alignment (Figures 3.2 – 3.5). The proposed location of the towers is likely to be in more stable sand bars for the majority of the time. It is difficult to predict the pattern of the changes of these sand bars as the lateral migration of the channel occurs which is the main driver of moving the sediment. It is anticipated that the small diameter of the bridge towers (11 meter) would have relatively little permanent impact on this area of sand bars.

5.1.8 A 3-Dimension model was created using four directly comparable topographic surveys, which allowed identification of areas of significant transport in the estuary. This also identified that in the vicinity of the proposed crossing there are likely to be ebb channels close to the north and south banks, and a sand bank in the centre, which are relatively stable.

5.1.9 The results of the mobility model for all sections from the oblique aerial photographs demonstrated that the proposed bridge alignment would be situated over a relatively stable stretch of the estuary. The clearest example is Figure 3.53 which shows the area of the proposed bridge crossing. It could be concluded from the mobility model analyses for the oblique aerial photographs (and also UMNC charts and historic aerial photographs) that:

(i) Areas where the main channel occupies the same location frequently, and may be considered relatively stable (shown in green) tend to occur in zones parallel to the northern and southern banks, underneath the Silver Jubilee Bridge, and in strips around Hempstones Point. This is where the main channel routed most of the time;

(ii) Areas where the main channel does not occupy the same location frequently and has high mobility (shown in red) tend to occur in the widest parts of the estuary. This often occurs during the flooding period and mostly represents the secondary channels;

(iii) Areas between green and red represent variable levels of channel mobility from low mobility (nearer the green), for example the area upstream of Hempstones Point, along the northern and southern banks and underneath the Silver Jubilee Bridge, to medium mobility (nearer the red), for example where it widespread in the central part of the estuary.

5.1.10 The factors controlling the channel mobility range from the high energy of incoming flow, the current and wind speed and direction, and the tide level. Despite considering all these factors, and based on the available data it seems that the main channel is relatively stable showing major variations in its route much less frequently than the secondary channels. This matches with most of the visual interpretation. It should be clear that zones of stability are not absolute and as was shown in Figure 4.5 the main channel has switched banks in recent history.

5.1.11 Channel mobility and sinuosity were studied on both spatial and temporal scales to see how the main ebb channel migrates and past channel locations. The probabilistic GIS model was developed to locate the most likely movements of the main channel and therefore the location of the secondary channels. The UMNC charts and long-term aerial photos were used for the long-term study. The oblique aerial photos were used for the short-term period analysis. The results of the GIS model from both datasets show agreement of a highly dynamic area with multiple channels under the Silver Jubilee Bridge. Conversely, a fairly stable area is observed to the north where the crossing is proposed.

5.1.12 It could be concluded that from both historical and contemporary datasets the proposed crossing of the Mersey Gateway occurs in an area of relative stability. It is interesting that the three proposed tower locations fall in a relatively stable area. This would suggest a minimal interaction or/and interference of the towers with the water and sediment flow.

6. Conclusions & Recommendations

6.0.1 The geomorphology of the Mersey Estuary was studied using variable sources of historical and contemporary information. The approach taken has provided a valuable baseline through which an understanding of the morphological processes operating in the Estuary has been gained. The methods applied to the analyses of the datasets has addressed the following key issues:

- Without knowing the past it is hard to understand the present and therefore difficult to predict the future. To understand the past the geomorphological behaviour of the Estuary, UMNC charts and aerial photographs from the last century were studied.

- Key outcomes from the study of long term behaviour of the Estuary are:

  - o The main channel generally maintains its route close to the south bank, however occasionally it migrates to different routes;
  - o Migration of the main ebb channel to coincide with the north and south towers of the proposed alignment is infrequent; in the last 50 years the main channel has not coincided with the location of the central tower; and channels coinciding with the locations of all three towers have not been recorded.

- The short term behaviour of the Estuary was studied using recent intensive topographic surveys and rectified oblique aerial photographs. The key outcomes from these short-term analyses are:

  - o The topographic survey methodology developed for this study was able to obtain the ground level surface profile of the estuary. This enabled 3-Dimension analysis of observed changes in morphology;
  - o The oblique aerial photographs have some limitations resulting from their capture and their analysis; however the information provided was vital in understanding the behaviour of the geomorphological process in the Estuary.

- The mobility model results for the UMNC charts, historic aerial photographs and oblique aerial photographs all showed that the bridge towers would be situated in a relatively stable area of the estuary. This is particularly clear in Figure 3.53, which shows the bridge alignment clearly. The main channel may be considered relatively stable and tends to occur in zones parallel to the northern and southern banks, whereas the central area underneath the bridge tends to consist of a stable sand bank. The UMNC charts showed that out of 940 mapped occasions, spanning 101 years, the channel occurred in the proposed location of the Bridge towers only 22 times. This gives a 0.02 probability that the channel might return to the bridge towers in 100 years to a limited level of accuracy.

- The physical processes occurring in the Upper Mersey Estuary conform in part to a closed cell pattern of circulation, as described by van Veen (1950) and Robinson (1960). The Mersey Estuary is an ebb dominated estuary and more detailed processes which may be operating have been identified (Figure 4.3). Observation suggests ebb channel evolution occurs in two ways:

  (i) gradual evolution over days and weeks until a predictable cut-off occurs, which can be explained by conceptual models synthesised from fluvial and estuarine geomorphology; and

  (ii) sudden shifts in ebb channel location, which is caused by unknown concatenations of circumstances

Recommendations

6.0.2 This report should be considered in conjunction with the results of the flat bed model (UCL) and the ABPmer hydrodynamic modelling results, to give a complete picture of the geomorphology, flat-bed and hydrodynamics of the Estuary. This would allow a realistic scenario to be built regarding the interaction of the bridge towers and the water/sediment dynamicity at the Estuary.

6.0.3 It is recommended that regular aerial photography of the Estuary continues until the end of 2007 in order to build a three year continuous record for use in further modelling of possible scenarios.

6.0.4 Continuation of geomorphological, flat-bed and hydrodynamic studies after the installation of the Bridge Towers is advised. This will enable the integration of predicted scenarios and reality, which would provide information to help ensure efficient and reasonable mitigation strategies are developed at an earlier stage.

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Glossary

Ebb channel – a channel formed principally by the down-estuary movement of ebb tide (van Veen, 1950; Robinson, 1960).

Ebb dominance – a term used to describe a part of an estuary where most morphological changes are caused by water flows whose vector is oriented down the estuary (i.e. the ebb tide).

Enclosing spit: a bar extending across the mouth of an estuary, caused by long shore drift

Flood channel – a channel formed principally by the up-estuary movement of flood tide (van Veen, 1950; Robinson, 1960).

Geomorphology – the study of processes that shape (morph) the surface of the earth (geo).

Hydrodynamics – the description of the physical movement of water within a confined area.

Ria: an estuary formed by the flooding of river valleys by sea level rise at the end of the last ice age (more or less complete 6,000 years Before Present (BP, where ‘present’ is set at 1950).

Sediment cell: A length of coastline and its associated nearshore area, within which the movement of coarse sediment (sand and shingle) is largely self-contained. Interruptions to the movement of sand and shingle within one cell should not affect beaches in a neighbouring sediment cell. A report was produced in 1994 defining sediment cells around the coast of England and Wales (author: HR Wallingford 1994).

Thalweg: The line of maximum depth along a channel.

APPENDICES

APPENDIX 1

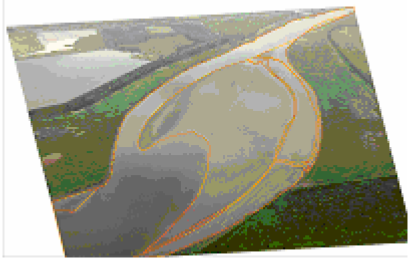
Flight program and schedule of the oblique aerial photo

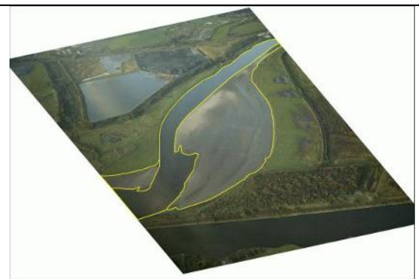
Oblique Aerial Photo Program			
Month	2005	2006	2007
Jan.		16/01/2006	22/01/2007
		23/01/2006	
Feb.		06/02/2006	22/02/2007
		13/02/2006	
		20/02/2006	
		28/02/2006	
Mar.	08/03/2005	06/03/2006	21/03/2007
	10/03/2005	13/03/2006	
	12/03/2005	20/03/2006	
		27/03/2006	
Apr.	25/04/2005	03/04/2006	24/04/2007
	26/04/2005	10/04/2006	
	27/04/2005	17/04/2006	
	28/04/2005	24/04/2006	
	29/04/2005		
	30/04/2005		
May	02/05/2005	01/05/2006	21/05/207
	04/05/2005	08/05/2006	
	06/05/2005	15/05/2006	
	12/05/2005	22/05/2006	
	13/05/2005	29/05/2006	
	14/05/2005		
	18/05/2005		
	26/05/2005		
Jun.	01/06/2005	05/06/2006	20/60/2007
	08/06/2005	12/06/2006	
	15/06/2005	19/06/2006	
	22/06/2005	26/06/2006	
	29/06/2005		
Jul.	06/07/2005	03/07/2006	
	11/07/2005	10/07/2006	
	12/07/2005	17/07/2006	
	13/07/2005	24/07/2006	
	14/07/2005	31/07/2006	
	20/07/2005		
Aug.	27/08/2007	07/08/2006	
	15/08/2005	14/08/2006	
		21/08/2006	
		28/08/2006	
Sep.	16/09/2005	04/09/2006	
	19/09/2005	11/09/2006	
	20/09/2005	18/09/2006	
	21/09/2005	25/09/2006	
Oct.	03/10/2005	02/10/2006	
		09/10/2006	
		16/10/2006	
		23/10/2006	
		30/10/2006	
Nov.	25/11/2005	20/11/2006	
		27/11/2006	
Dec.	21/12/2005	04/12/2006	
		11/12/2006	
		18/12/2006	
		25/12/2006	

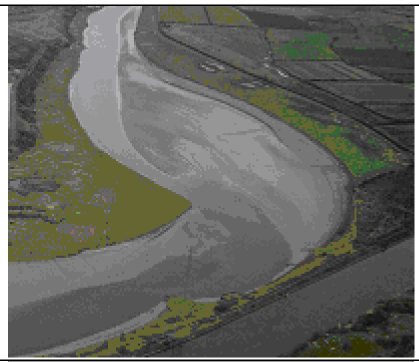
APPENDIX 2

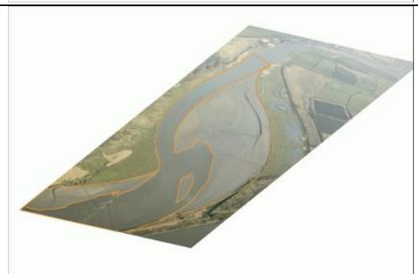
Tables of Analysis

S1 - Norton Marsh – Recording Channel Change
("-" means no data were available)

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
30/04/2005 **14.27 BST**	n300405i		2.54	221.3	1.34	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	Two small secondary flood channels located towards the south bank and join the main channel with a delta at the apex of Cuerdley Marsh.	-	-	-	-	-	-	-
04/05/2005 **07.14 BST**	n040505i		2.9	12.7	2.1	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	One secondary low flow channel located towards the south bank and joins the main channel with a delta at the apex of Cuerdley Marsh	Increase	Decay/infilling of one secondary low flow channel associated with bar migration. Large stable bar in centre of estuary channel with clear flood intrusion channel.	None	None	Small scale bar migration Widening of secondary low flow channel Erosion of main bar where dominant channel and flood intrusion channel meet	Neap 03/05/05	39.46 30/04/2005 41.31 01/05/2005 37.98 02/05/2005 46.33 03/05/2005 34.53 04/05/2005
01/06/2005 **18.07 BST**	n010605i		5.53	239.5	1.27	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	One secondary low flow channel located towards the south bank and joins the main channel with a delta at the apex of Cuerdley Marsh	-	Same broad pattern of bars and low flow channels as in image 04/05/05.	None	None	Continued erosion of main bar where dominant channel and flood intrusion channel meet	Spring 10/05/05 Neap 18/05/05 Spring 25/05/05	51.67 06/05/2005 69.62 07/05/2005 40.55 08/05/2005 33.96 09/05/2005 33.61 21/05/2005 36.65 22/05/2005 38.03 01/06/2005
08/06/2005 **11.09 BST**	n080605i		1.39	255.4	1.86	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	Two small secondary low flow channels located towards the south bank and join the main channel at the apex of Cuerdley Marsh	Increase	Low flow channel patterns appear similar to those of 30/04/05. Bar migration upstream and cut-off of a secondary low flow channel. Development of another low flow channel from 01/06/05 at the south bank.	None	None	Widening of secondary low flow channel. Narrowing of dominant low flow channel.	Neap 01/06/05 Spring 08/06/05	35.65 02/06/2005

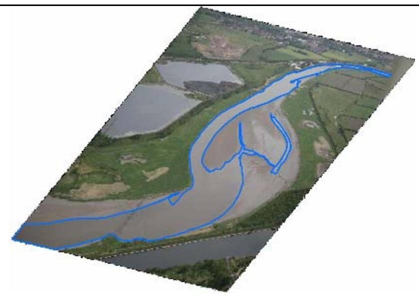
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
11/07/2005 **13.19 BST**	n110705i		1.52	58.3	1.02	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	One secondary low flow channel located towards the south bank and joins the main channel with a delta at the apex of Cuerdley Marsh	-	Same broad low flow channel patterns as in 01/06/05. Decay of a secondary low flow channel, coupled with bar growth. Extension of bar at northern bank towards the southern bank.	None	None	Widening of secondary low flow channel.	Neap 17/06/05 Spring 24/06/05 Neap 30/06/05 Spring 08/07/05	35.46 19/06/2005
20/07/2005 **09.06 BST**	n200705i		8.86	289.7	2.30	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	Two small secondary low flow channels located towards the south bank and join the main channel at the apex of Cuerdley Marsh	-	Resumption of pattern of two secondary low flow channels at the south bank, one at right angles to the other. Low flow channel joins dominant channel further downstream than in previous image. Change in shape of bar at northern bank, however remains relatively stable.	None	Small-scale switching of path of secondary low flow channel, visible by the presence of a scar indicative of former path in previous image (11/07/05).	Narrowing of secondary low flow channel.	Neap 16/07/05	-
25/11/2005 **15.00 BST**	n251105i		5.44	328.4	1.09	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channels visible	-	Decay/infilling of secondary low flow channels to leave one dominant low flow channel. Growth of stable bar in centre of channel.	None	None	Bar growth. Flood levee visible on the main bar, to the south of the main channel.	Spring 23/07/05 Neap 30/07/05 Spring 07/08/05 Neap 15/08/05 Spring 21/08/05 Neap 28/08/05 Spring 05/09/05 Neap 13/09/05 Spring 20/09/05 Neap 27/09/05 Spring 05/10/05 Neap 12/10/05 Spring 19/10/05 Neap 27/10/05 Spring 04/11/05 Neap 11/11/05 Spring 18/11/05 Neap 25/11/05	32.86 28/07/2005 37.13 13/08/2005 31.33 25/08/2005 33.05 26/08/2005 41.61 28/09/2005 51.94 29/09/2005 86.28 30/09/2005 74.59 01/10/2005 33.54 02/10/2005 42.06 12/10/2005 39.85 13/10/2005 38.07 19/10/2005 43.71 21/10/2005 35.08 22/10/2005 45.81 23/10/2005 126.4 24/10/2005 122.5 25/10/2005 105.5 26/10/2005 73.83 27/10/2005 58.10 28/10/2005 46.08 29/10/2005 46.99 30/10/2005 35.91 31/10/2005 53.01 01/11/2005 79.53 02/11/2005 82.15 03/11/2005

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
														112.1 04/11/2005 82.90 05/11/2005 105.3 06/11/2005 77.47 07/11/2005 116.4 08/11/2005 106.7 09/11/2005 90.87 10/11/2005 98.23 11/11/2005 80.66 12/11/2005 59.21 13/11/2005 58.2014/11/2005 58.20 15/11/2005 47.52 16/11/2005 37.83 17/11/2005 32.91 18/11/2005 33.78 19/11/2005 31.14 24/11/2005
21/12/2005 **12.22 BST**	n211205i		5.65	257.4	1.13	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible	-	Same pattern of low flow channels as in previous image (21/11/05).	None	None	Further accretion of secondary low flow channel. Erosion of downstream sill of bar in centre of estuary.	Neap 25/11/05 Spring 03/12/05 Neap 10/12/05 Spring 17/12/05	38.42 01/12/2005 51.88 02/12/2005 76.31 03/12/2005 112.8 04/12/2005 105.8 05/12/2005 94.75 06/12/2005 68.47 07/12/2005 59.91 08/12/2005 45.15 09/12/2005 47.55 10.12/2005 38.31 11/12/2005 35.04 12/12/2005
21/01/2006	n210106		4.18	310.4		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible	-	Same pattern of low flow channels as in previous image (21/12/05).	Some evidence that dominant channel has migrated downstream eroding upstream sill of bar at northern bank.	None	Continued accretion of former secondary low flow channels.	Neap 25/12/05 Spring 02/01/06 Neap 08/01/06 Spring 16/01/06	30.96 22/12/2005 37.2623/12/2005 40.42 24/12/2005 30.87 25/12/2005 56.83 30/12/2005 78.38 31/12/2005 62.66 01/01/2006 40.77 02/01/2006 40.68 03/01/2006 36.10 04/01/2006 31.54 05/01/2006 47.02 10/01/2006 65.87 11/01/2006 37.72 12/01/2006 32.96 13/01/2006 31.97 14/01/2006 34.59 16/01/2006 57.49 17/01/2006 63.17 18/01/2006 58.36 19/01/2006 77.25 20/01/2006 52.34 21/01/2006

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
23/01/2006 **14.56 BST**	n230106i		4.66	167.4	1.08	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible	-	Same pattern of low flow channels as in previous image (21/01/06).	None	None	None	-	40.18 22/01/2006 35.91 23/01/2006
20/02/2006 **13.18 BST**	n200206i		5.98	28.1	0.90	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible	-	Same pattern of low flow channels as in previous image (23/01/06).	None	None	None	Neap 24/01/06 Spring 31/01/06 Neap 07/02/06 Spring 15/02/06	32.50 24/01/2006 58.32 14/02/2006 97.49 15/02/2006 56.29 16/02/2006 57.28 17/02/2006 41.92 18/02/2006 34.54 19/02/2006 31.03 20/02/2006
28/02/06 **09.04 BST**	n280206i		5.19	326.2	1.15	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible		Same pattern of low flow channels as in previous image (20/02/06).	None	None	Potential steepening of river cliff of former secondary channel	Neap 23/02/06	30.94 21/02/2006 39.44 32/02/2006 63.86 24/02/2006 40.44 25/02/2006 33.74 26/02/2006 40.48 27/02/2006 45.04 28/02/2006
14/03/06 **09.24 BST**	n140306i		5.53	172.15	1.16	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible	-	Same pattern of low flow channels as in previous image (28/02/06).	None	None	Small dry topographic high exposed in dominant channel	Spring 02/03/06 Neap 08/03/06	34.38 01/03/2006 30.43 02/03/2006 59.44 07/03/2006 105.8 08/03/2006 101.1 09/03/2006 116.6 10/03/2006 78.66 11/03/2006 56.47 12/03/2006 58.73 13/03/2006 75.74 14/03/2006
14/04/06 **10.47 BST**	n140406i		6.31	291.8	3.13	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible	increase	Same pattern of low flow channels as in previous image (28/02/06).	Small amount of downstream channel migration of the dominant channel.	None	None	Spring 16/03/06 Neap 24/03/06 Spring 31/03/06 Neap 07/04/06 Spring 15/04/06	122.3 15/03/2006 82.20 16/03/2006 60.34 17/03/2006 48.9618/03/2006 41.05 19/03/2006 37.92 20/03/2006 33.62 21/03/2006 31.52 22/03/2006 37.83 24/03/2006 74.86 25/03/2006 79.72 26/03/2006 95.57 27/03/2006 129.0 28/03/2005 100.9 29/03/2006 113.0 30/03/2006 94.94 31/03/2006 119.2 01/04/2006

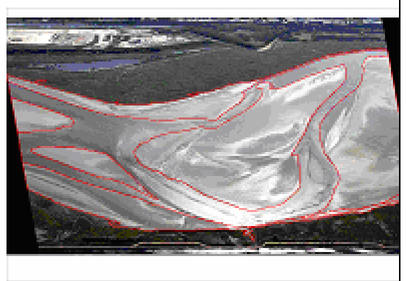
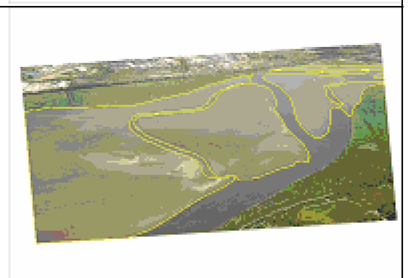
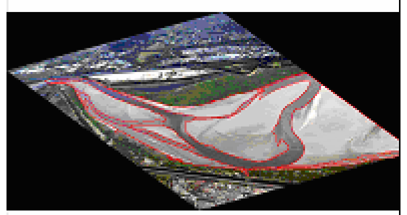
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
														113.9 02/04/2006 104.4 03/04/2006 67.26 04/04/2006 51.82 05/04/2006 51.65 06/04/2006 57.49 07/04/2006 76.56 08/04/2006 64.14 09/04/2006 50.75 10/04/2006 78.70 11/04/2006 50.63 12/04/2006 44.85 13/04/2006 37.50 14/04/2006
18/04/2006			5.05	277.3						None	None			
25/05/2006			3.45	259.9		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			27.76
19/06/2006			4.33	365.5		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			10.73

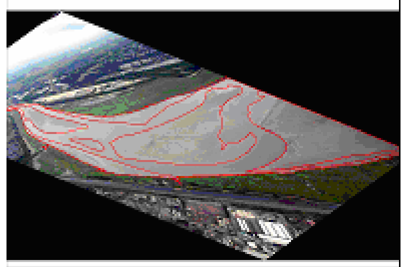
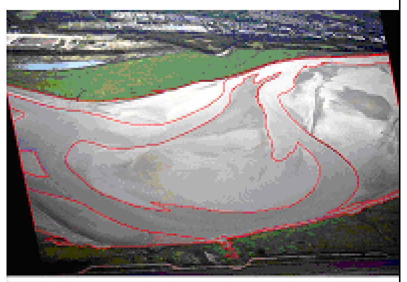
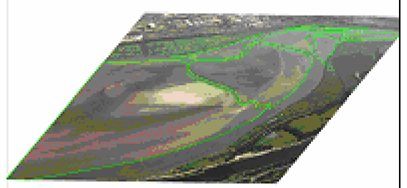
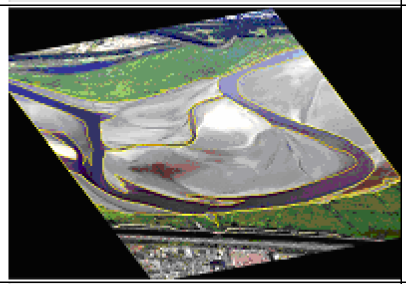
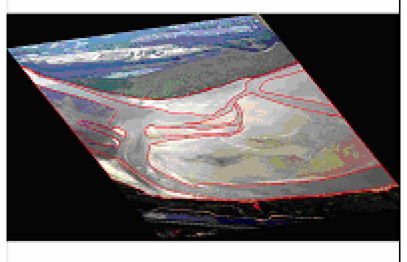
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
25/07/2006			5.17	141.5		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			7.718
21/08/2006			6.94	298.1		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			31.73
19/09/2006			7.24	257.5		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			22.79
20/10/2006			1.69	193		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			28.96

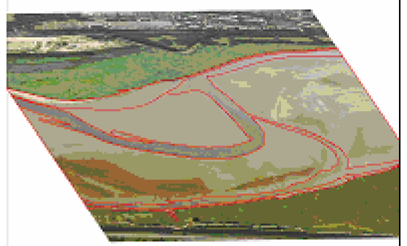
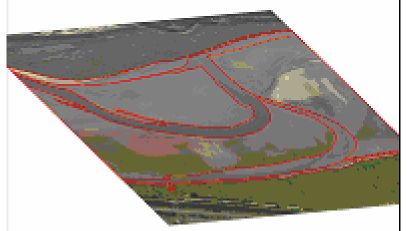
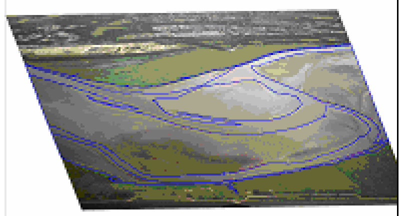
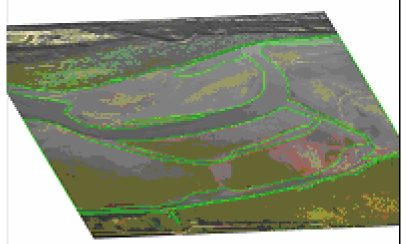
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed (ms^{-1})	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
06/11/2066			2.28	241.5		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			20.86
07/01/2007			5.38	214		Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			91.23
24/03/2007			1.87	310.2	0.5	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			-
24/04/2007 15-51 BST			n/a	n/a	0.4	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			-
21/05/2007 13-38 BST			n/a	n/a	0.5	Dominant channel located towards then north bank and meanders across the estuary to the south bank. Lobate flood intrusion channel cuts into main bar	No active secondary low flow channel visible			None	None			-

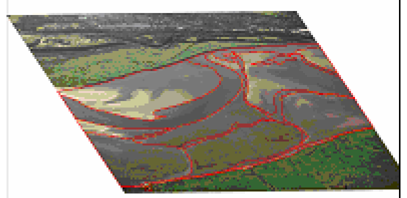
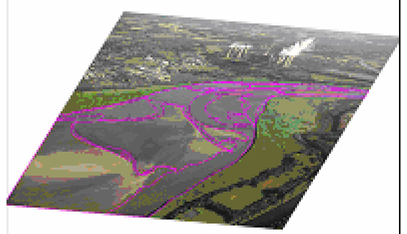
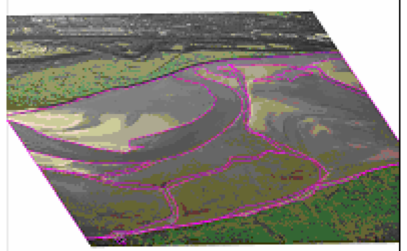
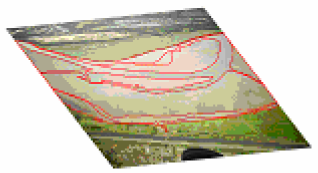
S2 - Wigg Island – Recording Channel Change

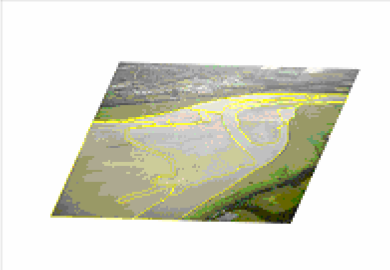
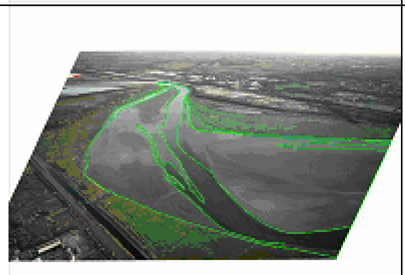
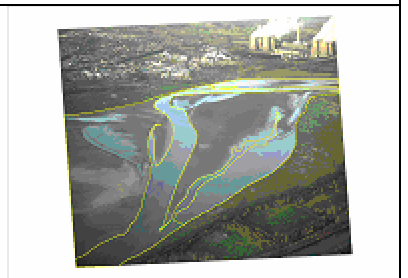
("-" means no data were available)

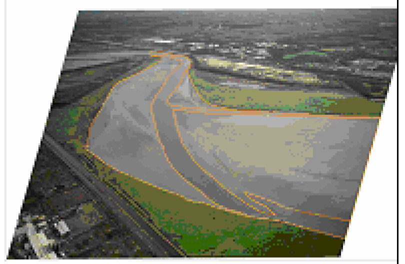
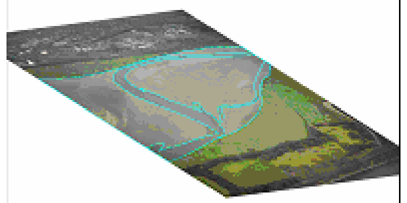
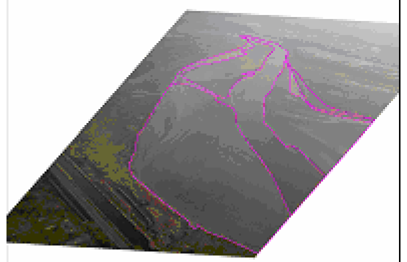
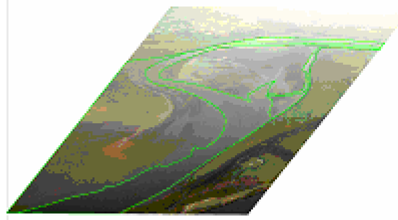
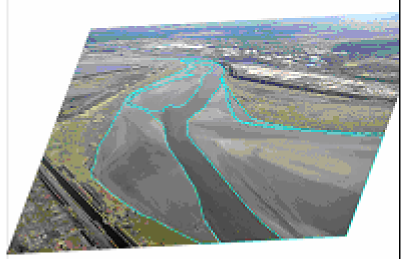
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
29/04/2005 **13.31 BST**	s290405i		4.53	242.6	1.47	Leaves Hempstones point, meanders part way across estuary, then turns south to abut southern bank where a delta forms. Then runs parallel to south bank out of image.	Ebb flow is split between main channel and secondary channel at northern bank. Relict ebb channel visible towards east (left of image) with a delta at its outlet	-	-	-	-	-	-	-
06/05/2005 **09.01 BST**	w060505i		6.84	296.3	3.29	Main channel has captured secondary channel at north bank.	Loss of secondary channel carrying ebb flow.	-	Secondary channel captured by main channel	-		-	-	39.46 30/04/2005 41.31 01/05/2005 37.98 02/05/2005 46.33 03/05/2005 34.53 04/05/2005
12/05/2005 **12.38 BST**	w120505i s120505i	 	5.06	106.9	1.11	Main channel increasing sinuosity by eroding at outside of bend near apex.	Secondary ebb channel carries some flow along the flood intrusion channel parallel to the south bank. On LH side of image, flow splits into several branches.	Increasing	The number of bars and channels remains the same but their position and shape have changed through bar accretion and channel migration downstream. Meander loop of dominant channel shows increased sinuosity and scar evident where dominant channel was formerly located. Infilling of secondary channel.	Dominant channel migrating downstream and towards the north bank.	None	Crevassing of former bank line due to water drawdown. Flood intrusion pathway and delta visible in bottom centre of image on the inner apex of main channel meander.	Spring 10/05/05	51.67 06/05/2005 69.62 07/05/2005 40.55 08/05/2005 33.96 09/05/2005
14/05/2005 **13.55 BST**	w140505i		6.64	64	0.90	As for w120505i	As for w120505i	Increasing	As for w120505i	As for w120505i	None	-	-	-

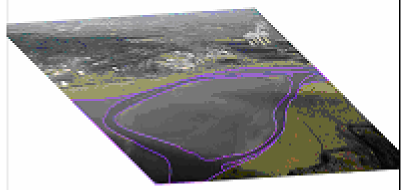
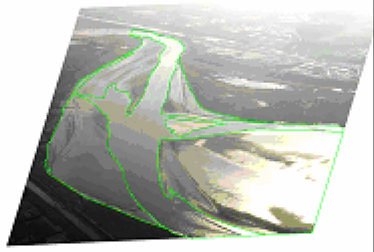
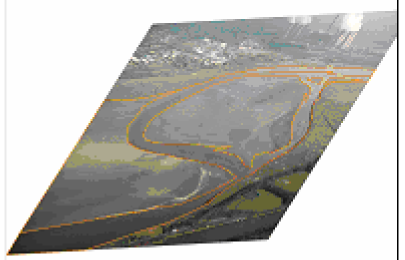
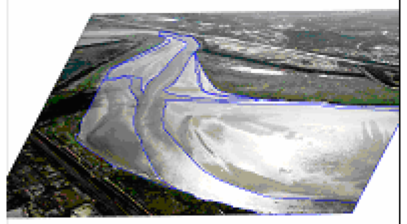
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
26/05/2005 **11.53 BST**	w260505i		4.71	249.6	3.22	As for w120505i	Secondary channel along south bank carries more flow	Increase	The number of bars and channel remains the same but their position and shape have changed. Dominant and secondary channels migrating downstream.	Dominant channel and secondary channel migrating downstream.	None	Secondary channel widening	Neap 18/05/05 Spring 25/05/05	33.61 21/05/2005 36.65 22/05/2005
01/06/2005 **18.07 BST**	w010605i		5.51	234.9	1.27	As for w120505i	Secondary channel developing across large bar and carrying increasing ebb flow	Increase	The pattern of channels and bars remains the same, but the dominant and secondary channels are migrating downstream and towards the north bank.	Dominant channel and secondary channel migrating downstream.	Slow switch starting to secondary channel.	Flood intrusion scouring the bar lying on the inside of the main channel meander	Neap 01/06/05	38.03 01/06/2005
08/06/2005 **11.09 BST**	s08605i		1.21	250.5	1.86	Main channel increasing sinuosity	Secondary channel across large bar carries less ebb flow. Evidence of flow spilling out of this secondary channel and across the bar	Increase	Bar growth on the inside of meander bends where main channel is increasing in sinuosity	Some channel migration and bar extension	None	Bank failure on outer edge of meander bend. Supplies sediment to delta downstream where main channel abuts southern bank	Neap 01/06/05 Spring 08/06/05	35.65 08/06/2005
15/06/2005 **16.12 BST**	w150605i		4.63	216.5	1.40	Continued increase in sinuosity as erosion continues on outside of meander bend	Secondary channel has migrated towards the north bank, increased in sinuosity and is infilling/ decaying.	Increase	Dominant channel migrates towards the north bank and increases in sinuosity.	Dominant channel and secondary channel migrating downstream.	None	Siltation of secondary channel	-	-
22/06/2005 **10.11 BST**	w220605i		3.55	227.8	3.13	Continued increase in sinuosity as erosion continues on outside of meander bend	Several channels capturing ebb flow and cutting across neck of meander loop	Increase	Accretion of a channel at the north bank feeding the dominant channel. Dominant channel subsequently fed from upstream by a low flow channel which is located at the south bank.	Small amount of downstream migration of dominant channel	None	Decay of upstream channel located at the north bank feeding the dominant channel.	Neap 17/06/05	35.46 19/06/2005

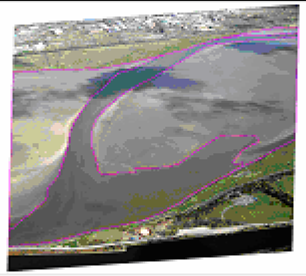
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
13/07/2005 **14.34 BST**	w130705i		3.35	313.5	0.85	New dominant channel across the centre of the bar. Course of main channel on preceding image now abandoned.	Secondary channel at north bank	Decrease	Notable change to previous image. Siltation/decay of the dominant channel. Accretion/amalgamation of two of the secondary low flow channels and development as the dominant channel. Flood intrusion channel runs parallel to southern bank	None	Capture of main flow by secondary channels	Infilling of abandoned channel	Spring 24/06/05 Neap 30/06/05 Spring 08/07/05	32.10 29/06/2005 51.11 05/07/2005 31.96 06/07/2005
	s130705i													
14/07/2005 **15.19 BST**	w140705i		4.35	251.8	0.92	As for w130705i	Decay of abandoned channel at north bank	Small increase	Flood intrusion channel runs parallel to southern bank	-	None	Secondary channel located at the north bank reactivated.	-	-
20/07/2005 **09.06 BST**	w200705i		8.29	288.3	2.30	As for w130705i	One secondary channel (formerly the dominant channel) at the north bank. Flood intrusion channel on south bank	Slight increase	The pattern of channels and bars remains the same, although some minor position and form changes.	Downstream migration of dominant and secondary low flow channels	None	Dominant channel widens	Neap 16/07/05	-
15/08/2005 **17.59 BST**	w150805i		3.88	296.3	1.81	Extends towards the centre of the estuary immediately downstream of Hempstones Point.	One secondary channel (formerly the dominant channel) located at the north bank. A further decaying secondary channel (dominant channel in previous image) located to the north of the	Decrease	Evidence that over a month, the dominant channel has decayed. The secondary channel at the neck of the meander bend in the previous image appears to have migrated towards	Migration of a secondary channel and development into a dominant channel.	Dominant low flow channel migrated towards the north bank, decayed and channel	Decay/siltation of formerly dominant channel	Spring 23/07/05 Neap 30/07/05 Spring07/08/05 Neap 05/08/05	32.86 28/07/2005 37.13 13/08/2005

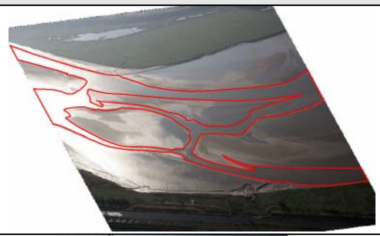
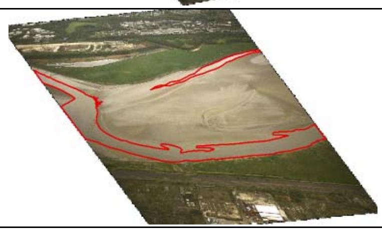
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
15/08/2005 **17.59 BST**	s150805i		3.88	296.3	1.81	Extends towards the centre of the estuary immediately downstream of Hempstones Point.	dominant channel.	Increase	the north bank and has become the dominant channel.		dominance switched to a former secondary channel located at the north bank which subsequently migrated towards the north bank.	Decay/siltation of formerly dominant channel	Spring 23/07/05 Neap 30/07/05 Spring07/08/05 Neap 05/08/05	32.86 28/07/2005 37.13 13/08/2005
16/09/2005 **08.54 BST**	w160905i s160905i	 	4.7	357.8	2.27	Extends towards the centre of the estuary immediately downstream of Hempstones Point.	Two secondary low flow channels located between the dominant channel and the north bank (both formerly dominant channels)	Increase	Scale of morphological activity is less than that seen in the previous month (20/07/2005 – 15/08/2005).	Some small-scale adjustments of channel locations visible.	None	Decay of low flow channels and widening of dominant channel.	Spring 05/09/05 Neap 28/08/05	31.33 25/08/2005 33.05 26/08/2005
21/09/2005 **12.25**	w210905i		3.35	201	3.52	Main channel occupies centre of estuary	Abandoned secondary channels – former location of main channel	Decrease	Several flood intrusion channels on major bar attached to southern bank. Growth in ebb channel delta where main channel abuts southern bank.	None	None	Erosion on outside of meander bend	Spring 20/09/05	-
03/10/2005 **10.23 BST**	w031005i		1.36	271	2.8	Main channel has moved towards the southern bank.	Three secondary low flow channels present. One inside and outside the dominant channel and a further	Increase	New main channel formed close to the southern bank. Former main channel now drains a small portion of	None	Yes - southwards migration of main channel to		Neap 27/09/05	41.61 28/09/2005 51.94 29/09/2005 86.28 30/09/2005 74.59 01/10/2005 33.54 02/10/2005

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
	s031005i						secondary low flow channel located at the north bank.		ebb flow. Flood intrusion channel visible (s031005i) along the southern bank, pushing upstream across the bar.		new location			
25/11/2005 **15.00 BST**	w251105i		5.49	327.2	1.09	New location abutting north bank.	Secondary channel at south bank.	-	Migration of dominant channel towards north bank. Abandoned flood levee / old bank line visible on s251105i – suggests evolution of channel to present position, rather than sudden avulsion.	Migration of dominant channel downstream towards the north bank.	None	Decay of two secondary low flow channels.	Spring 05/10/05 Neap 12/10/05 Spring 19/10/05 Neap 27/10/05 Spring 04/11/05 Neap 11/11/05 Spring 18/11/05 Neap 25/11/05	42.06 12/10/2005 39.85 13/10/2005 38.07 19/10/2005 43.71 21/10/2005 35.08 22/10/2005 45.81 23/10/2005 126.4 24/10/2005 122.5 25/10/2005 105.5 26/10/2005 73.83 27/10/2005 58.10 28/10/2005 46.08 29/10/2005 46.99 30/10/2005 35.91 31/10/2005 53.01 01/11/2005 79.53 02/11/2005 82.15 03/11/2005 112.1 04/11/2005 82.90 05/11/2005 105.3 06/11/2005 77.47 07/11/2005 116.4 08/11/2005 106.7 09/11/2005 90.87 10/11/2005 98.23 11/11/2005 80.66 12/11/2005 59.21 13/11/2005 58.2014/11/2005 58.20 15/11/2005 47.52 16/11/2005 37.83 17/11/2005 32.91 18/11/2005 33.78 19/11/2005 31.14 24/11/2005
	s251105i													

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
21/12/2005 **12.22 BST**	w211205i s211205i	 	5.5	258.1	1.13	Abutting north bank and increasing in sinuosity	Secondary channel present at south bank	Increase	Evolution of main channel from previous image. Main channel has meandered, and the point where it abuts the southern bank has moved upstream. During this process a new point bar has been created (visible on s211205i). Little or no evidence of previous dominant or secondary channels within bar structure north of Wigg Island.	Migration of dominant channel.	None	Bar deposition on inside of meander bend (on the left of image s211205i)	Neap 25/11/05 Spring 03/12/05 Neap 10/12/05 Spring 17/12/05	38.42 01/12/2005 51.88 02/12/2005 76.31 03/12/2005 112.8 04/12/2005 105.8 05/12/2005 94.75 06/12/2005 68.47 07/12/2005 59.91 08/12/2005 45.15 09/12/2005 47.55 10.12/2005 38.31 11/12/2005 35.04 12/12/2005
23/01/2006 **14.56 BST**	w230106i s230106i	 	4.67	163.7	1.08	Similar to 211205	Secondary low flow channel located at the south bank. Originates further upstream than the secondary low flow channel in 21/12/2005.	Increase	Similar morphological pattern to 21/12/2005. Small scale planform movements.	Downstream migration of dominant channel	None	None	Neap 25/12/05 Spring 02/01/06 Neap 08/01/06 Spring 16/01/06	40.18 22/01/2006 35.91 23/01/2006
20/02/2006 **13.18 BST**	w200205i		5.76	30	0.90	Dominant channel located towards the centre of the estuary and extends towards the north bank then meanders towards the south bank	Secondary low flow channel located at the south bank.		Similar broad morphological pattern to 23/01/2005.	Downstream migration of dominant channel.	None	None	Neap 24/01/06 Spring 31/01/06 Neap 07/02/06 Spring 15/02/06	32.50 24/01/2006 58.32 14/02/2006 97.49 15/02/2006 56.29 16/02/2006 57.28 17/02/2006 41.92 18/02/2006 34.54 19/02/2006 31.03 20/02/2006

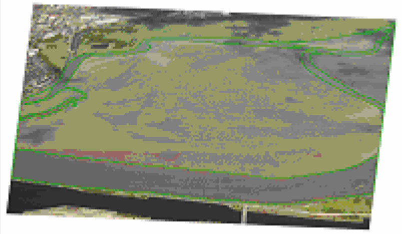
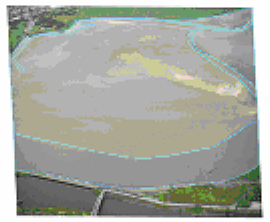
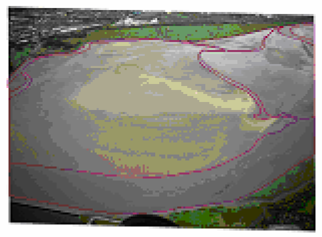
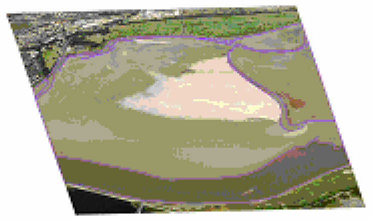
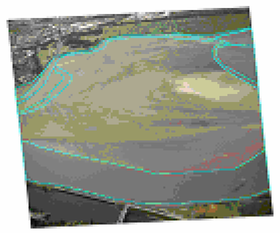
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
	s200205i													
28/02/2006 **09.04 BST**	s280206i		5.24	325.6	1.15	Dominant channel located towards the centre of the estuary and extends towards the north bank then meanders towards the south bank	Secondary low flow channel located at the south bank.		Similar broad morphological pattern to 20/02/2006.	Downstream migration of dominant channel.	None	None	Neap 03/02/06	30.94 21/02/2006 39.44 32/02/2006 63.86 24/02/2006 40.44 25/02/2006 33.74 26/02/2006 40.48 27/02/2006 45.04 28/02/2006
14/03/2006 **09.24 BST**	w140306i		3.85	170.9	1.16	Dominant channel located towards the centre of the estuary and extends towards the north bank then meanders towards the south bank	Secondary low flow channel located at the south bank.		Similar broad morphological pattern to 28/02/2006.	Downstream migration of dominant and secondary low flow channels.	None	Widening of secondary low flow channel	Spring 02/03/06 Neap 08/03/06	34.38 01/03/2006 30.43 02/03/2006 59.44 07/03/2006 105.8 08/03/2006 101.1 09/03/2006 116.6 10/03/2006 78.66 11/03/2006 56.47 12/03/2006 58.73 13/03/2006 75.74 14/03/2006
	s140306i													
14/04/2006 **14.04 BST**	w140406i		5.73	293.6	3.13	Dominant channel located towards the centre of the estuary and extends towards the north bank then meanders towards the south bank	Secondary low flow channel located at the south bank.		Similar broad morphological pattern to 14/03/2006. Flood intrusion channel very obvious on s140406i (running along southern bank), and into this a secondary ebb	Downstream migration of dominant low flow channel.	None	Decay/narrowing of secondary low flow channel	Spring 16/03/06 Neap 24/03/06 Spring 31/03/06 Neap 07/04/06 Spring 15/04/06	122.3 15/03/2006 82.20 16/03/2006 60.34 17/03/2006 48.9618/03/2006 41.05 19/03/2006 37.92 20/03/2006 33.62 21/03/2006 31.52 22/03/2006 37.83 24/03/2006 74.86 25/03/2006

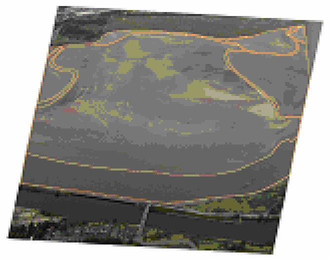
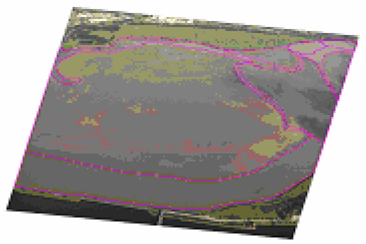
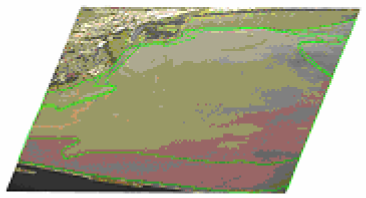
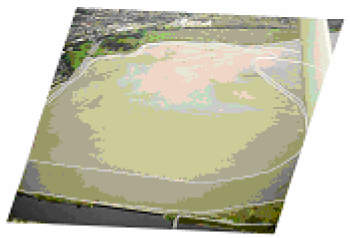
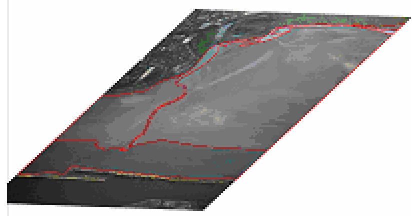
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
	s140406i								channel is building a small delta.					79.72 26/03/2006 95.57 27/03/2006 129.0 28/03/2005 100.9 29/03/2006 113.0 30/03/2006 94.94 31/03/2006 119.2 01/04/2006 113.9 02/04/2006 104.4 03/04/2006 67.26 04/04/2006 51.82 05/04/2006 51.65 06/04/2006 57.49 07/04/2006 76.56 08/04/2006 64.14 09/04/2006 50.75 10/04/2006 78.70 11/04/2006 50.63 12/04/2006 44.85 13/04/2006 37.50 14/04/2006
25/05/2006 **8:45 BST**			3.45	259.9	-	-	-	-	-	-	-	-	-	27.76
19/06/2006 **16:29 BST**			4.33	265.5	-	-	-	-	-	-	-	-	-	10.73
25/07/2006 **10:38 BST**			5.17	141.5	-	-	-	-	-	-	-	-	-	7.718
21/08/2006 **9:03 BST**			6.94	298.1	-	-	-	-	-	-	-	-	-	31.73

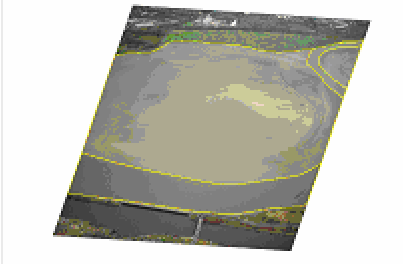
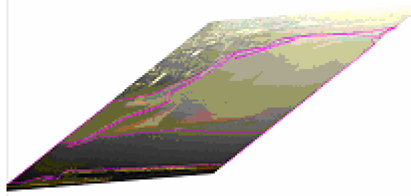
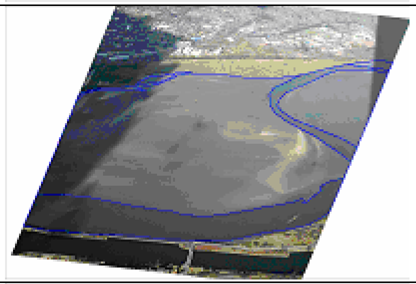
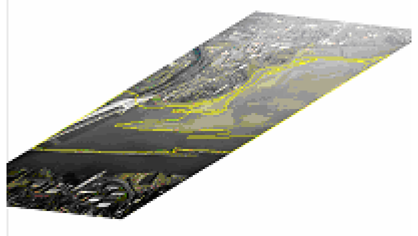
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
19/09/2006 **10:00 BST**			7.24	257.5	-	-	-	-	-	-	-	-	-	22.79
20/10/2006 **9:26 BST**			1.69	193	-	-	-	-	-	-	-	-	-	28.96
06/11/2066 **9:30 BST**			2.28	241.5	-	-	-	-	-	-	-	-	-	20.86
07/01/2007 **11:37 BST**			5.38	214	-	-	-	-	-	-	-	-	-	91.23
24/03/2007 **10:53 BST**			1.87	310.2	-	0.5	-	-	-	-	-	-	-	-
24/04/2007 **15-51 BST**			n/a	n/a	-	0.4	-	-	-	-	-	-	-	-

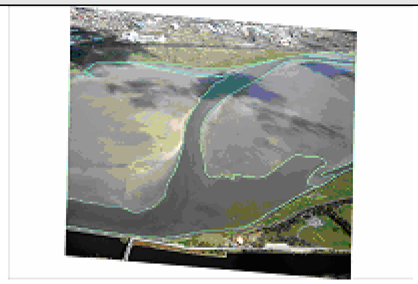
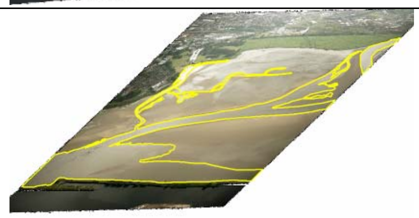
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (Degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
21/05/2007 13-38 BST			0	n/a	0.5	-	-	-	-	-	-	-	-	-

S3 – Runcorn Sands – Recording Channel Change
("-" means no data were available)

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
29/04/2005 **13.31 BST**	bp290405i		4.53	242.6	1.47	Located at the south bank. Stable bar in centre of estuary Abandoned channel traverses estuary from north to south at apex of Widnes Warth. Bedforms visible.	Located at north bank. Flood levee of northern channel visible	-	-	-	-	-	-	-
04/05/2005 **07.14 BST**	bp040505i		5.9	12.7	2.1	As 29/04/2005	As 29/04/2005	None	Little change. Bar remains stable. Sediment accreting immediately downstream of the abandoned channel.	None	None	None	Neap 03/05/05	39.46 30/04/2005 41.31 01/05/2005 37.98 02/05/2005 46.33 03/05/2005 34.53 04/05/2005
01/06/2005 **18.07 BST**	bp010605i		5.53	239.5	1.27	As 04/05/2005	As 04/05/2005	None	Shoaling evident in dominant channel. Abandoned channel accreting.	None	None	None	Spring 10/05/05 Neap 18/05/05 Spring 25/05/05 Neap 01/06/05	51.67 06/05/2005 69.62 07/05/2005 40.55 08/05/2005 33.96 09/05/2005 33.61 21/05/2005 36.65 22/05/2005 38.03 01/06/2005
13/07/2005 **14.34 BST**	bp130705i		3.35	313.5	0.85	As 01/06/2005	As 01/06/2005	None	Significant bar development immediately downstream of abandoned channel. Flood levee of secondary channel more pronounced than in 29/04/2005.	None	None	None	Neap 01/06/05 Spring 08/06/05 Neap 17/06/05 Spring 24/06/05 Neap 30/06/05 Spring 08/07/05	38.03 01/06/2005 35.65 08/06/2005 35.46 19/06/2005 32.10 29/06/2005 51.11 05/07/2005 31.96 06/07/2005
20/07/2005 **09.06 BST**	bp200705i		8.86	289	2.30	As 13/07/2005	As 13/07/2005	None	Erosion of bar.	None	None	None	Neap 16/07/05	-

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
15/08/2005 **17.59 BST**	bp150805i		3.88	296.3	1.81	As 20/07/2005	As 20/07/2005	None	Accretion of abandoned channel. Bedforms visible. Topographic high of bar partially inundated. Flood levee of secondary channel apparent.	None	None	None	Neap 16/07/05 Spring 23/07/05 Neap 30/07/05 Spring 07/08/05 Neap 15/08/05	32.86 28/07/2005 37.13 13/08/2005
19/09/2005 **11.08 BST**	bp190905i		4.56	202	3.99	As 15/08/2005	As 15/08/2005	None	Height of bar reduced.	None	None	None	Neap 15/08/05 Spring 21/08/05 Neap 28/08/05 Spring 05/09/05 Neap 13/09/05	31.33 25/08/2005 33.05 26/08/2005
21/09/2005 **12.25 BST**	bp210905i		3.35	201	3.52	As 19/09/2005	As 19/09/2005	None	Secondary channel braided at West Bank.	None	None	Cutting of braided secondary low flow channels	Spring 20/09/05	-
03/10/2005 **10.23 BST**	bp031005i		1.36	271	2.8	As 21/09/2005	As 21/09/2005	None	Loss of braiding of secondary channel at West Bank.	None	None	None	Neap 27/09/05	41.61 28/09/2005 51.94 29/09/2005 86.28 30/09/2005 74.59 01/10/2005 33.54 02/10/2005
25/11/2005 **15.00 BST**	bp251105i		5.49	327.2	1.09	As 03/10/2005	As 03/10/2005	None	Development of an ebb delta from the secondary channel at the north bank at Spike Island discharging into the dominant channel.	None	None	Cutting of an ebb channel	Spring 05/10/05 Neap 12/10/05 Spring 19/10/05 Neap 27/10/05 Spring 04/11/05 Neap 11/11/05 Spring 18/11/05 Neap 25/11/05	42.06 12/10/2005 39.85 13/10/2005 38.07 19/10/2005 43.71 21/10/2005 35.08 22/10/2005 45.81 23/10/2005 126.4 24/10/2005 122.5 25/10/2005 105.5 26/10/2005 73.83 27/10/2005 58.10 28/10/2005 46.08 29/10/2005 46.99 30/10/2005 35.91 31/10/2005 53.01 01/11/2005 79.53 02/11/2005 82.15 03/11/2005 112.1 04/11/2005

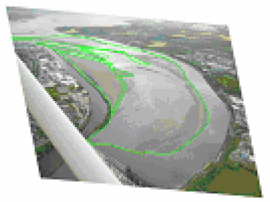
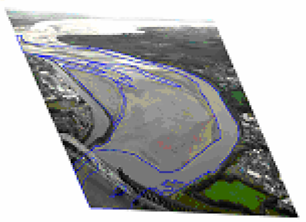
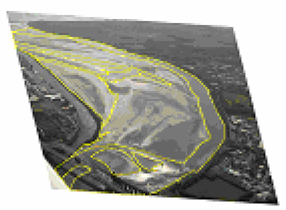
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
														82.90 05/11/2005 105.3 06/11/2005 77.47 07/11/2005 116.4 08/11/2005 106.7 09/11/2005 90.87 10/11/2005 98.23 11/11/2005 80.66 12/11/2005 59.21 13/11/2005 58.2014/11/2005 58.20 15/11/2005 47.52 16/11/2005 37.83 17/11/2005 32.91 18/11/2005 33.78 19/11/2005 31.14 24/11/2005
21/12/2005 **12.22 BST**	bp211205i		5.5	258.1	1.13	As 25/11/2005	Located at north bank, but much less pronounced than in 25/11/2005	None	Dominant channel in S2 observed as migrating towards the abandoned channel.	None	None	None	Neap 25/11/05 Spring 03/12/05 Neap 10/12/05 Spring 17/12/05	38.42 01/12/2005 51.88 02/12/2005 76.31 03/12/2005 112.8 04/12/2005 105.8 05/12/2005 94.75 06/12/2005 68.47 07/12/2005 59.91 08/12/2005 45.15 09/12/2005 47.55 10.12/2005 38.31 11/12/2005 35.04 12/12/2005
23/01/2006 **14.56 BST**	bp230106i		4.67	163.7	1.08	As 21/12/2005	Located at north bank, reactivated since 21/12/2005	None	Braiding of secondary channel at Spike Island. Movement of ebb channel to join dominant channel downstream.	None	None	Cutting of braided secondary low flow channels	Neap 25/12/05 Spring 02/01/06 Neap 08/01/06 Spring 16/01/06	40.18 22/01/2006 35.91 23/01/2006
20/02/2006 **13.18 BST**	bp200206i		5.76	30	0.90	As 23/01/2006	As 23/01/2006	None	Dominant channel in S2 has migrated to occupy location of abandoned channel.	Yes – dominant channel	None	None	Neap 24/01/06 Spring 31/01/06 Neap 07/02/06 Spring 15/02/06	32.50 24/01/2006 58.32 14/02/2006 97.49 15/02/2006 56.29 16/02/2006 57.28 17/02/2006 41.92 18/02/2006 34.54 19/02/2006 31.03 20/02/2006
14/03/2006 **09.24 BST**	bp140306i		3.85	170.9	1.16	As 20/02/2006	As 20/02/2006	None	Ebb channel delta orientated downstream	Migrating section of dominant channel not captured in image	None	None	Neap 23/02/06 Spring 02/03/06 Neap 08/03/06	34.38 01/03/2006 30.43 02/03/2006 59.44 07/03/2006 105.8 08/03/2006 101.1 09/03/2006 116.6 10/03/2006 78.66 11/03/2006 56.47 12/03/2006 58.73 13/03/2006 75.74 14/03/2006

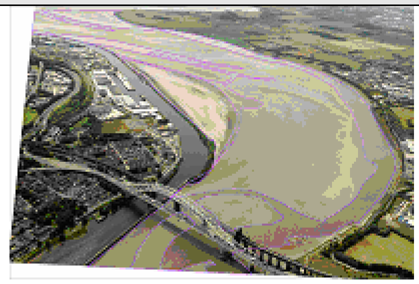
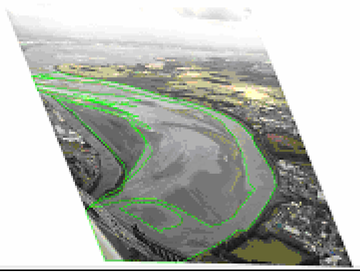
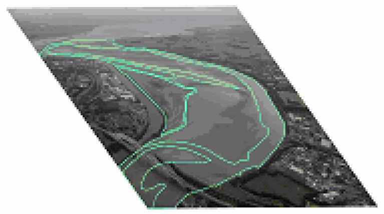
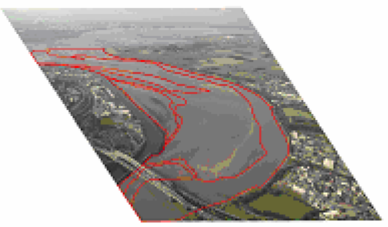
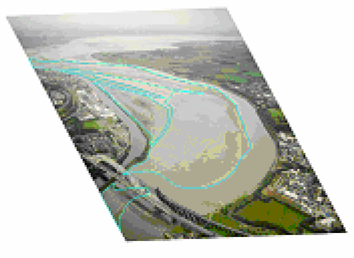
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
14/04/2006 **10.47 BST**	bp140406i		5.73	293.6	3.13	Dominant channel cuts across centre of estuary to the south bank	Secondary channel at north bank cut off from upstream flows by dominant channel	Increase	Downstream migration of dominant channel from S2.	Yes – dominant channel	None	None	Spring 16/03/06 Neap 24/03/06 Spring 31/03/06 Neap 07/04/06 Spring 15/04/06	122.3 15/03/2006 82.20 16/03/2006 60.34 17/03/2006 48.9618/03/2006 41.05 19/03/2006 37.92 20/03/2006 33.62 21/03/2006 31.52 22/03/2006 37.83 24/03/2006 74.86 25/03/2006 79.72 26/03/2006 95.57 27/03/2006 129.0 28/03/2005 100.9 29/03/2006 113.0 30/03/2006 94.94 31/03/2006 119.2 01/04/2006 113.9 02/04/2006 104.4 03/04/2006 67.26 04/04/2006 51.82 05/04/2006 51.65 06/04/2006 57.49 07/04/2006 76.56 08/04/2006 64.14 09/04/2006 50.75 10/04/2006 78.70 11/04/2006 50.63 12/04/2006 44.85 13/04/2006 37.50 14/04/2006
25/05/2006 **8:45 BST**			3.45	259.9	-	-	-	-	-	-	-	-	-	27.76
19/06/2006 **16:29 BST**			4.33	265.5	-	-	-	-	-	-	-	-	-	10.73
25/07/2006 **10:38 BST**			5.17	141.5	-	-	-	-	-	-	-	-	-	7.718
21/08/2006			6.94	298.1	-	-	-	-	-	-	-	-	-	31.73

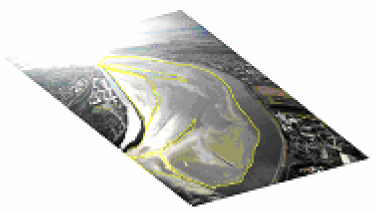
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
9:03 BST														
19/09/2006 **10:00 BST**			7.24	257.5	-	-	-	-	-	-	-	-	-	22.79
20/10/2006 **9:26 BST**			1.69	193	-	-	-	-	-	-	-	-	-	28.96
06/11/2066 **9:30 BST**		 2.28	241.5	-	-	-	-	-	-	-	-	-	-	20.86
07/01/2007 **11:37 BST**			5.38	214	-	-	-	-	-	-	-	-	-	91.23
24/03/2007 **10:53 BST**			1.87	310.2	0.5	-	-	-	-	-	-	-	-	-
24/04/2007 **15-51 BST**			0	n/a	0.4	-	-	-	-	-	-	-	-	-

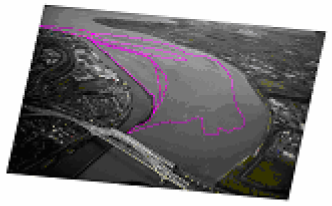
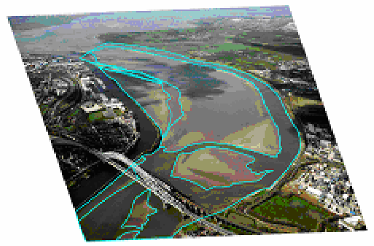
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
21/05/2007 13-38 BST			0	n/a	-	-	-	-	-	-	-	-	-	-

S4 – Silver Jubilee Bridge – Recording Channel Change
(“-” means no data were available)

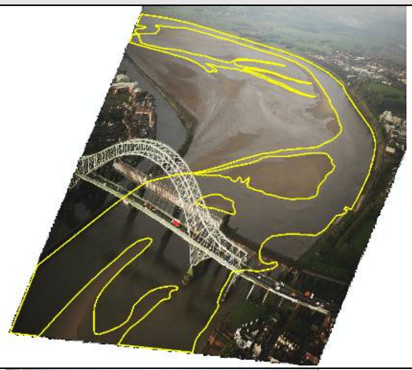
Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
04/05/2005 **07.14 BST**	sjb040505i		5.9	12.7	2.1	Dominant channel located at the south bank immediately upstream of the SJB, and flows towards the north bank immediately downstream of the SJB. Dominant channel follows the north bank downstream towards Hale Head	Secondary low flow channel cutting across the estuary from the centre of the channel to the downstream edge of stable point bar towards the south bank at Weston Point. Presence of a bedrock outcrop at the north bank	-	-	-	-	Levee on southern side of main channel.	-	-
12/05/2005 **12.38 BST**	sjb120505i		5.06	106.9	1.11	As 04/05/05	Flood intrusions over main bar. As 04/05/05	-	Same broad morphological pattern as 04/05/05. Bar beneath the railway bridge and SJB and immediately upstream of the SJB. Flood levee on southern side of dominant channel	None	None	Breaches in levee being cut on opposite side of estuary to Runcorn Docks.	Spring 10/05/05	39.46 30/04/2005 41.31 01/05/2005 37.98 02/05/2005 46.33 03/05/2005 34.53 04/05/2005 51.67 06/05/2005 69.62 07/05/2005 40.55 08/05/2005 33.96 09/05/2005
01/06/2005 **18.07 BST**	sjb010605i		5.53	239.5	1.27	As 12/05/05	As 12/05/05	-	As 12/05/05	None	None	Flood delta forming in main channel where incoming (flood) tide cuts main bar	Neap 18/05/05 Spring 25/05/05 Neap 01/06/05	33.61 21/05/2005 36.65 22/05/2005 38.03 01/06/2005
15/06/2005 **16.12 BST**	sjb150605i		4.63	216.5	1.40	Dominant channel meanders from south bank towards north bank immediately downstream of the SJB, bifurcates in the centre of the estuary.	Secondary low flow channel present at a breach of the flood levee.	-	Bifurcation of dominant channel. Mind-channel bar remains beneath the railway bridge and SJB, although downstream extent of bar has eroded, but appears wider. Sedimentation behind bedrock outcrop at north bank.	Dominant low flow channel immediately downstream of the SJB migrates downstream.	None	Bar migration. Breach in flood levee evident; secondary low flow channel continuous with dominant channel.	Neap 01/06/05 Spring 08/06/05	35.65 02/06/2005

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
13/07/2005 **14.34 BST**	sjb130705i		3.35	313.5	0.85	Dominant channel meanders from south bank towards north bank immediately downstream of the SJB, bifurcation has decayed.	As 15/07/05	-	Bifurcation no longer present, although broad morphological pattern is constant.	Downstream migration of dominant low flow channel.	None	Decay of a channel bifurcation; breach in mid-channel barrier island remains. Cuspate bar formed d/s of SJB	Neap 17/06/05 Spring 24/06/05 Neap 30/06/05 Spring 08/07/05	35.46 19/06/2005
20/07/2005 **09.06 BST**	sjb200705i		8.29	288.3	2.30	Downstream of SJB main channel cuts main bar from S to N	-	-	Same broad morphological pattern as 13/07/05. Increased sedimentation behind bedrock outcrop.	None	None	Breach in mid-channel barrier island remains.	Neap 16/07/05	-
15/08/2005 **17.59 BST**	sjb050805i		3.88	296.3	1.81	Downstream of SJB main channel cuts main bar from S to N	Secondary low flow channel present at a breach of the flood levee, but breach in flood levee appears to be aggrading.	-	Same broad morphological pattern as 20/07/05	None	None	Aggradation of breach in flood levee. Change in profile of levee from sinuous to straight. Erosion on outside of main channel downstream of SJB	Spring 23/07/05 Neap 30/07/05 Spring 07/08/05 Neap 15/08/05	32.86 28/07/2005 37.13 13/08/2005
19/09/2005 **11.08 BST**	sjb190905i		4.56	202	3.99	Main channel lies at north bank downstream of the SJB.	Decaying secondary channel downstream of SJB (this used to be main channel)	-	Dominant low flow channel beneath the Railway Bridges and SJB is more poorly defined in comparison to that of15/08/06.	None	None	Widening of dominant low flow channel at the north bank, Southwards movement of flood levee. Bedrock outcrop is submerged. Narrowing of mid-channel bar beneath SJB and Railway Bridge.	Neap 15/08/05 Spring 21/08/05 Neap 28/08/05 Spring 05/09/05 Neap 13/09/05	31.33 25/08/2005 33.05 26/08/2005
03/10/2005 **10.23 BST**	sjb031005i		1.36	271	2.8	As 19/09/05	As19/09/05	-	Dominant low flow channel beneath the Railway Bridges and SJB remains poorly defined, however bar remains present, although narrowed.	None	None	Further narrowing of bar beneath Railway Bridge and SJB.	Spring 20/09/05 Neap 27/09/05	41.61 28/09/2005 51.94 29/09/2005 86.28 30/09/2005 74.59 01/10/2005 33.54 02/10/2005

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
25/11/2005 **15.00 BST**	sjb251105i		5.49	327.2	1.09	Dominant channel now cuts obliquely across the main bar downstream of SJB	Shallow secondary channel across main bar	Increasing	As 03/10/05, however topographical high of flood levee is less well defined and the dominant low flow channel overspills towards the centre of the estuary.	Downstream migration of part of the dominant low flow channel immediately before it abuts the north bank.	None	Movement of mid-channel bar beneath Railway Bridge/ SJB towards the north bank.	Spring 05/10/05 Neap 12/10/05 Spring 19/10/05 Neap 27/10/05 Spring 04/11/05 Neap 11/11/05 Spring 18/11/05 Neap 25/11/05	42.06 12/10/2005 39.85 13/10/2005 38.07 19/10/2005 43.71 21/10/2005 35.08 22/10/2005 45.81 23/10/2005 126.4 24/10/2005 122.5 25/10/2005 105.5 26/10/2005 73.83 27/10/2005 58.10 28/10/2005 46.08 29/10/2005 46.99 30/10/2005 35.91 31/10/2005 53.01 01/11/2005 79.53 02/11/2005 82.15 03/11/2005 112.1 04/11/2005 82.90 05/11/2005 105.3 06/11/2005 77.47 07/11/2005 116.4 08/11/2005 106.7 09/11/2005 90.87 10/11/2005 98.23 11/11/2005 80.66 12/11/2005 59.21 13/11/2005 58.2014/11/2005 58.20 15/11/2005 47.52 16/11/2005 37.83 17/11/2005 32.91 18/11/2005 33.78 19/11/2005 31.14 24/11/2005
21/12/2005 **12.22 BST**	sjb211205i		5.5	258.1	1.13	Dominant channel actively cutting obliquely across the main bar downstream of SJB	No discernible secondary low flow channel	Increasing	Low flow channel patterns are similar to those observed on 30/07/05	Downstream migration of dominant low flow channel	None	Increase in development of mid-channel bar beneath the Railway Bridge/SJB. Possible flood intrusion channel forming under SJB	Neap 25/11/05 Spring 03/12/05 Neap 10/12/05 Spring 17/12/05	38.42 01/12/2005 51.88 02/12/2005 76.31 03/12/2005 112.8 04/12/2005 105.8 05/12/2005 94.75 06/12/2005 68.47 07/12/2005 59.91 08/12/2005 45.15 09/12/2005 47.55 10.12/2005 38.31 11/12/2005 35.04 12/12/2005
20/02/2006 **13.18 BST**	sjb200206i		5.76	30	0.90	The meandering dominant channel downstream of SJB has moved up-estuary	No flowing secondary channel, but bedforms visible on main bar imply coherent flow	Decreasing	Broad morphological pattern persists, however the bifurcation of the dominant low flow channel is replaced by a single, wide channel.	Dominant low flow channel migrated upstream of its previous location	Dominant channel was formerly bifurcated, then becomes one wide channel upstream of its former location.	Aggradation of breach in flood levee. Bedforms visible on main bar	Neap 25/12/05 Spring 02/01/06 Neap 08/01/06 Spring 16/01/06 Neap 24/01/06 Spring 31/01/06 Neap 07/02/06 Spring 15/02/06	32.50 24/01/2006 58.32 14/02/2006 97.49 15/02/2006 56.29 16/02/2006 57.28 17/02/2006 41.92 18/02/2006 34.54 19/02/2006 31.03 20/02/2006

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
28/02/2006 **09.04 BST**	sjb280206i		5.24	325	1.15	Delineation of low flow channels poorly defined by high water	Delineation of low flow channels poorly defined by high water	N/A	Dominant low flow channel remains at the north bank.	Delineation of low flow channels poorly defined by high water	Delineation of low flow channels poorly defined by high water	Delineation of low flow channels poorly defined by high water	Neap 23/02/06	30.94 21/02/2006 39.44 32/02/2006 63.86 24/02/2006 40.44 25/02/2006 33.74 26/02/2006 40.48 27/02/2006 45.04 28/02/2006
14/03/2006 **09.24 BST**	sjb140306i		3.85	170.9	1.16	Dominant channel now cuts obliquely across the main bar downstream of SJB	Secondary low flow channel present at a breach of the flood levee.	-	Broad morphological pattern similar, however secondary low flow channel present following a breach in the mid-channel barrier island.	None	None	Movement of mid-channel bar beneath Railway Bridge/ SJB towards the south bank.	Spring 02/03/06 Neap 08/03/06	34.38 01/03/2006 30.43 02/03/2006 59.44 07/03/2006 105.8 08/03/2006 101.1 09/03/2006 116.6 10/03/2006 78.66 11/03/2006 56.47 12/03/2006 58.73 13/03/2006 75.74 14/03/2006
14/04/2006 **10.47 BST**	sjb140406i		5.73	293.6	3.13	Dominant channel bifurcates before joining the north bank.	No discernible secondary low flow channel	-	Broad morphological pattern of meandering of dominant channel from the south bank to the north bank persists; however bifurcated dominant channel pattern is repeated.	Dominant low flow channel immediately downstream of the SJB migrates downstream.	None	Aggradation of breach in flood levee.	Spring 16/03/06 Neap 24/03/06 Spring 31/03/06 Neap 07/04/06 Spring 15/04/06	122.3 15/03/2006 82.20 16/03/2006 60.34 17/03/2006 48.9618/03/2006 41.05 19/03/2006 37.92 20/03/2006 33.62 21/03/2006 31.52 22/03/2006 37.83 24/03/2006 74.86 25/03/2006 79.72 26/03/2006 95.57 27/03/2006 129.0 28/03/2005 100.9 29/03/2006 113.0 30/03/2006 94.94 31/03/2006 119.2 01/04/2006 113.9 02/04/2006 104.4 03/04/2006 67.26 04/04/2006 51.82 05/04/2006 51.65 06/04/2006 57.49 07/04/2006 76.56 08/04/2006 64.14 09/04/2006 50.75 10/04/2006 78.70 11/04/2006 50.63 12/04/2006 44.85 13/04/2006 37.50 14/04/2006

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
25/05/2006 **8:43 BST**			3.45	259.9	-	-	-	-	-	-	-	-	-	27.76
19/06/2006 **16:29 BST**			4.33	265.5	-	-	-	-	-	-	-	-	-	10.73
25/07/2006 **10:39 BST**			5.17	141.5	-	-	-	-	-	-	-	-	-	7.718
21/08/2006 **9:03 BST**			6.94	298.1	-	-	-	-	-	-	-	-	-	31.73
19/09/2006 **10:00 BST**			7.24	257.5	-	-	-	-	-	-	-	-	-	22.79

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
20/10/2006 **9:26 BST**			1.69	193	-	-	-	-	-	-	-	-	-	28.96
06/11/2066 **9:30 BST**			2.28	241.5	-	-	-	-	-	-	-	-	-	20.86
07/01/2007 **11:37 BST**			5.38	214	-	-	-	-	-	-	-	-	-	91.23
24/03/2007 **10:53 BST**			1.87	310.2	0.5	-	-	-	-	-	-	-	-	-

Date and time of image	Image reference	Thumbnail (tracing)	Wind speed ms^{-1}	Wind direction (degrees)	Tide gauge level (m) at Old Quay Lock	Main Channel Location and Activity	Secondary Channel Location and Activity	Change in sinuosity of dominant channel (increase/decrease)	Change in morphology from previous date (e.g. no. or location of low flow channels or bars; infilling, cut-off and decay)	Migration	Avulsion/ Switching	Other (bank failure; scour; channel widening; siltation)	Nature of tides between current and preceding image	Above/below average fluvial flows between current and preceding image (average mean daily flow 30.34 m^3/sec)
24/04/2007 15-51 BST			0	n/a	0.4	-	-	-	-	-	-	-	-	-
21/05/2007 13-38 BST			0	n/a	0.5	-	-	-	-	-	-	-	-	-