THE MERSEY GATEWAY PROJECT

HYDRODYNAMICS AND ESTUARINE PROCESSES

CHAPTER 7.0

HYDRODYNAMICS AND ESTUARINE PROCESSES

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7. HYDRODYNAMICS AND ESTUARINE PROCESSES

7.1 Introduction

7.1.1 The Project has the potential to change the way that water moves around within the Mersey Estuary (hydrodynamic regime). This arises due to the placement of the bridge piers and towers in the Estuary and from temporary structures embedded in the Estuary during construction. The Project has the potential to affect current speeds and direction, water levels, the duration of slack water and tidal propagation within the Estuary system.

7.1.2 The hydrodynamics and morphology of an estuary are permanently joined in an iterative relationship. The flow of water around an estuary provides the force which moves sediment and consequently alters the form and shape of an estuary. Simultaneously however, the form and shape of an estuary direct and influence the flow of water. The non-uniformity of sediment within an estuary and the variable characteristics of water movement, dictated for example by tides and fluvial events, create a dynamic system in which channel movement and flow patterns are always changing in a complex relationship. Thus any changes in the flow pattern, or hydrodynamics, caused by the construction of a bridge or subsequently during its operational life, will be seen in physical changes in the morphology of an estuary. The degree of this change will depend on the forces involved and the chaotic nature of the influences on the estuary.

7.1.3 It is through this mechanism that the potential exists for effects on the Silver Jubilee Bridge (SJB), the railway bridge, the saltmarsh edges, the Special Protection Area (SPA) downstream of Runcorn Gap, the Manchester Ship Canal and other nearby structures.

7.1.4 Changes to the hydrodynamic regime of the Estuary could give rise to potential effects on a number of receptors, for example changes to the integrity of the saltmarsh could affect ecology and landscape. A change in the hydrodynamics or morphology of the Estuary itself has no intrinsic positive or negative value. This assessment comes when the impact of the change is considered upon relevant receptors. Consequently hydrodynamics and estuarine processes of the estuary have been assessed as pathways. The outcomes of this assessment inform other assessments reported in this ES. It is in these other assessments that the effects of the Project are assessed and implications for mitigation measures identified. The work described in this Chapter and the appended detailed reports provides data for the following Chapters:

a. Terrestrial and Avian Ecology;
b. Aquatic Ecology;
c. Surface Water Quality;
d. Landscape and Visual Amenity;
e. Contamination of Soils, Sediments and Groundwater; and
f. Navigation.

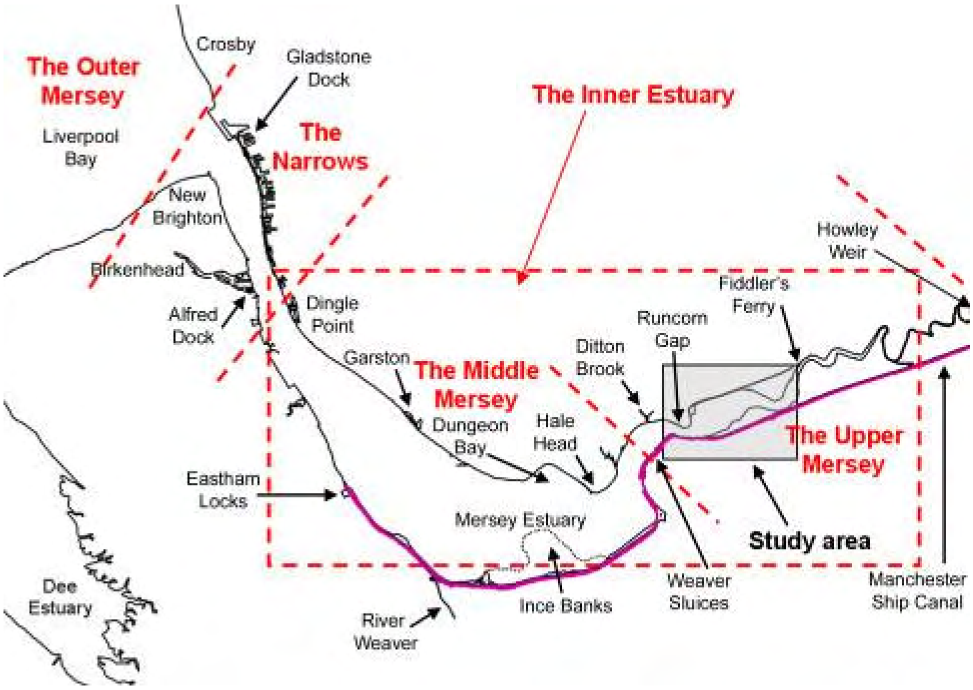
7.1.5 This Chapter describes the existing environment of the potentially affected areas with respect to the morphological and hydrodynamic regime and assesses the predicted effects of the construction and operation of the Project on the various aspects of this regime.

7.1.6 Objectives of this Chapter are:

a. To provide a baseline for estuarine morphology and hydrodynamic processes so that potential changes can be identified and used for assessment and monitoring; and
b. To evaluate the likely significant environmental changes to the baseline characteristics from the construction and continued presence of the structures of the New Bridge (piers and towers) in the Estuary.

7.1.7 The baseline will consider the whole Estuary in outline, but will focus in detail on the Study Area as shown in Figure 7.1. This baseline assessment will include an investigation of the changes in morphology due to naturally occurring events in order to place any changes predicted from the Project in the context of the magnitude and rate of natural changes.

Figure 7.1 - The Mersey Estuary



7.1.8 This Chapter aims to determine the effects of the New Bridge on:

a. Flood defences;
b. Intertidal areas and saltmarshes;
c. The characteristic dynamic nature of the Estuary, in particular the frequent migration of low water channels;
d. The potential for channels to ‘attach’ (remain permanently located next) to structures within the Estuary and thus change the chaotic character of sediment movement within the Study Area;
e. The SPA and Ramsar site downstream of Runcorn, designated due to the large areas of saltmarsh and extensive intertidal sand- and mud-flats which provide feeding and roosting sites for large populations of waterbirds; and
f. Existing structures, in particular the Manchester Ship Canal and the existing bridges at the Runcorn Gap.

7.1.9 In addition, estimates are made of the potential for scour around the proposed structures of the New Bridge and the effect this may have on channel migration and the adjacent saltmarsh edges.

7.1.10 This Chapter also considers the implications of the hydrodynamic regime on the construction methods which may be used and for certain elements of the design for the New Bridge and its approaches.

7.1.11 This Chapter makes no attempt to identify whether changes to the hydrodynamic regime and associated morphological effects are in themselves positive or negative. This Chapter simply identifies those elements of the estuarine environment which will undergo change and states whether these changes are significant in comparison to natural changes occurring within the Estuary.

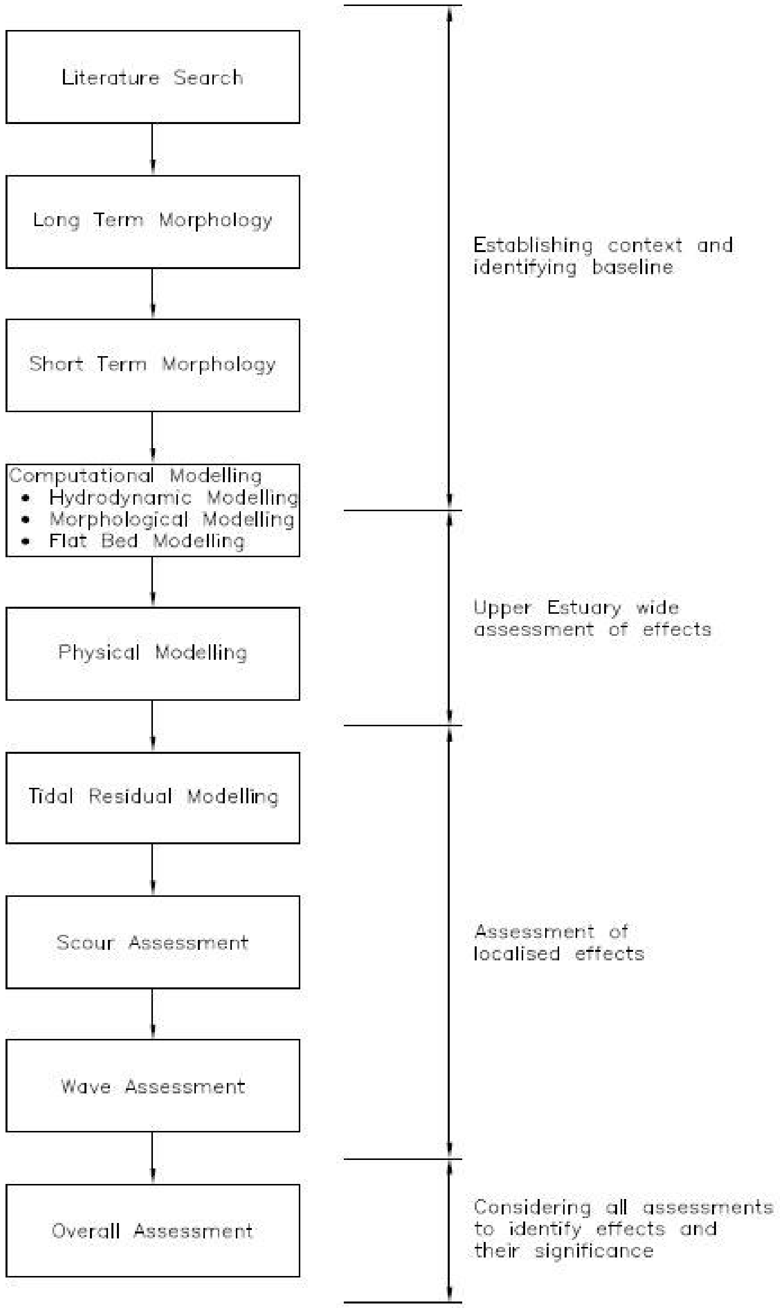
Structure of this Chapter

7.1.12 A number of methods have been used to investigate the existing nature of the Estuary and the possible effects of the New Bridge. Within this Chapter each method is discussed separately for clarity. However it is important to understand that each method provides different aspects of the overall assessment, with some methods identifying the baseline while others look at some aspect of the effect of the New Bridge. The different methods used and their purposes are briefly identified below together with the Section of this Chapter in which they can be found. Diagram 7.1 shows this in a graphical form.

a. Literature Search: A search for background information on the Estuary, structures constructed in similar tidal situations within estuaries with a highly mobile bed and specific impacts associated with scour. This information was used to prepare Section 7.3 and is referred to, as necessary, throughout the assessment;
b. Long Term Morphology. Assessment of the patterns of channel movement based on historic records and published information. This information was collected to set the assessment in context and assist in providing the baseline (see Section 7.4);
c. Short Term Morphology: Assessment of the patterns of channel movement based on information gathered during this study. This data again provides detail of the existing situation to assist with establishing the baseline (see Section 7.5);
d. Computational Modelling: Modelling of the existing and proposed situations to identify existing values for water velocities, water levels, bed shear stress, erosion of bed material and deposition of bed material in the Upper Estuary and the effects of the New Bridge on these. This modelling establishes a baseline position and then identifies the hydrodynamic and morphological changes that result from the construction and operation of the New Bridge. This was done by running hydrodynamic models of the estuary for a given scenario of tidal and fluvial flows with and without the presence of the New Bridge structure or the temporary construction structures. The results were compared and the *differences* in predicted values of the set of chosen parameters were noted. These differences form the basis of the assessment. As a continuation of this work, a flat bed model was used to verify that the model could reasonably reflect the formation of channels typically seen within the estuary and to investigate the likelihood of channels attaching to the new structure (see Sections 7.6 to 7.9);
e. Tidal Residual Modelling: The residuals within the hydrodynamic computational model were used to assess the effects of the shape of the tower structure and the spacing of these structures on the potential for channel realignment and attachment. (see Section 7.10);
f. Local Scour: Estimating scour local to the bridge towers using published formulae and output from physical modelling carried out by University College, London to assist in identifying the localised effects of the New Bridge(see Section 7.11);
g. Physical Modelling of Estuary: This was undertaken to assist in understanding of estuarine processes within the Study Area and compare observations of the physical model with the findings of the computational modelling (see Section 7.12); and
h. Wave Action: Investigating the extent of wave action and the likely effect on any changes to the morphology that wave action may cause (see Section 7.13).

7.1.13 The results from all the different investigations have then been considered together to assess the effects of the New Bridge and provide details of management and monitoring requirements and conclusions (see Sections 7.14 to 7.16).

Diagram 7.1 Process Used to Investigate Hydrodynamic and Estuarine Processes



7.2 Project Description

7.2.1 The Project involves a large number of structures and engineered aspects across a wide area. However, only the construction of the New Bridge and its approaches has any relevance to a consideration of the hydrodynamics and morphology of the Estuary. Further details of all the construction proposals are given in the Construction Methods Report (Appendix 2.1). Although there are changes proposed to the use and approaches of the SJB, there are no changes to the footprint of the structure within the Estuary and therefore there will be no effects on the hydrodynamic regime resulting from this.

7.2.2 The supports for the permanent bridge structure will comprise three circular towers each about 10m in diameter, located in the intertidal part of the Estuary in the Study Area and thirty rectangular plate bridge piers each about 5m x 2m located on the saltmarsh areas.

7.2.3 The towers will be founded on a base of about 24m diameter base set at a level beneath the predicted depth of scour. In order to construct this, a temporary 30m diameter cofferdam will be formed at each tower location.

7.2.4 In addition, it is proposed that for the construction phase of the permanent works, an aligned temporary jetty will be constructed parallel to the New Bridge. This will cross the Estuary from the north saltmarsh to the location of the central tower cofferdam. A separate similar temporary jetty will be constructed from the south saltmarsh to provide access to the position of the southern tower.

7.2.5 At each tower position, two short, finger jetties will be constructed from the aligned jetty to provide access to each side of the cofferdam.

7.2.6 The temporary jetty structure will consist of piles of about 500mm diameter piles at about 5m centres with about 12m between each pair of piles. The deck will be set at a level such that the soffit will provide some freeboard to the highest extreme tide thus ensuring that the deck does not impact on the tidal flows within the Estuary.

7.2.7 A temporary piled structure will also be needed to carry a crane for the construction of each tower. This will be positioned in the Estuary in-line with the cofferdam in the ‘normal’ direction of flow of the nearest channel so that the impact of the additional piling will be masked by the effects stemming from the tower cofferdam.

7.2.8 Access across the saltmarshes will be provided from a temporary stone causeway formed on the surface of the saltmarsh. It will be constructed to a level to provide access during all but the highest spring tides. This will connect to the aligned jetty.

7.2.9 Each of the approach piers within the saltmarshes would require a cofferdam of about 12m x 14m rectangular cofferdam. It has been assumed that the maximum number of piers under construction at any one time would be six and that these would each take three months to complete. It is possible that the temporary structures required for the construction of the towers will be in place for a period of up to two years duration.

7.2.10 All of the temporary structures will be completely removed when these are no longer needed for the construction of the works. Any re-instatement works will then be undertaken.

7.2.11 Hover platforms may also be used to deliver materials to the construction site. However, these have no impact on the hydrodynamics of the Estuary and will not be considered further in this Chapter.

7.3 Description of the Mersey Estuary and the Study Area

Location

7.3.1 The Estuary is sited on the northwest coast of England north and east of the Dee estuary (Figure 7.1). The Estuary extends from Liverpool Bay at the mouth, to the tidal limit at Howley Weir (Warrington), some 48km upstream. The River Mersey is one of five main river systems draining Northern England (Ref. 1).

Palaeohydrological Context

7.3.2 It is generally accepted that the major drainage alignment of the Estuary developed during the Tertiary period. The modern river has developed since the retreat of the Devensian ice sheet between 16,000 and 14,000 Before Present (BP) and is, therefore, of late Pleistocene age. In the early Holocene (circa 7000-5000 BP) post-glacial temperate climates meant that the land surface of the Mersey catchment became colonised by deciduous woodland, leading to stabilisation of a previously unstable landscape. However, the increasing influence of man led to deforestation in the later Holocene, with woodland becoming replaced with open moorland vegetation types, (Ref. 2). Finally, during historic times, rich oak woodlands in the lowland part of the catchment were replaced with agricultural land.

7.3.3 Adjustment to Holocene water and sediment regimes led to the incision of Pleistocene glacial and periglacial deposits, with the formation of terraces in parts of the catchment (Ref. 3). The Estuary itself was formed about 5000 BP as sea levels rose to their near present levels. Sediments were transported to the Estuary, particularly from the uplands.

7.3.4 The geology underlying the Estuary is alluvium overlying Glacial Till, which in turn overlies Bunter Upper Mottled Sandstone and/or Pebble Beds of the Triassic System (Ref. 4). The mouth of the Estuary is constrained by the underlying bedrock. The southern coastal zone between the Estuary and the Dee estuary is composed of a low-lying alluvial plain, much of which was formerly marshland, whilst the northern coastline has an extensive sand dune system extending from Crosby northward (Ref. 5).

7.3.5 The Estuary has an unusual bottle-shaped plan-form, with a narrow deep entrance channel (the Narrows), owing its existence to the underlying geology. This opens into a shallow wide inner basin of shifting banks and channels, which in turn leads, via a further narrowing at Runcorn Gap, to a meandering river stage further upstream.

Characteristics of Sections of the Estuary

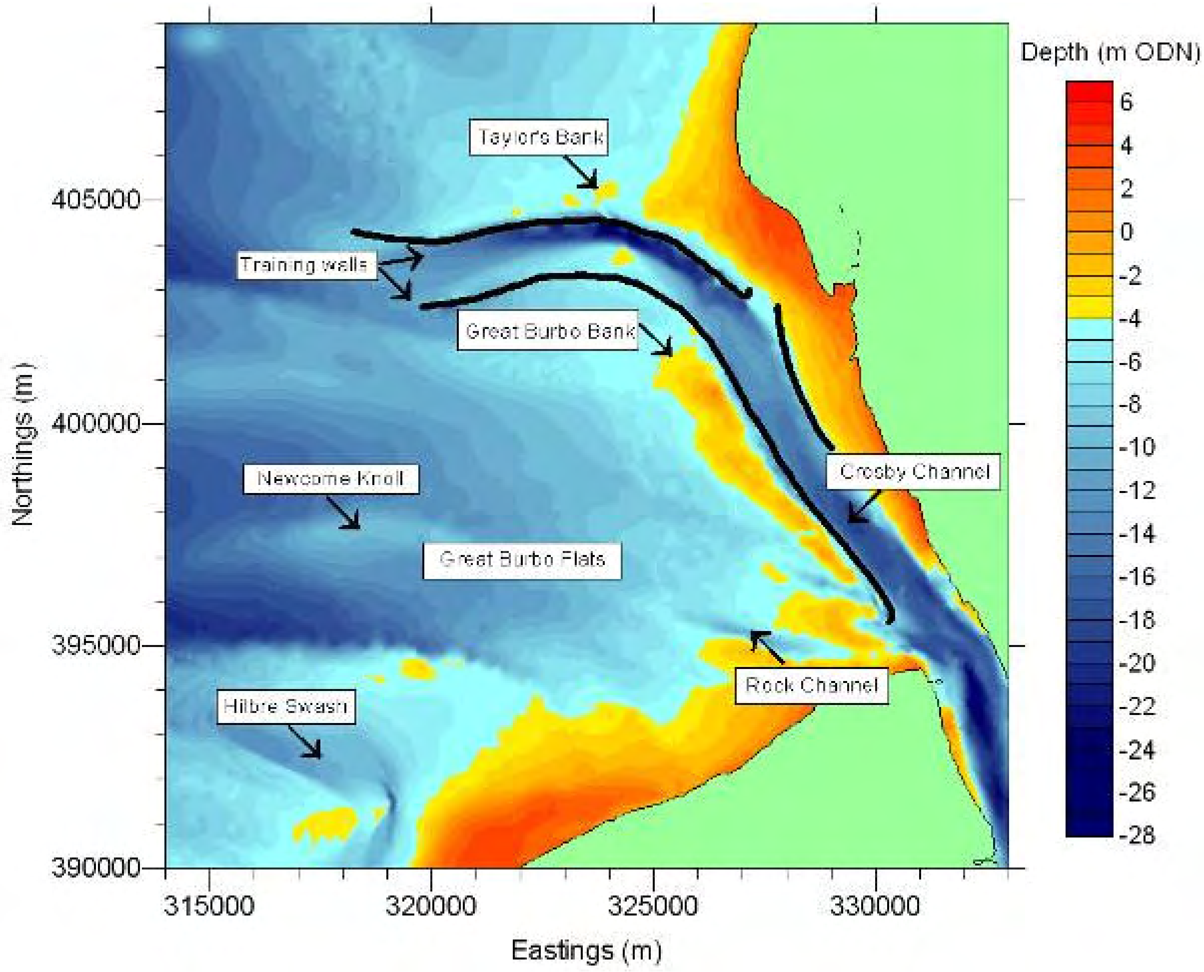
7.3.6 The Estuary can be divided into four regions (Figure 7.1):

a. The Outer Mersey (New Brighton to the seaward extent of the Training Walls);
b. The Narrows (Dingle Point to New Brighton);
c. The Middle Mersey (Hale Head to Dingle Point);
d. The Upper Mersey (Howley Weir to Hale Head), (which includes the Study Area).

The Outer Mersey (the seaward extent of the Training Walls to New Brighton)

7.3.7 As can be seen from Figure 7.2, the Outer Mersey is characterised by a trained channel, which crosses a region containing a number of sand banks. The Outer Mersey will not be discussed in detail within this report as no effects from the Project extend this far.

Figure 7.2 - Characteristics of the Outer Mersey Estuary



The Narrows (New Brighton to Dingle Point)

7.3.8 At the mouth of the Estuary near Liverpool, the 'Narrows' represent a geological constraint to the Estuary system, with the bedrock preventing any further expansion of the channel. The Narrows stretch for about 10km, have a width of approximately 1 km, a mean depth of 15m and some depths in excess of 20m. The Narrows are subjected to high tidal currents, which can exceed 3m/s, and scour the bed down to rock and gravel.

The Middle Mersey (Dingle Point to Hale Head)

7.3.9 The Middle Mersey has similar characteristics to the Upper Mersey, consisting predominantly of intertidal banks, composed of sand/silt, with saltmarshes on the surrounding shores. This area is designated as a Special Protection Area (SPA), Site of Special Scientific Interest (SSSI), Ramsar Site and European Marine Site. At low tide this reach almost completely dries out due to the large tidal range. There are typically three channels that meander through this reach.

7.3.10 Many of the Estuary's major freshwater sources enter the Middle Mersey adding to the already complex channel flow patterns. On the north bank, Ditton Brook enters the Estuary just downstream of the SJB. On the south bank, the Manchester Ship Canal and the River Weaver enter the Estuary at Weaver Bend via the Weaver Sluices. The Weaver Sluices only operate when water levels in the river/canal system exceed a certain level. The discharge from the sluices flows around Ince Banks into the Estuary. The resulting flow predominantly travels down the northern Garston Channel. Pye and Van de Wal (Ref. 6) suggest that the northern Garston Channel and the Middle Mersey channels have a tendency to switch in dominance periodically. The River Gowy enters the Estuary on the downstream side of Ince Banks, and flows down the southern Eastham Channel where it joins water entering from the Manchester Ship Canal via Eastham locks.

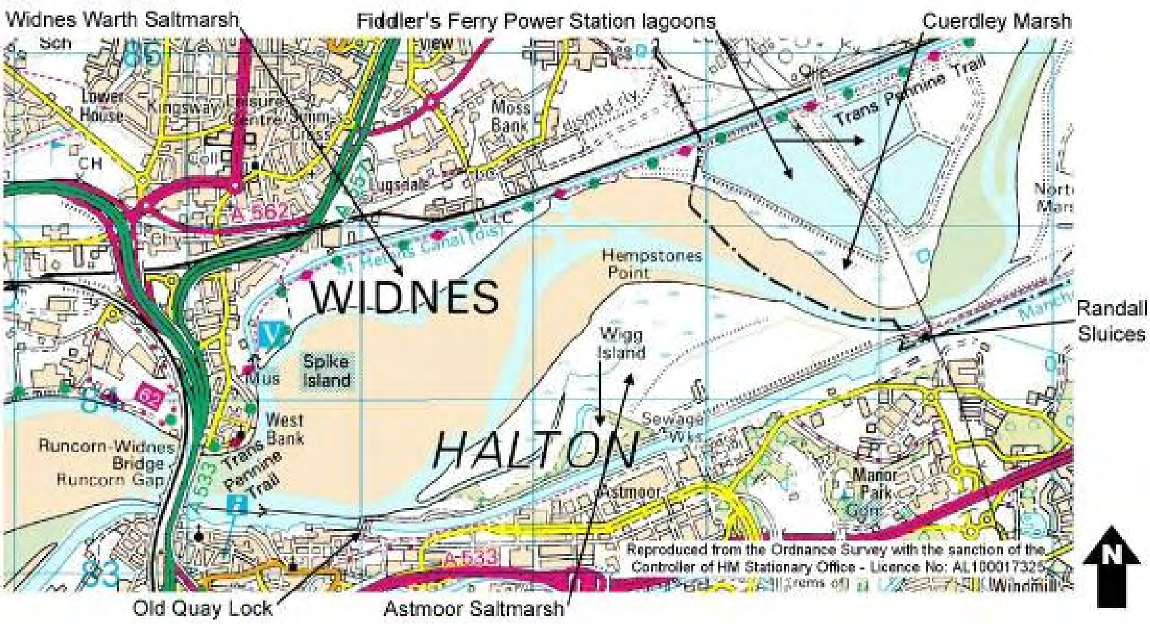
The Upper Mersey (Hale Head to Howley Weir)

7.3.11 The upstream end of the Upper Mersey is Howley Weir, which is the tidal limit of the Estuary. The Upper Mersey consists of a highly mobile sand/mudflat area, parts of which are exposed in all but the highest tides. The whole area is relatively shallow in depth and is periodically reworked by actively migrating low water channels. The tidal cycle is significantly affected by the geological formation that creates the Runcorn Gap constriction. The majority of the north and south banks are covered with saltmarshes, which are only inundated at times of peak tides.

7.3.12 The Study Area for the New Bridge falls within the Upper Mersey approximately 31km from the mouth of the Estuary to 10km downstream from the tidal limit. It is situated between Runcorn Gap (with the SJB) in the west and the Fiddler's Ferry in the east. The town of Runcorn is located to the south of the area, whilst Widnes lies to the north.

7.3.13 The Study Area is characterised by the chaotic movement of channels, sand bars and intertidal banks. These features change on each tide and, on occasion, the changes can be substantial. There are two areas of intertidal saltmarsh habitat; Astmoor Saltmarsh and Cuerdley Marsh, which lie on the southern and northern banks respectively. The majority of Cuerdley Marsh has been reclaimed and now sites Fiddler's Ferry Power Station Lagoons. The intertidal area is classified as a Grade A Site of Biological Importance (SBI). It includes the Astmoor Saltmarsh, Widnes Warth Saltmarsh, St Helens Canal, Fiddler's Ferry Power Station lagoons and Cuerdley Marsh (Figure 7.3).

Figure 7.3 - Study Area for the New Bridge



Tidal Cycle

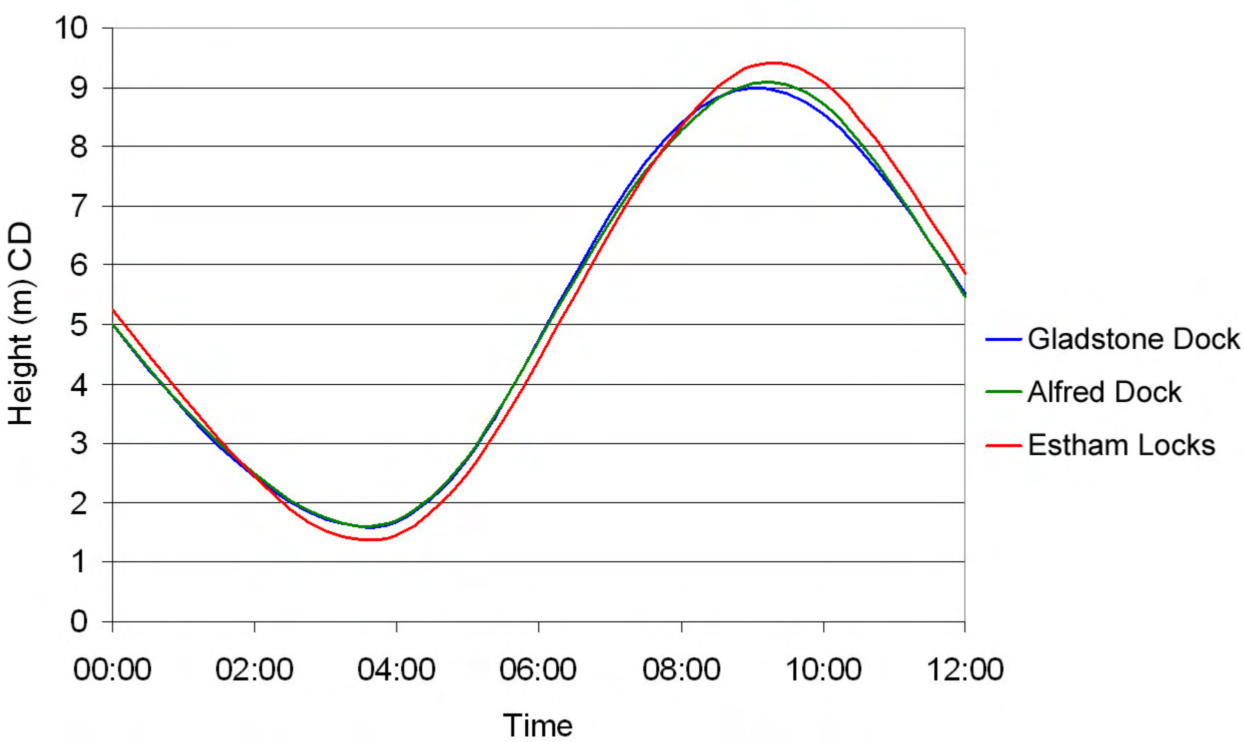
7.3.14 The Estuary is subject to a semi-diurnal macrotidal regime, and has one of the largest tidal ranges in Britain. The mean spring tide range is 9m at Eastham, decreasing to 4.5m at Widnes, and 2.9m at Fiddler's Ferry. The tide gauge at Widnes indicates a tidal range of 4.5m during spring tides, and 2.6m during neap tides. At low water, much of the area dries and flow in the channels is dominated by seaward flowing fluvial water.

7.3.15 Analysis of the seven tidal gauges in the Estuary (Table 7.1) illustrates that from the Narrows moving upstream to Eastham, there is a tidal amplification effect, which increases tidal range. This amplification effect is illustrated in Figure 7.4 using three datasets from the three tidal gauges situated in the Narrows.

Table 7.1 - Tidal Data Obtained from Admiralty Charts (Chart 1 and Chart 2)

Place	Distance from Mouth (km)	Lat.	Long.	Height in m above Chart Datum		Height in m above Chart Datum		Datum relative to ODN
		N	W	MHWS	MHWN	MLWN	MLWS	
Gladstone Dock	0	53°27'	3°01'	9.2	7.3	2.9	0.8	- 4.93m
Liverpool (Alfred Dock)	5	53°24'	3°01'	9.3	7.4	2.9	0.9	- 4.90m
Eastham	12	53°19'	2°57'	9.6	7.5	2.8	0.6	- 4.93m
Hale Head	21	53°19'	2°48'	6.9	4.9	-	-	- 2.00m
Widnes	26	53°21'	2°44'	5.1	3.0	0.4	0.6	0.00m
Fiddler's Ferry	31	53°22'	2°39'	3.4	1.1	0.5	0.5	2.00m
Warrington	38	53°23'	2°36'	2.7	-	-	-	2.90m

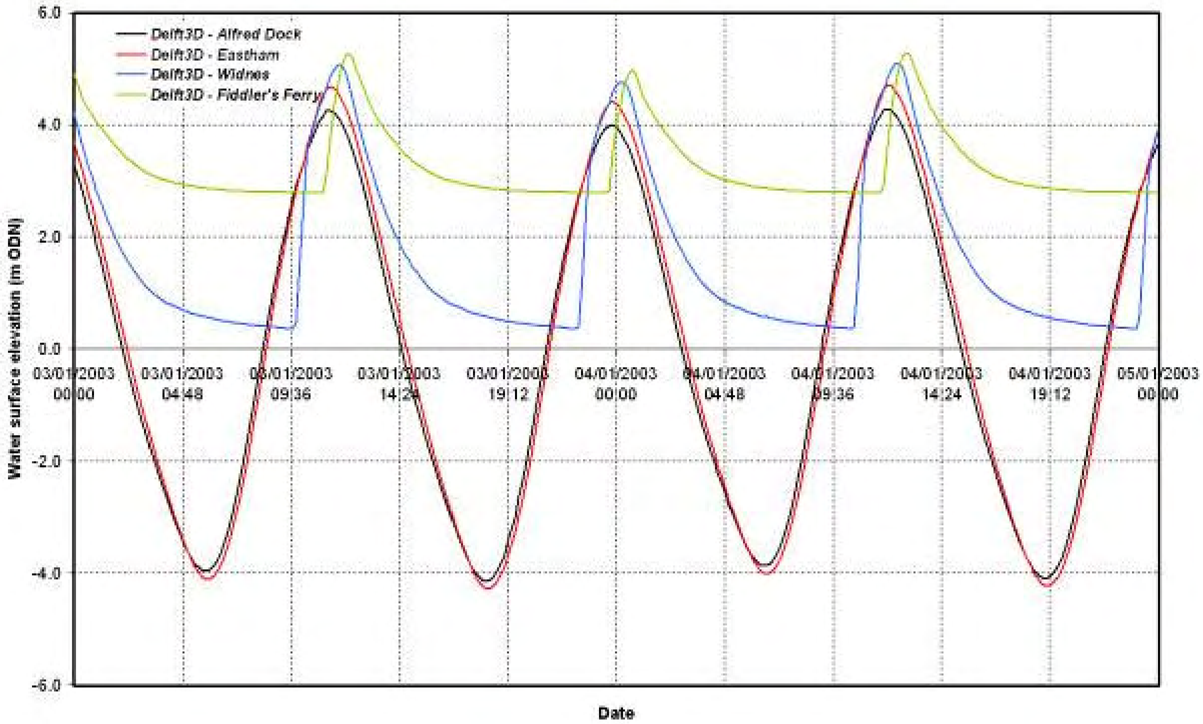
Figure 7.4 - Tidal Amplification



7.3.16 The Estuary is generally flood dominant with the ebb having a slightly longer phase compared to the flood. At Liverpool the ebb is 6.75 hours, whilst the flood is 5.5 hours. However, previous work indicates that the Estuary may be becoming less flood dominant overall, showing an increased tendency to ebb dominance towards the mouth, whilst becoming more flood dominant in the Inner reaches (Ref. 7).

7.3.17 The narrowing of the Estuary at Runcorn Gap contributes to a significant change in the tides within the Study Area. The tidal cycle has a pronounced asymmetry; the flood tide filling the Upper Estuary in approximately 2 hours, whilst the ebb tide takes approximately 10 hours to retreat. This is demonstrated in Figure 7.5.

Figure 7.5 - Changes in tide elevation along the Estuary



Tidal bore

7.3.18 The tidal bore on the River is most prominent when very high tides are expected, (above 10 metres CD at Liverpool), which occurs on only a few days each year. However, lower tides can produce tidal bores if other factors are favourable such as a period of dry weather reducing fresh water flow in the rivers. The River bore may be seen opposite Hale Point about 2hr 25 min before HW Liverpool. From the park at Widnes West Bank it may be seen passing under the Runcorn road and rail bridges about 1hr 50min before HW Liverpool. Under good conditions the bore may be seen as far as Warrington passing under the rail bridge south of Bank Quay station about 20 min before HW Liverpool. It passes rapidly upstream and arrives at Howley Weir just before HW Liverpool.

Fluvial Inputs

7.3.19 For its size, the Estuary has a relatively low freshwater input. A typical freshwater flow from the River is 66m^3/s whilst the tidal influx into the Narrows is 2000m^3/s during a spring tide (Ref. 8).

7.3.20 Table 7.2 displays the modal flow in the main freshwater inputs to the Estuary. However, these freshwater flows vary seasonally from 25 - 200 m^3/s (Ref. 9), with flood flows exceeding 1200 m^3/s (Ref. 10).

Table 7.2 - Modal flows for Fresh Water Inputs to the Estuary (from Ref. 11)

Fresh Water Input	Modal Flow m^3/s
Mersey (at Westy)	37.22
Weaver (at Pickerings Cut)	16.55
Sankey Brook (at Causey Bridge)	2.61
Ditton Brook (at Greens Bridge)	1.38
River Gowy (at Picton)	1.23
Total	**58.99**

Mixing of salt water and fresh water within the Estuary

7.3.21 The Mersey is a well-mixed estuary due to high tidal current velocities and relatively low freshwater inputs. Prandle & Lane (Ref. 9) calculated the mean flow ratio (volume of freshwater flow × 12.42 hr / volume between low and high water) of approximately 0.01, indicating well-mixed conditions. However, Prandle & Lane (Ref. 9) also state that in certain sections during part of the tidal cycle, the Estuary may become partially mixed.

Estuary Form

7.3.22 A number of the Estuary properties are summarised in Table 7.3.

Table 7.3 - Summary of the Estuary Properties

Property	Values for the Mersey
Lengths from mouth of Estuary[1]	To Runcorn Sands[2], 33km; to tidal limit at Howley Wier, 48km.
Volumes[3]	Total volume at MHW = 881 Mm^3 Total volume at MLW = 164 Mm^3 Total volume at MTL = 392 Mm^3
Widths and depths	Width of the Narrows = 1.5 km (at mouth → reduces to ~ 800m at Pier Head) Average depth at the Narrows = 15m Max. width of Middle Mersey = 4.0km Max width of Upper Estuary = 1.3km
Areas[4]	The total area of the Estuary = 8,914ha The intertidal area = 5,606 ha
[1] taken to be at grid reference SJ 314954 at the apex of a political boundary (see Map 1) [2] taken to be at grid reference SJ 520839 at the apex of a political boundary (see Map 2) [3] obtained from Ref. 12 [4] obtained from Ref. 4	

Sediment Sources

7.3.23 The two main sediment sources for the Estuary are:

a. Marine sources from the glacial and fluvioglacial deposits covering large parts of the eastern Irish seabed; and
b. Fluvial sources from the rivers.

7.3.24 The Estuary is sensitive to morphological change (in particular at the mouth of the Estuary) although parts of the system are confined by geology and (in some places) bank protection and seawalls (Ref. 13).

7.3.25 Previous work indicates that marine sources of sediment are the most dominant, with O'Connor (Ref. 14) estimating that over 1,000,000m^3/year of sediment has been delivered to the Estuary since the turn of the century. Price & Kendrick (Ref. 15) concluded that the mechanism for sediment transport from these offshore sources is via density stratification, which causes a net inland movement along the bed. Heaps (Ref. 16) also demonstrated that small density gradients found in the near-shore regions contribute to the net landward drift of near-bed water and sediments in Liverpool Bay.

7.3.26 Although the fluvial sources are believed to be small compared with offshore sources, the magnitude and duration of freshwater inputs may affect the lateral migration of low water channels in the Upper and Middle Mersey (Ref. 17). Additionally, localised erosion of the Ince Banks region and Dungeon Bay (for locations see Figure 7.1) has provided a recent source of sediment; however, this quantity is very small compared to marine sources (Ref. 10).

7.3.27 The exact balance of marine versus fluvial sediment sources in the Study Area is not clear. Although the Estuary as a whole is considered to be heavily influenced by marine sediment sources, the distance of the Study Area from the mouth of the Estuary may mean that these have a less prominent role and that fluvial sources are more significant. Field data from 1955-1965 (Ref. 14) found that the average yearly volumes of sediment were as follows:

a. Sand influx (S_n) = 1.85 Mm^3/yr - no dredging influence;
b. Silt influx (SS_n) = 2.43 Mm^3/yr - no dredging influence; and
c. River influx (S_r) = 0.04 Mm^3/yr.

7.3.28 The River has always been thought of as an accreting estuary and up until very recently there has been significant accretion taking place within most sections. However, work by Thomas (Ref. 7; Ref. 10) suggests that the Estuary may be entering a new state of morphological equilibrium with little overall estuary capacity change. Thomas (Ref. 10) also noted that although capacity change has stabilised, there is a substantial amount of sediment redistribution particularly within the Middle Mersey around Ince and Stanlow Banks and Dungeon Bay. In these areas, post 1956 surveys indicate periods of significant erosion and accretion.

7.3.29 Based on these characteristics of the Estuary, it is reasoned that in the Study Area the fluvial input is low based on the differences between tidal discharge and fluvial discharge, and that sediment transport is therefore likely to be flood dominant.

Anthropogenic Influences

7.3.30 There have been a number of significant anthropogenic modifications to the Estuary over the last few centuries (detailed in Table 7.4). The main activities include dredging of channels for navigation and the construction of training walls and other structures.

Dredging

7.3.31 Dredging started in 1833 to provide access to the Ports of Liverpool and Birkenhead. However, regular dredging of the channel only commenced after 1890 and, by the time of training wall construction in 1909, significant dredging was needed to maintain the approaches to the port of Liverpool. Volumes of material removed through dredging peaked between 1912 and 1950, removing 320 Mm^3 (8.4 Mm^3 per year) in comparison to the 100 Mm^3 between 1950 and 1988 (2.6 Mm^3 per year). Currently on average 0.4 Mm^3 of sediment is removed from the Estuary per year (Ref. 13).

7.3.32 Prandle (Ref. 18.) 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. Table 7.5 summarises estuary wide capacity changes and associated dredging activities.

Table 7.5 - Capacity Changes in Relation to Past Dredging Activities (from Ref. 18)

Period	Net volume change		Dredging in Outer Channel	Dredging in Upper Mersey	Disposal within system
	Liverpool Bay	Upper Mersey			
1833-1871	71 Mm^3	-16 Mm^3	0 Mm^3	0 Mm^3	0 Mm^3
1871-1906	65 Mm^3	5 Mm^3	After 1860 60 Mm^3	After 1890 15 Mm^3	Not known but small
1906-1936	-22 Mm^3	33 Mm^3	180 Mm^3	65 Mm^3	30 Mm^3
1936-1977	130 Mm^3	40 Mm^3	135 Mm^3	75 Mm^3	25 Mm^3

Training wall construction started

Table 7.4 - Timeline of events

	Pre 1830s	1830s - 1870s	1880s - 1900s	1910s - 1930s	1940s - 1960s	1970s - present
Route change	Two main approaches to the Estuary in 1766 – Rock channel (west) and Formby channel (north)	Between 1838 – 1854 the Crosby Channel became a separate feature from the Formby Channel	Crosby Channel moved north and Askew spit had advanced into the channel (1885-1909)	NW passage alignment altered and main route into estuary by 1912 Rock Channel relict feature by 1938	Rock channel completely disappeared by 1955 Infilling of Formby Channel 1950 - 1961	Taylor's Bank and Formby Bank amalgamated in 1970 Taylor's Bank continues to erode eastward finally reaching equilibrium in 2002
Channel change patterns	1738 – Inner estuary had two channels (hugged north and south banks and joined at Devils Bank off Eastham)	1842 (and onwards) – Inner estuary had three channels. Channel could occupy any part of the Estuary between 1867 and 1918	High lateral change of the lower water channel in the Inner estuary (1861 – 1911)	Reduced channel movement from 1911 in the Inner estuary.	Channel restricted and hugged the northern shore between 1921 and 1961	Increased lateral channel activity from 1961 to present day
Volume change	Sand flats west of Formby Point decreased in area between 1738 and 1833	Sand flats west of Formby Point grew considerably in size between 1838 - 1854 Rock Channel began to infill between 1833 and 1912 Capacity ranged between 770 and 730 million m^3 (1860 to 1910)	Between 1906 and 1936 accretion rates of 5mm/yr (in Inner estuary)	Reduction in capacity from 750 to 680 million m^3 (1910 to 1960)	Sediment infill at Bromborough Bar (1954) Between 1936 and 1956 accretion rates of 24mm/yr (in Inner estuary) Between 1956 and 1977 accretion rates of 3mm/yr (in Inner estuary)	Increase in capacity from 680 to 700 million m^3 (1960 to 1990) Between 1977 and 1997 erosion rates of 19mm/yr (in Inner estuary) Net accretion of 70 x 10^6 m^3 in the Estuary during 1900 to 1988
Training walls			Taylor's Bank revetment (1909 – 1910)	Crosby West Training Bank (1923 – 1930) Crosby East Training Bank (1929 – 1930) Askew Spit Training Bank (1933 – 1935) Queens North Training Bank (1933 – 1938) South Training Bank (1935 – 1938)	Queens North Training Bank (1946 – 1957) South Training Bank (further extended to 1957)	
Management		1868 - Aethelfleada Bridge was constructed for the railway	1894 - Manchester Ship Canal completed 1896 – River Weaver diverted and slag embankments placed between Widnes and Hale Head	Construction on the Transporter Bridge started in 1901 and opened in 1905. It was demolished in 1961 and replaced by the SJB.	Construction on the SJB started in 1954 and was opened to traffic in 1961	Loss of capacity of the Estuary due to land reclamation since 1861 approx 12 x 10^6 m^3 (Van der Wal and Pye, 2000)
Dredging		Approaches to the River dredged for navigation purposes from 1833	Dredging of the Bar and deepening of the sea channel in Liverpool Bay 1890	320 x 10^6 m^3 dredged between 1912 and 1950	Maintenance dredging of the Eastham channel and ship canal approach 1950's 1953-4 – dredging of Bromborough Bar 100 x 10^6 m^3 dredged between 1950 and 1988	Currently 0.4 x 10^6 m^3 dredged every year from the Estuary to ensure depths are maintained for navigation purposes (Combe *et al* .,1993).
Floods	1767, 1799, 1828	1837, 1852, 1866, 1872, 1877	1886, 1890	1911, 1923	1933, 1948	
Droughts	1785, 1788, 1791					

For larger version please see Appendix 7.2

Training Walls

7.3.33 The training walls were constructed along the face of Taylor's Bank in the Outer Mersey in 1909 to initially 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 (as detailed in Table 7.4) and included the Queens North, South, Askew Spit, Crosby West and Crosby East Training Banks (Ref. 13).

Other Activities

7.3.34 The Irwell, Mersey and Bollin all flow into the Manchester Ship Canal (completed in 1894), each river carrying sufficient suspended sediment to enhance requirements for canal maintenance. The material (mainly sand but also silt) has been periodically removed and deposited upstream over a large area of land near Warrington. The Manchester Ship Canal clearly acts as a sediment trap, limiting the supply of fluvial sediment to the Study Area. Fluvial sediment supply is therefore limited to inputs from remaining tributaries such as the Sankey Brook. The fluvial supply of sediment to the Estuary is small compared to the supply of sediment from offshore sources (Ref. 13; Ref. 14).

7.3.35 Other man-made structures within the main channel, including flood embankments and bridges (detailed in Table 7.4), will have also had some impact on the sediment system. These features could have affected circulation patterns leading to increased scour or deposition in localised areas (as detailed in Ref. 15).

7.4 Long term morphology

Introduction

7.4.1 Long term morphology provides a valuable means through which the processes operating in the Estuary can be understood and is used as part of the baseline assessment. Analyses of historic maps and charts enable recurring patterns in estuary morphology, frequency of change and overall trends in estuary evolution to be exposed. In addition how the Estuary has reacted to previous manmade installations, such as the Manchester Ship Canal training wall are all exposed. Consequently looking at how the Estuary has behaved in the past is used here to provide an insight into the future.

7.4.2 A range of sources of historic data have been used as part of the baseline assessment to investigate the long term changes within the Estuary to identify any trends or patterns within those changes.

7.4.3 A number of potential data sources were considered as described below. (See Appendix 7.2 and 7.3).

Data sources

Maps and Bathymetric Surveys

7.4.4 Ordnance Survey (OS) maps of an area (Map 1; Map 2), which include the Estuary, were considered. However, it is recognised that historical mapping does not accurately record the position of sedimentary features within the permanent banks of an estuary. The position of any channel shown on such a map would be uncertain and use of this source of maps was discounted.

7.4.5 Bathymetric surveys for the Estuary have been obtained from a number of different sources (see Appendix 7.2). These include:

a. The Upper Mersey Navigation Commission (UMNC) charts (Chart 3) provide a long term record for the period July 1871 to March 1973, a total of 940 charts. It is understood that each of the earlier UMNC surveys took over six months to produce. In this period, surveyed data would have been subject to error as the morphology changed on each tidal cycle. It is also not certain what level of detail the surveyors were required to record and it is likely that only main navigational channels were accurately recorded. As such these charts are unsuitable for use in comprehensive analysis of channel change. A photographic record was made of these charts. An example is given in Figure 7.6;

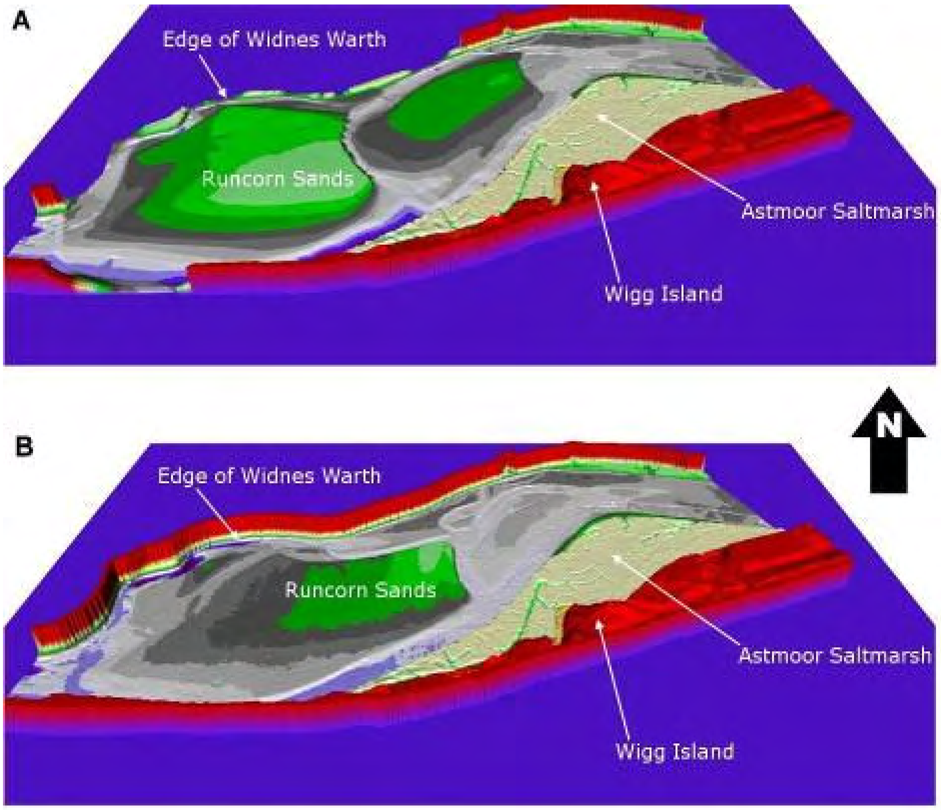
Figure 7.6 - Example of the UMNC charts – September 1873

b. Bathymetric surveys were obtained of the Upper Mersey Estuary undertaken by The Mersey Docks and Harbour Commission. The surveys were taken at five yearly intervals covering the period from 1936 to 1977 (Chart 4). A final survey was taken in 1997 with the assistance of HR Wallingford (Chart 5);

c. Hydrographic surveys charting information for intertidal and offshore areas produced by The United Kingdom Hydrographic Office (UKHO) are marketed by the Admiralty. The current chart entitled 'Manchester Ship Canal and Upper River Mersey', May 2001 (Chart 1) was felt to have insufficient detail of the Study Area to be of value in this study and this source of data was not pursued further; and

d. LIDAR and Sonar Survey data was obtained from the Environment Agency (EA) (Ref. 19). The LIDAR survey was dated 2002 and had been calibrated from field surveys conducted by the EA. It is this data set that has been used as the base morphology for the majority of the hydrodynamic modelling done in this study (Figure 7.7A). The 2002 bathymetry shows a cross-estuary channel located downstream of the proposed position of the New Bridge. The southern channel is less distinct. However, the northern and southern towers of the New Bridge would be located in or near the northern and southern channels on this bathymetry. A recent bathymetric survey from 2005 was also used in the modelling and this is also shown on Figure 7.7(B). This bathymetry has clearly defined northern and southern channels. The northern and southern towers of the New Bridge would be located in or near the northern and southern channels on this bathymetry. Given the difference in format, data collection methods and sensitivity of the LIDAR survey, the LIDAR survey data was not used for analysing changes over time in this study.

Figure 7.7 - 2002 Bathymetry (A) and 2005 Bathymetry (B)



EMPHASYS Data

7.4.6 The Estuaries Research Programme, funded by MAFF (now DEFRA), the EA and English Nature (now Natural England), was established in response to the need for methods to predict changes to estuary functioning. EMPHASYS (Estuarine Morphology and Processes Holistic Assessment SYStem) was the first phase of the Research Programme and aimed at providing guidance on the prediction of morphological change in estuarine systems in the UK.

7.4.7 GIS data from the EMPHASYS database (Ref. 20) for years 1906, 1936, 1956, 1977, and 1997 was obtained for the Study Area.

7.4.8 The EMPHASYS data was used to investigate saltmarsh edge change over the period covered by these charts.

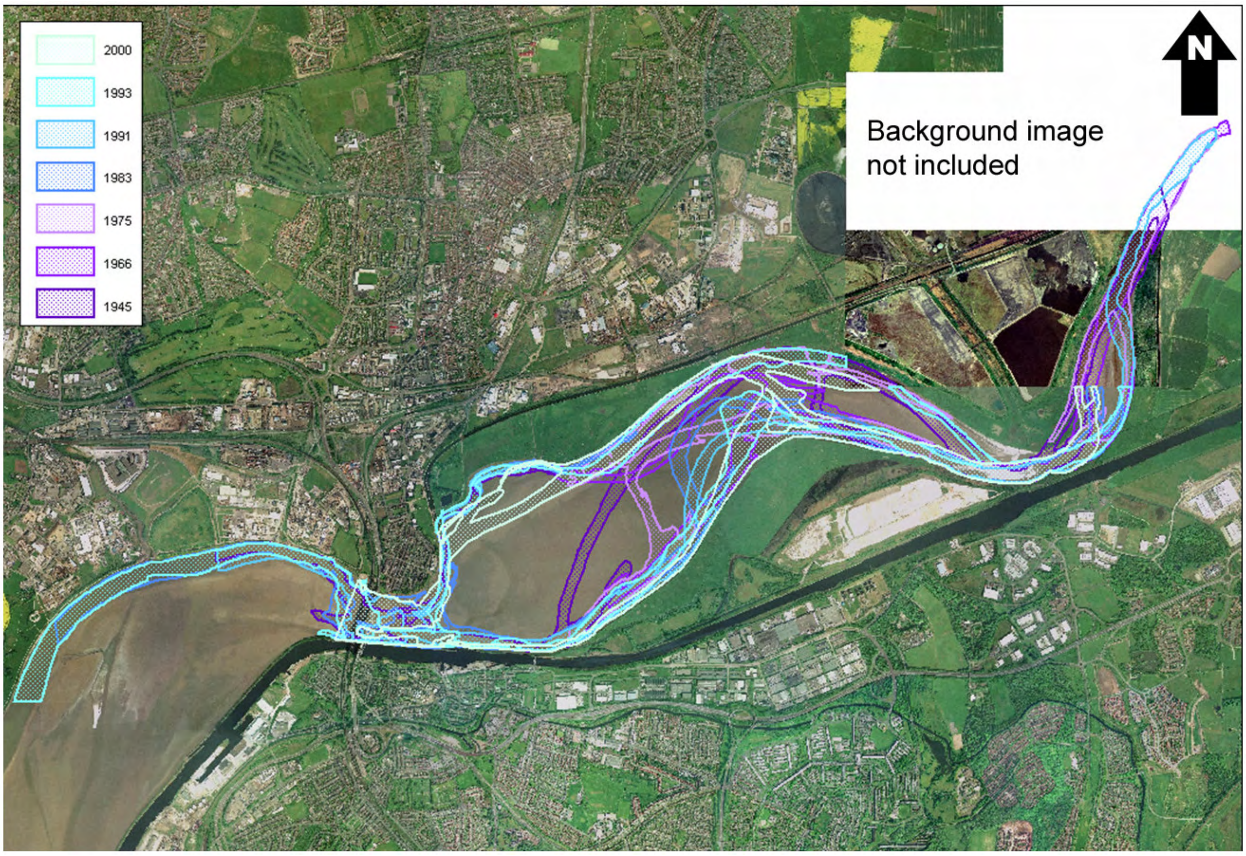
Aerial Photographs

7.4.9 The map and chart record has been supplemented with a limited number of aerial photographs from the period 1945 to 2000.

7.4.10 Aerial photographs were obtained for 1945, 1951, 1959, 1963, 1966, 1975, 1979, 1983, 1991 and 2000. Out of these, the 1945, 1966, 1975, 1983 and 1991 photographs showed the main channels. The locations of the channel were captured in electronic format through onscreen digitising and stored as images in MapInfo GIS, geographic information system software. An additional record showing the channel positions from 1993 was obtained using landline data.

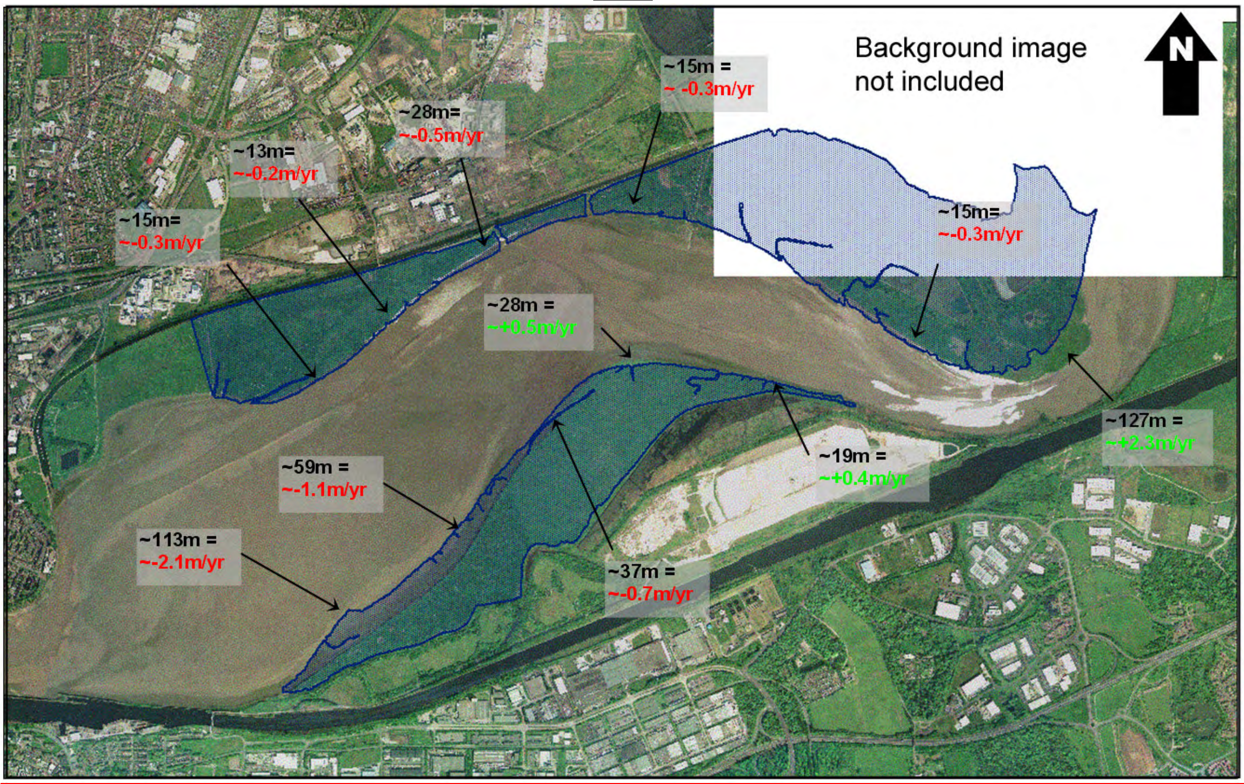
7.4.11 These channel locations at various dates were laid over the 2000 aerial photo to put the data into context and compare them to the most recent known location of the channel as detailed in Figure 7.8.

Figure 7.8 - Locations and rates of saltmarsh loss and gain from 1945 to 2000



7.4.12 In addition to the locations of historical channels, saltmarsh locations were also digitised for a number of years including 1945, 1951, 1959, 1936 (part), 1966, 1979 (part), 1983, and 1991 (see Figure 7.9. These were also overlain on the 2000 aerial photo to compare to the 2000 position of the saltmarsh edge.

Figure 7.9 - Location and rates of saltmarsh loss and gain from 1945 to 2000



Limitations of long-term morphology data

7.4.13 It is understood that each of the earlier UMNC surveys took over six months to produce. In this period, surveyed data would have been subject to error as the morphology changed on each tidal cycle. It is also not certain what level of detail the surveyors were required to record. It is unlikely that every minor channel or developing channel would have been recorded. It is also unclear whether the channel positions have been surveyed at the same time as the bathymetric survey.

7.4.14 In addition there are limitations inherent in the conversion of the charts to a digital image. The photographs of the UMNC charts were taken using a hand held camera and converted into digital images using computer aided design (CAD) software. The accuracy of the CAD work from these photographs was limited by the photographic image and the poor quality of many of the original charts.

7.4.15 In addition, the variation in the 18.6 years lunar nodal cycle will lead to different values in intertidal position. To assess these changes, charts with a period of 18.6 (~ 19 years) should be compared. However, given the accuracy of the plotting of many of the older charts used in this study, it is doubtful if this phenomenon would be detectible.

7.4.16 There is a lack of precision associated with aerial photos, although the more recent photographs: 1983, 1991 and 2000 are more precise. It is generally accepted (Ref. 21) that the older aerial photographs (pre 1983) are only precise to +/- 5m and therefore any change in the channel of less

Volume Change

7.4.17 The Estuary as a whole has been infilling naturally since the beginning of the Holocene at a steady rate (Ref. 15).

7.4.18 Bathymetric changes in the Estuary have been well documented over the last century, with surveys being conducted every 10 years since 1861, and every 5 years from 1881 until 1977. This has led to a number of studies on historical bathymetric analysis of the Estuary (Ref. 8; Ref. 10; Ref. 13; Ref. 14; Ref. 15; Ref. 22). The studies confirm that from 1900 to 1977 the Estuary has been slowly infilling, with the largest rate of accretion occurring between 1936 and 1956. However, more recent studies suggest that the rate of infilling has slowed in the second half of the century, and that since 1977 the Estuary capacity has increased. In fact, Van der Wal & Pye (Ref. 13) and Pye, Blott & Van der Wal (Ref. 8) predict that erosion is part of this new sediment regime.

7.4.19 Accretion in the Estuary has not been evenly distributed, and the most substantial decrease in estuary volume has occurred in the Middle Mersey basin. Comparatively little accretion has taken place in the Narrows, (the high flows ensure sedimentation is limited as was described earlier), and very limited change has occurred within the Upper Mersey and around the site of Project.

7.4.20 Nevertheless, using data from the EMPHASYS GIS data, within the Study Area the overall trend between 1906 and 1997 has been one of siltation and, therefore, a reduction in storage capacity.

Long-term Morphological Change

UMNC Charts

7.4.21 The Department of Transport archive holds the Upper Mersey Navigation Commission (UMNC) Charts from July 1871 to March 1973. This historical record of UMNC constitutes a record of the navigable channels to the port of Runcorn within the Upper Estuary. The record terminates in 1973 when the UMNC disbanded. The period of record indicates that in general, a drawing of the location of the navigable channel was drawn every month. However, the record is incomplete with months missing and in some instances, no record exists 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).

7.4.22 The aim of using the UMNC charts is to trace back the history of the Estuary and understand the geomorphological behaviour in the last century. It might help in:

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

Analysis of UMNC Charts

7.4.23 The photographic images of the UMNC charts were scanned and converted to AutoCAD files to allow the production of scaled drawings showing the main channel locations. The different scaled drawings for selected years were overlain and rectified to each other (matched) using a number of common fixed features. Once this was achieved, the overlays were used to investigate the changes of channel position over different time periods.

7.4.24 Screening of the 940 charts showed that the navigable channel rarely coincided with the proposed position of the central tower of the New Bridge. However the north and south towers of the New Bridge are in locations which are much more commonly occupied by channels.

7.4.25 The Manchester Ship Canal was completed in 1894. It is interesting to note that the observed movement in the position of the navigable channels downstream of Runcorn Gap reduced significantly, and almost no change in the range of movement was observed from approximately August 1896 through to the end of record in 1973. However, upstream of Runcorn Gap the movement in channel position was maintained following 1896, however the range in the data are not quite as pronounced as those records prior to 1896.

Channel Mobility Model

7.4.26 A GIS model of the UMNC 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 navigable channel.

7.4.27 Two sets of charts were used as defined in Table 7.6 below:

Table 7.6 - List of the UMNC charts used in the channel mobility model

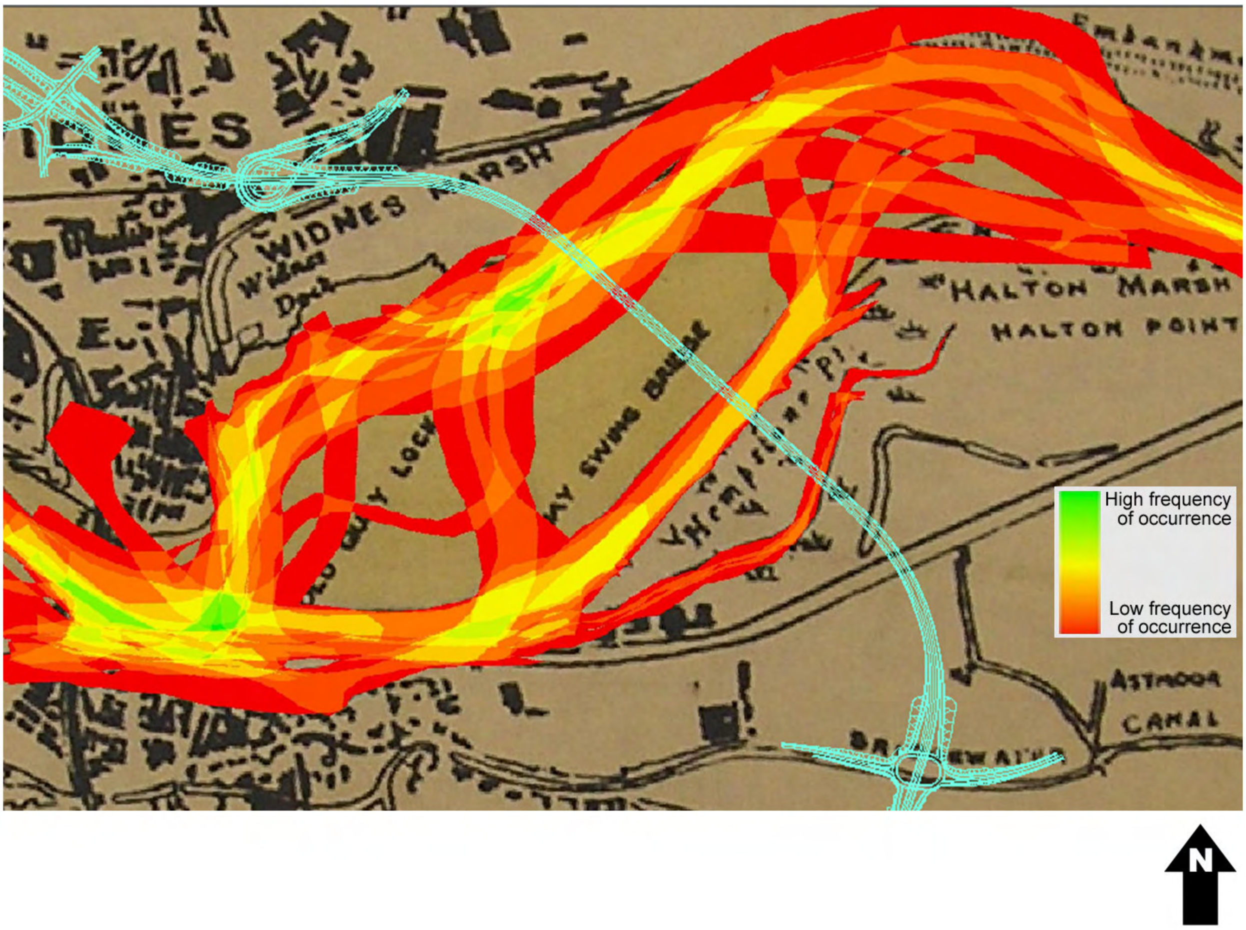
Chart Set 1 UMNC Chart Date	Comments	Chart Set 2 UMNC Chart Date	Comments
01/1973, 02/1973 03/1973	Combined chart for Jan., Feb. & Mar.	01/1973, 02/1973 03/1973	Combined chart for Jan., Feb. & Mar.
01/1969, 02/1969	Combined chart for Jan. & Feb.	11/1962	
01/1959, 02/1959	Combined chart for Jan. & Feb.	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.		

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 of channel positions found to coincide with the New Bridge; and
b. For Chart Set 2, 10 charts were chosen on a 10 years interval focusing on charts from December.

7.4.28 The charts were rectified to the National Grid and the channel boundaries were digitised. Eleven distinct channel locations were identified and modelled into a GIS mobility model covering the last 100 years. Figures 7.10 and 7.11 show the highest frequency of occurrence at a particular location in the green colour and the lowest in red (based on the fact that the channel was located in the position shown by the red colour at least once). Areas with no colour indicate zones where, from this chart record, no channels occurred during the period. These figures illustrate that there is some degree of dynamic stability within the area shown, with channels tending to move within bands rather than completely at random over the whole of the study area. It should be noted that the background to Figures 7.10 and 7.11 is taken from the UMNC chart set and therefore does not necessarily represent the present position of the edge of the saltmarshes. Also some of the landward extents of channel positions shown stem from early charts; these channels would now be constrained by more recent constructions.

Figure 7.10 - UMNC – Historical record of the channel location and sinuosity within the Upper Mersey Estuary (Chart Set 1)

Figure 7.11 - UMNC – Historical record of the channel location and sinuosity within the Upper Mersey Estuary (Chart Set 2)



Channel Change

7.4.29 In order to identify the main trends in channel location change, analysis and interpretation has been undertaken for three data sets:

a. The 55 years between 1945 and 2000 (Aerial Photographs);
b. The 41 years between 1936 and 1977 (Historical bathymetric data); and
c. The 91 year period between 1906 and 1997 (EMPHASYS data).

Aerial Photographs

7.4.30 The record of the aerial photographs from 1945 to 2000 was used to look at a) changes in estuary edges, b) channel cross-sectional area, c) plan-form shape and the location of the low water channels and d) the channel mobility.

7.4.31 The outcome of the analysis is:

a. The Estuary banks have changed relatively little (maximum loss 12m within 46 years);
b. The low water channel system is very dynamic with variability in channel positions; and
c. The intertidal areas vary in frequency of significant morphological change, with Runcorn Sands (north east of Runcorn Gap) undergoing less frequent change than the areas next to Hempstones Point.

7.4.32 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 south and north banks of the saltmarshes, they are not permanently fixed to the banks. In particular, the low water channel in the 1945 aerial photograph has no southern channel (Figure 7.12). This anomaly is not found in any of the other aerial photographs or other datasets available.

Figure 7.12 - Location of channel in Study Area from aerial photography taken in 1945

7.4.33 Between 1945 and 1993 the position of the southern channel meander in the vicinity of Hempstones Point changes from east to west. Extensive flats of mud or sand surround the channel, with some displaying more frequent change than others. For example, the flats between Hempstones Point and the Swing Bridge that lies on the southern bank were reworked several times between 1945 and 1993; but Runcorn Sands, which lie to the northeast of Runcorn Gap, have changed little.

7.4.34 Using this dataset, the zones of relatively high stability (i.e. where morphological change, such as channel movement, does not occur frequently), have been identified (Figure 7.13).

Figure 7.13 - Channel mobility from historical aerial photographs 1945 – 2000

Historical bathymetric data

7.4.35 The historical bathymetric data illustrates that the channel split at the eastern end of the Study Area has been associated with the meandering of the south channel and its subsequent cut-off and capture by the north channel. One of the most noticeable aspects of channel variability is the movement of the south channel from adjacent to the south bank to a more northerly position in the centre of the Estuary.

7.4.36 This change in channel position may have been as a reaction to the training walls work at the mouth of the Estuary that was completed in the late 1930s. The low water channels' shapes, sizes and, to a certain extent, locations are controlled through supplies of sediment and water. If these supplies are changed then the patterns of the channels change. A reaction to the changes in circulation patterns as a result of the training walls may have induced the channel to change in the 1936-1946 period. It returned then to its previous form when the system had adjusted.

7.4.37 Over time (1945 -1993) the southern channel meander extensions have scrolled and extended across the southern edge of the Estuary (Ref. 23) migrating further south and east over time reducing in meander wavelength[1] and increasing in sinuosity[2]. These changes in channel size and shape may be a response to changes in supplies of sediment (as mentioned previously), either fluvial or marine. It has been suggested by Van der Wal & Pye (Ref. 13) and Pye, Blott & Van der Wal (Ref. 8) that this pattern of accretion is slowing down and in the future erosion will dominate the system.

7.4.38 Using the surveys of the bathymetry of the Study Area by the Mersey Docks and Harbour Commission, five cross-sections have been drawn for the years 1967, 1972 and 1997 (Figures 7.14, 7.15a and 7.15b). The surveys show that the channel splits at the location of Fiddler's ferry

[1] The distance between two meander crests
[2] Meander wavelength ÷ valley length

and two channels form. One of the channels flows close to the southern bank of the Estuary and the other to the northern bank.

Figure 7.14 - Locations of cross sections

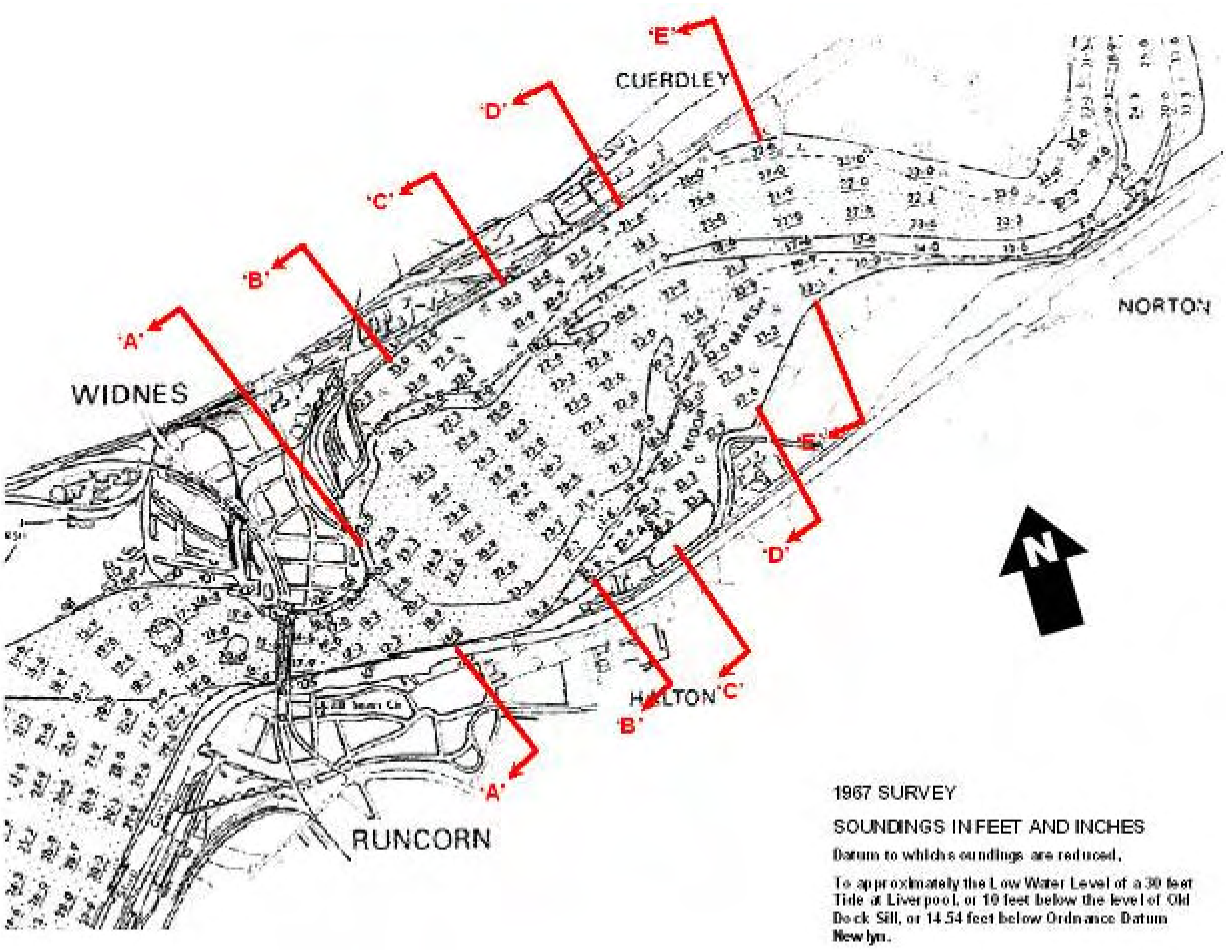
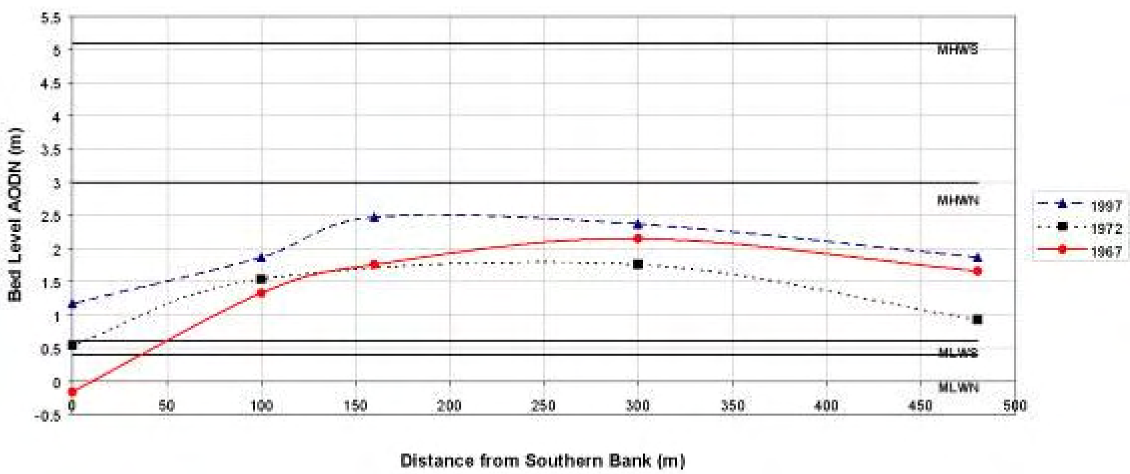
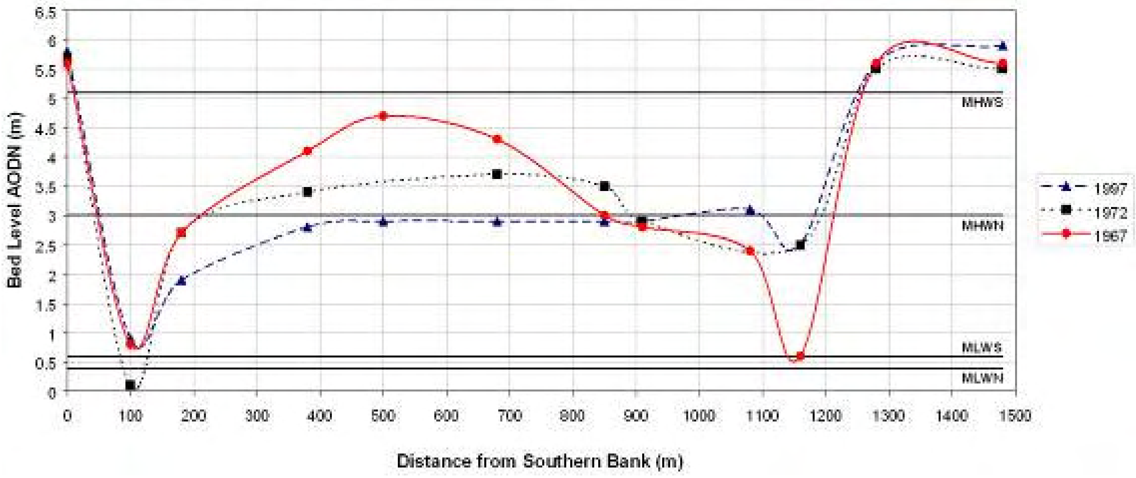


Figure 7.15a Cross Sections – see Figure 7.14 for locations of cross sections

Cross Section A-A



Cross Section B-B



Cross Section C-C

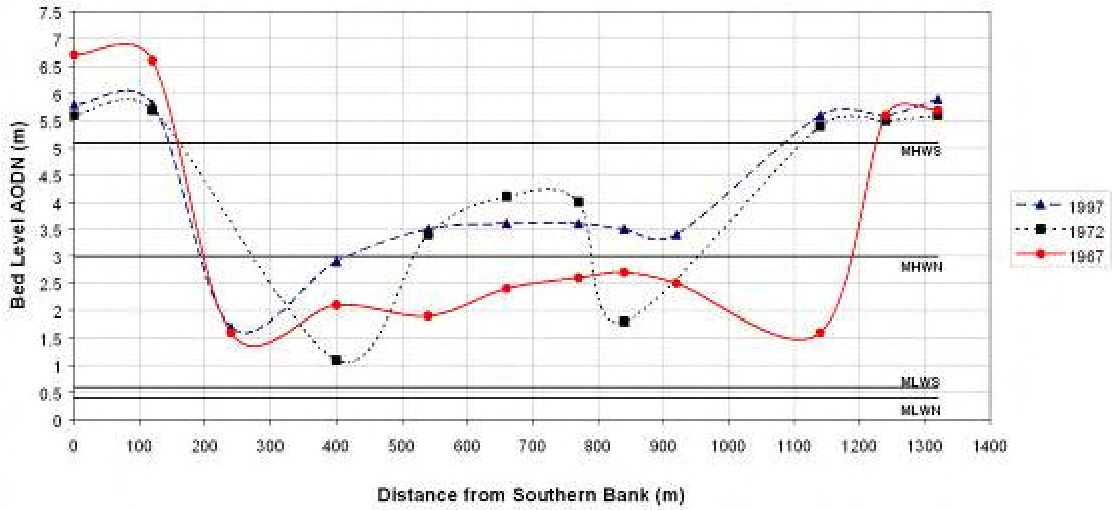
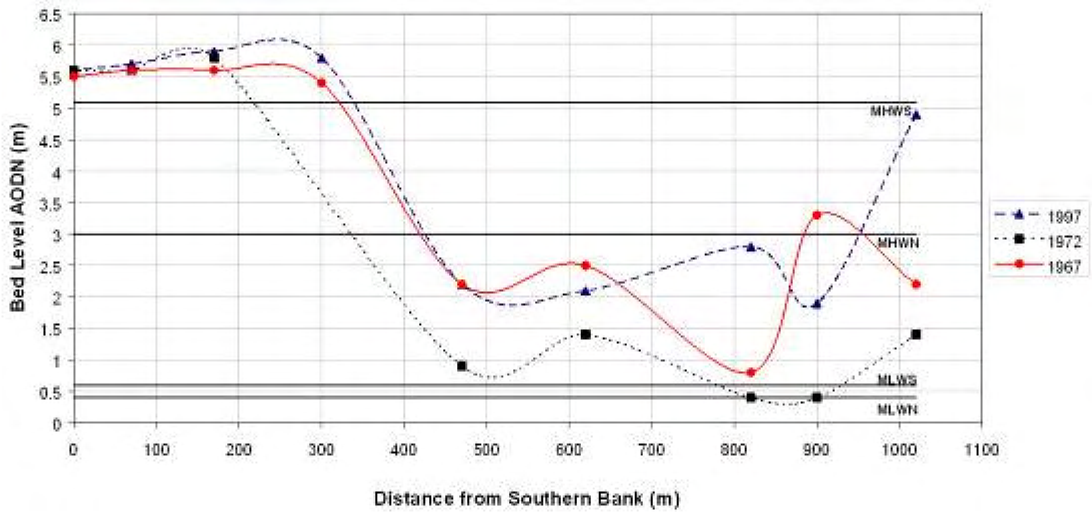
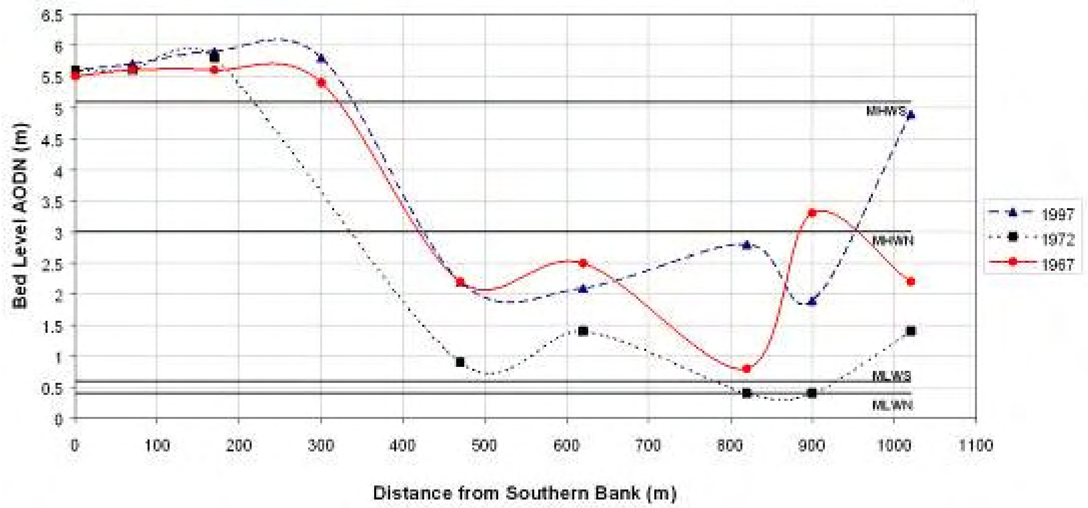


Figure 7.15b Cross Sections – see Figure 7.14 for locations of cross sections (continued)

Cross Section D-D



Cross Section E-E



7.4.39 This basic channel pattern is reflected in the EMPHASYS data and aerial photos discussed below. The point where the Estuary splits consistently appears to be just to the east of the head of Hempstones Point. Figure 7.15a, cross-section C-C, indicates that the northern channel has moved laterally by approximately 300m in the five-year period between 1967 and 1972. The two channels then converge just upstream of the Runcorn gap.

EMPHASYS data

7.4.40 The area of mud flat in the centre of the Estuary, between 700m and 1,500m to the east of the Runcorn Gap, was present in the 41 years from 1936 to 1977, as well as the 91 years from 1906 to 1997 and the 55 years from 1945 to 2000. Additionally, along the banks of the Estuary, the locations of both Astmoor Saltmarsh and Cuerdley Marsh remain unchanged from 1936 to 2000.

7.4.41 Figures 7.16 and 7.17 show channel configurations and demonstrates, through a thalweg diagram, the most likely positions of channels based on the EMPHASYS dataset.

Figure 7.16 - EMPHASYS data of channel configuration

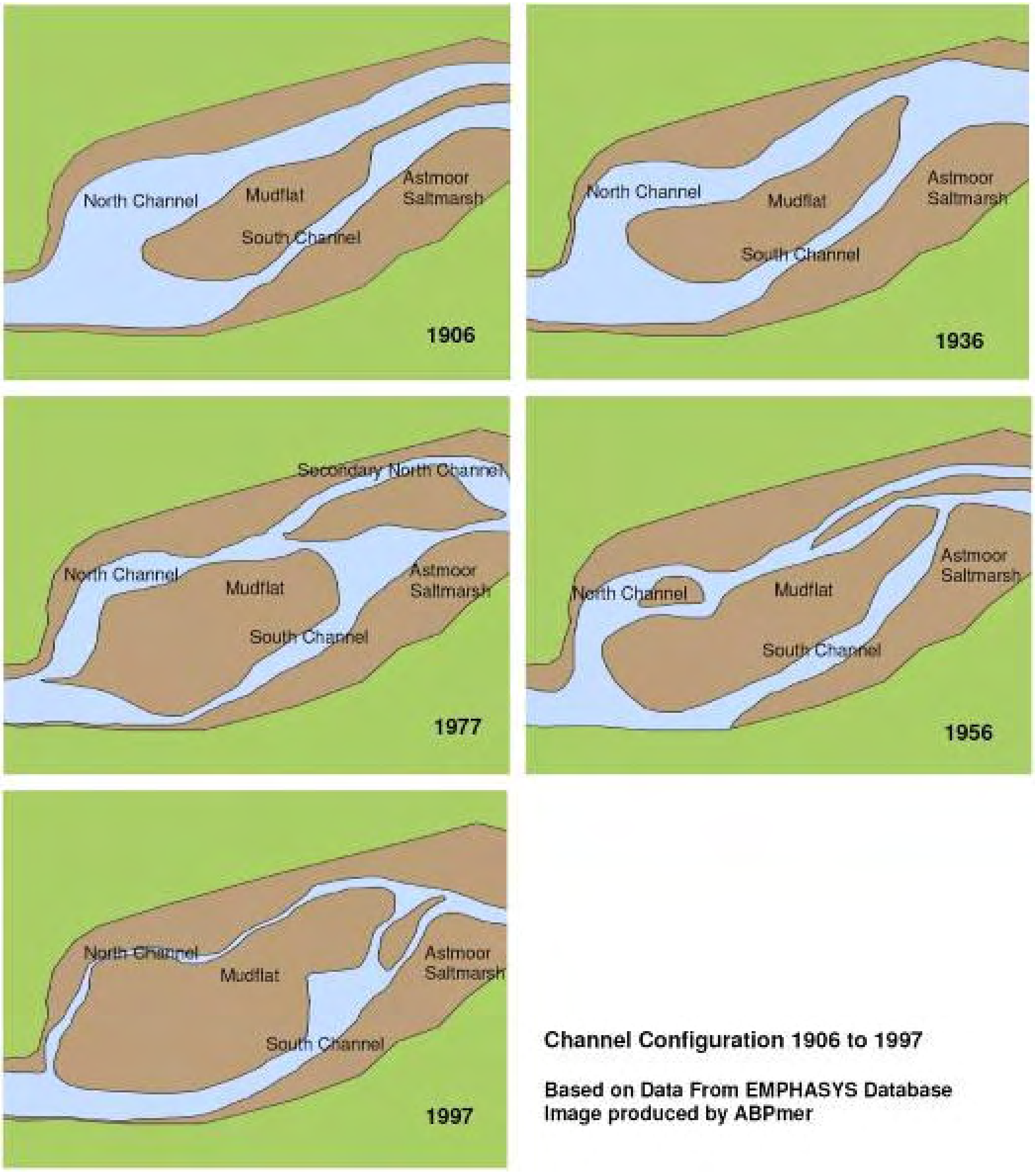
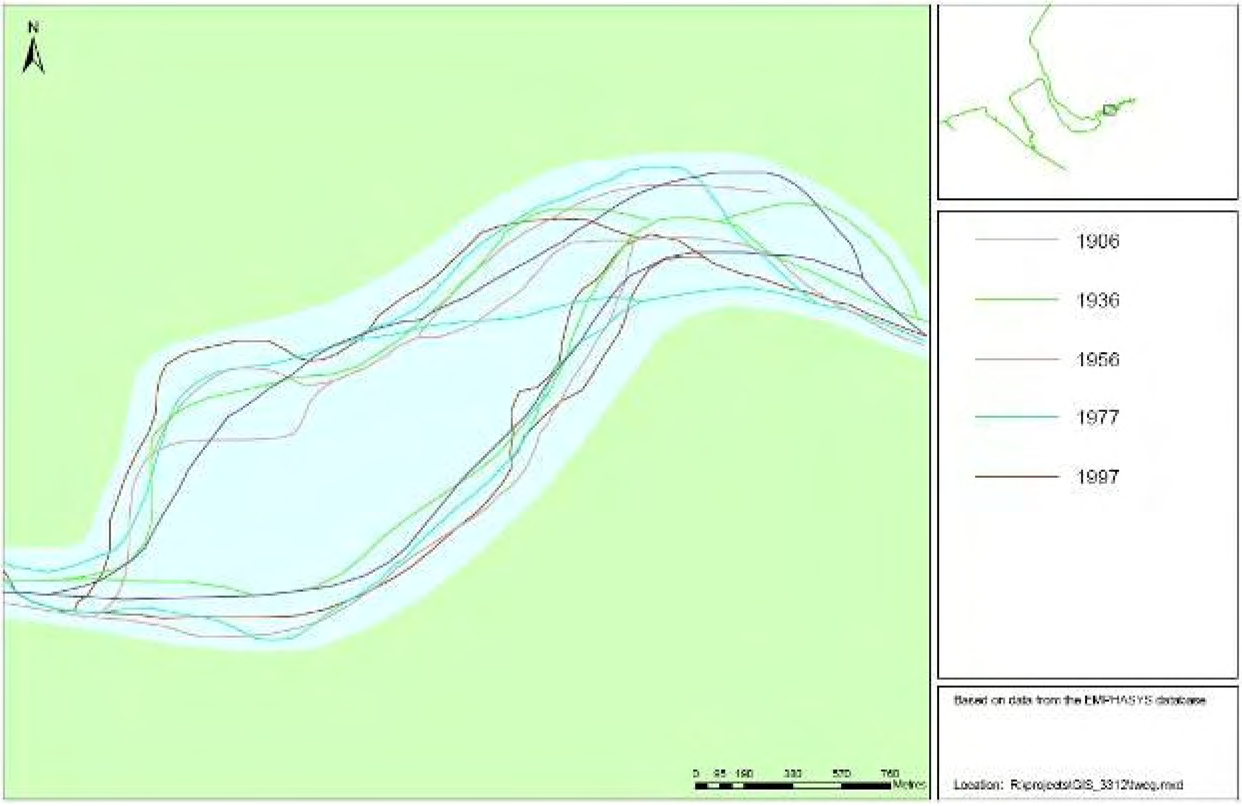


Figure 7.17 - Thalweg plot of channel positions, EMPHASYS data (image from ABPmer)



7.4.42 Kendrick & Stevenson (Ref. 24) as cited in Van der Wal & Pye (Ref. 13.) and Pye, Blott & Van der Wal (Ref. 8) suggest that there are three main periods of lateral channel activity and movement within the Inner Estuary as a whole (which includes the Study Area). The Narrows have remained relatively stable over this time period due to the geology in this area restricting movement. From 1861 to 1911 the Inner Estuary low water channel experienced a period of high activity and lateral movement with wide fluctuations in channel position and a gradual trend in decreasing volume of the Estuary. Between 1911 and 1961 this lateral activity of the low water channel significantly reduced and was matched with a consistent and rapid reduction in estuary volume. From 1961 to 1977 (and to present, as suggested by Ref. 13 and Ref. 8) there has been an increase in lateral channel activity and an apparent levelling off of estuary volume changes.

Saltmarsh Edge Change

7.4.43 The saltmarshes are of importance to wildfowl and are a substantial feature of the Estuary in the Study Area. Consequently the impact of hydrodynamic change on the erosion and accretion of these areas is investigated in order that these impacts may be evaluated in the Ecology Chapters (Chapters 10 and 11).

7.4.44 Aerial photographs provide a useful overview of the trends of saltmarsh advance and retreat. However, there are certain limitations that need to be considered when analysing these datasets. These include:

a. Aerial photography rectification errors;
b. Accuracy of data capture;
c. Correct identification of saltmarsh; and
d. An incomplete dataset for the northern saltmarsh.

7.4.45 It is important to note here that any movement in the position of the saltmarsh edge less than 5m is considered to be an artefact of the rectification process associated with the aerial photographs.

7.4.46 Nevertheless, it is possible to identify trends of either advance or retreat over a number of years as is demonstrated earlier in Figure 7.9.

7.4.47 The 18.6 years lunar modal cycle may have an impact on saltmarsh change since the difference in tidal range between the peak and trough of the nodal cycle would generate a difference in the position of the mean tide level. However, the observed pattern of either continuous retreat or advance does not suggest that this lunar model cycle has influenced saltmarsh change in the Study Area.

7.4.48 Another form of saltmarsh change is that of reclamation. This occurs typically on the landward edge of the saltmarsh where it is reclaimed for alternative use. The most significant loss of saltmarsh is at Cuerdley Marsh which has been largely reclaimed for the construction of the Fiddler's Ferry Power station lagoons.

7.4.49 Figure 7.9 shows the locations of these areas which have consisted of saltmarsh at some point between 1945 and prior to 2000 (shaded blue area). This is overlaid on the current situation. The peak rate of recession of saltmarsh edge can be approximated to a maximum net loss of 2.1m per year and a net gain in some areas of up to 2.3m per year. The areas looked at include Widnes Warth and Cuerdley Marsh to the north and Astmoor saltmarsh to the south.

7.4.50 Table 7.7 shows the changes in saltmarsh area from 1945 to 1991 for the south and north saltmarshes. Although some of the aerial photo datasets are incomplete the table does allow the general trend of loss of saltmarsh to be identified.

Table 7.7 - Rate of change in area of both north and south saltmarshes

Year	South saltmarsh		North saltmarsh		Comments
	Area (m^2)	Change between consecutive surveys (m^2)	Area (m^2)	Change between consecutive surveys (m^2)	
1945	581000	-	1271000	-	No development on north marsh
1951	581000	-	1360000	+89000	No development on north marsh
1959	592000	+2000	1295000	-65000	No development on north marsh
1966	593000	+1000	1063000	-232000	Power station lagoons partly constructed on north marsh
1975	546000	-47000	928000*	-135000*	Power station lagoons partly constructed on north marsh
1979	526000	-20000	*	*	Power station lagoons construction completed on north marsh
1983	551000	+25000	557000*	-371000*	Power station lagoons present on north marsh
1991	527000	-24000	552000	-5000	Power station lagoons present on north marsh

* Aerial photo datasets are incomplete

7.4.51 The southern saltmarsh has an overall net loss of 0.054 km^2 or 54000m^2 and it is reasonable to assume that this trend will continue. However, on the northern shore this trend is overshadowed by the reclamation of a large area of saltmarsh (now the site of a power station) and the incomplete dataset. Although the overall trend on both south and north saltmarshes is one of either retreat or loss of land, there is a certain amount of fluctuation and in some years there has been gain in saltmarsh area.

7.4.52 The loss of saltmarsh is not necessarily a linearly progressive process; significant changes can occur suddenly under the action of a single event. An example of this took place in January 2007; an area of almost 800m^2 was lost over a single tide (Ref. 25).

7.4.53 In order to consider the specific changes that are ongoing at the two positions where the New Bridge meets the saltmarshes, two survey baselines were established and offsets taken to the edge of the saltmarsh periodically since December 2004. The rate of loss is shown on Figures 7.18 and 7.19 and equates to an average rate of 3.4m/yr for the southern Astmoor saltmarsh. This rate includes the January 2007 event and may therefore be higher than the long-term rate. It nevertheless indicates a progressive loss of saltmarsh at this location. The rate is much lower on the edge of the Widnes Warth saltmarsh in the north where a figure of 0.3m/yr has been recorded.

Figure 7.18 - Saltmarsh retreat at New Bridge crossing, southern bank

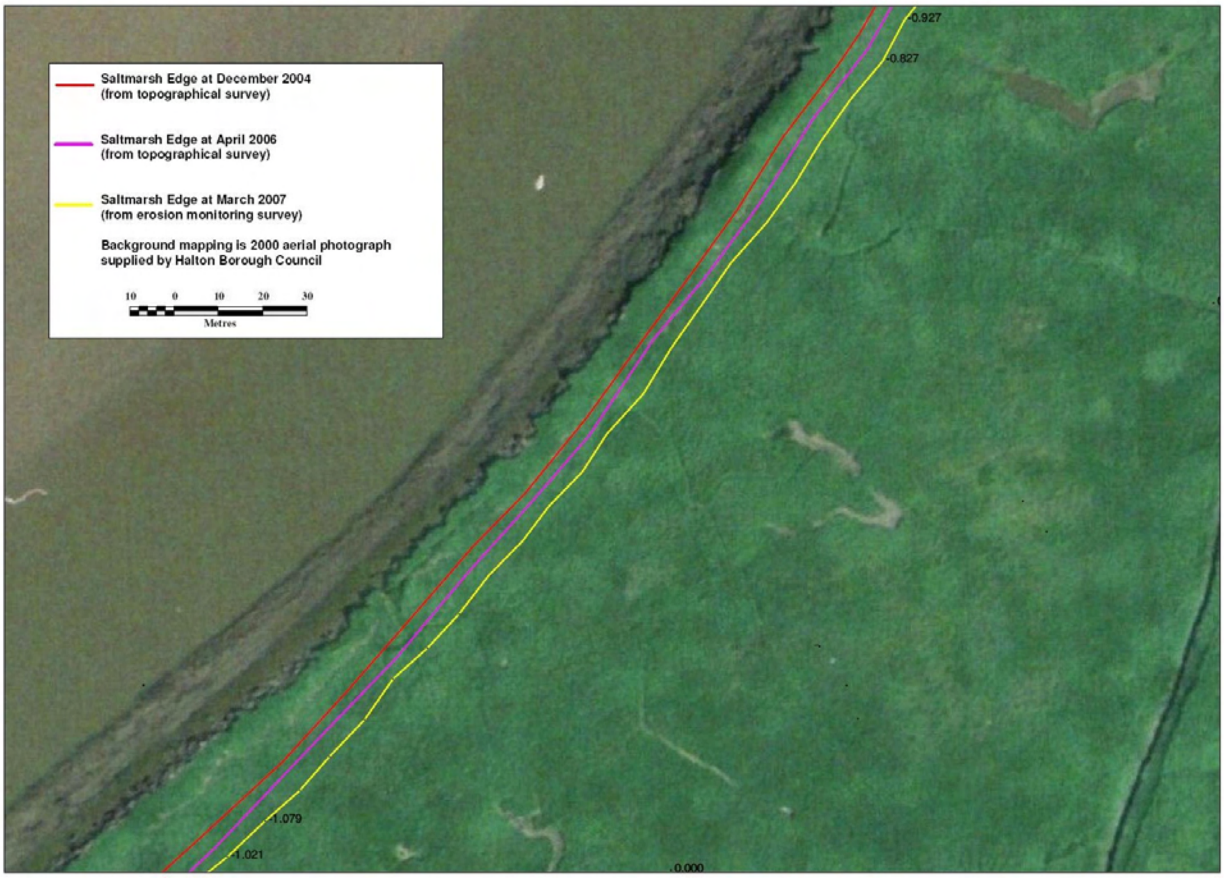
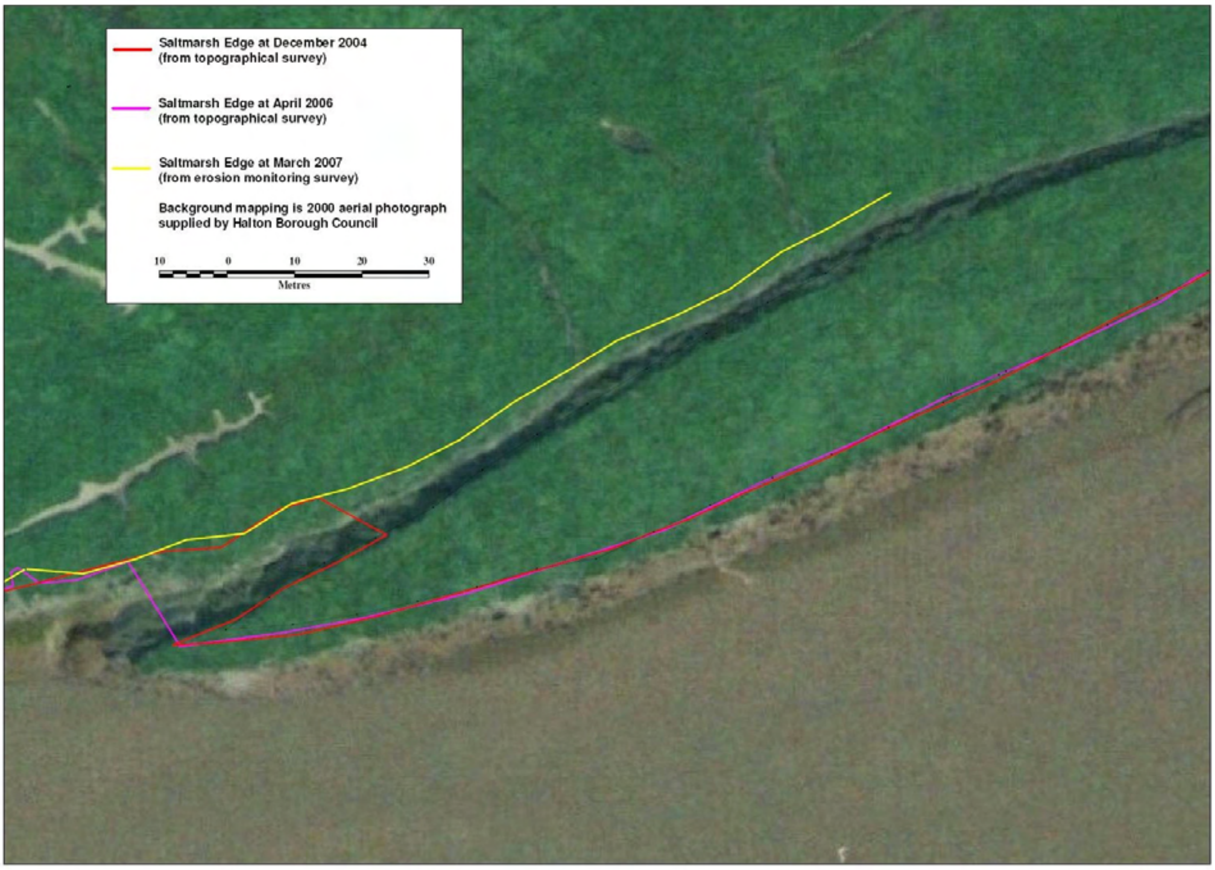


Figure 7.19 - Saltmarsh retreat, New Bridge crossing northern bank



Implications for Construction

7.4.54 The dynamic nature of the Estuary and the areas of saltmarsh loss that occur will necessitate extra care being taken in temporary works design. The mobile characteristic of the channels in the Upper Estuary is a major feature and analysis of the long-term morphological record shows that it is not possible to predict migration of channels. Were channels to become attached to a structure this would be a significant change to the character of the Estuary and were they to become fixed to the edge of the saltmarsh, this would increase the rate of erosion. Both situations should be avoided.

7.4.55 Any structures or material placed in the Estuary will have to be positioned so that the construction is not compromised during movement of the sediment. Most significantly, it is important that the temporary works are completely removed post-construction to ensure that there is no impact on the long-term mobility of sediment within the Estuary. The movement within the soft material is such that leaving any hard features within the Estuary would have an effect on its long term behaviour.

7.4.56 Methods of reaching the construction areas have to be considered in the context of these rapidly changing profiles. This will also have to be considered in assessing risks to the health and safety of construction workers.

7.4.57 All temporary structures will be removed upon completion of the New Bridge. This includes the cofferdams, the aligned jetty and stone causeways on the saltmarshes. This will ensure that their impacts are limited. The Estuary is predicted to recover quickly from their presence (see 7.8.52). The dynamic nature and tidal flows of the Estuary mean that voids left by removal of structures will naturally infill and consequently no additional works will be needed. Natural infilling is the most desirable option as it minimises further disturbance to the environment and ensures no additional foreign material is added to the Estuary.

Implications for Operation

7.4.58 The sand bar located within the central part of the Estuary in the Study Area is relatively stable. A channel forms through this bar very infrequently and thus such a channel will rarely, if ever, coincide with the position of the central tower for the New Bridge.

7.4.59 However the north and south towers will be close to or in channels on a regular basis. It is thus necessary to ensure that the design of the towers takes account of the depth of scour that may occur and the impact this may have on channel migration. The impact the towers will have on hydrodynamics in the Estuary can be minimised by reducing their plan area and adopting as close to a circular shape as possible. This then presents the same aspect to tidal flow no matter from which direction this impinges on the tower.

7.4.60 In addition, in order to minimise the extent of scour action, the top of the pile caps will be set beneath the depth of any scour. This level will be based on scour occurring in the deepest channel that is likely to occur adjacent to a bridge tower in the Study Area.

Summary

7.4.61 All datasets conclude that the main channel splits into two just north of Hempstones Point and then converges just upstream of the Runcorn Gap. One channel runs along the north bank (referred to as the north channel) and one along the south bank (the south channel). This channel arrangement has meant that there have been two areas of sand bars, one to the south of Cuerdley Marsh and one in the centre of the Estuary near to the Runcorn Gap, although the exact positions have varied.

7.4.62 The aerial photographs suggest that there are small changes in the physical location of the seaward edges of the saltmarsh with an overall trend of saltmarsh loss through erosion and reclamation. The current direct measurements of the saltmarsh edge indicate that saltmarsh loss is continuing at Astmoor but that the edge at Widnes Warth is relatively stable.

7.4.63 The results from the accumulation of the aerial photographs, bathymetric surveys and EMPHASYS data confirms that the low water channel system is very dynamic.

7.4.64 By comparing the positions which the channels have occupied at different times in the past, the frequency of a channel occupying a particular location can be estimated for this dataset. This analysis confirms that a channel coinciding with the proposed position of the central bridge tower is likely to form only very rarely. Conversely it is very likely that the chosen positions for the northern and southern towers will coincide with the position of a channel at times as these channels migrate within the Study Area.

7.5 Short-term morphology

Introduction

7.5.1 In order to investigate morphological changes over a shorter time scale, as part of the baseline assessment, aerial photographic surveys have been carried out over the period 8 March 2005 through to 20 June 2007, supplemented with seven topographic surveys covering the same period. Full details are provided in Appendix 7.3.

7.5.2 A morphological trend defined from observations taken infrequently over a long period of time is uncertain in such an estuary and only provides a snapshot of the state of the estuarine environment captured at a particular point in time. Such observations with daily, weekly, monthly and annual degrees of morphological change are not recorded.

7.5.3 In order to increase the level of understanding of the morphological changes that occur in these shorter time periods in the Upper Mersey Estuary, the following surveys from the period March 2005 and March 2007 were used in analysis:

a. Oblique aerial photography, and
b. Topographical surveying.

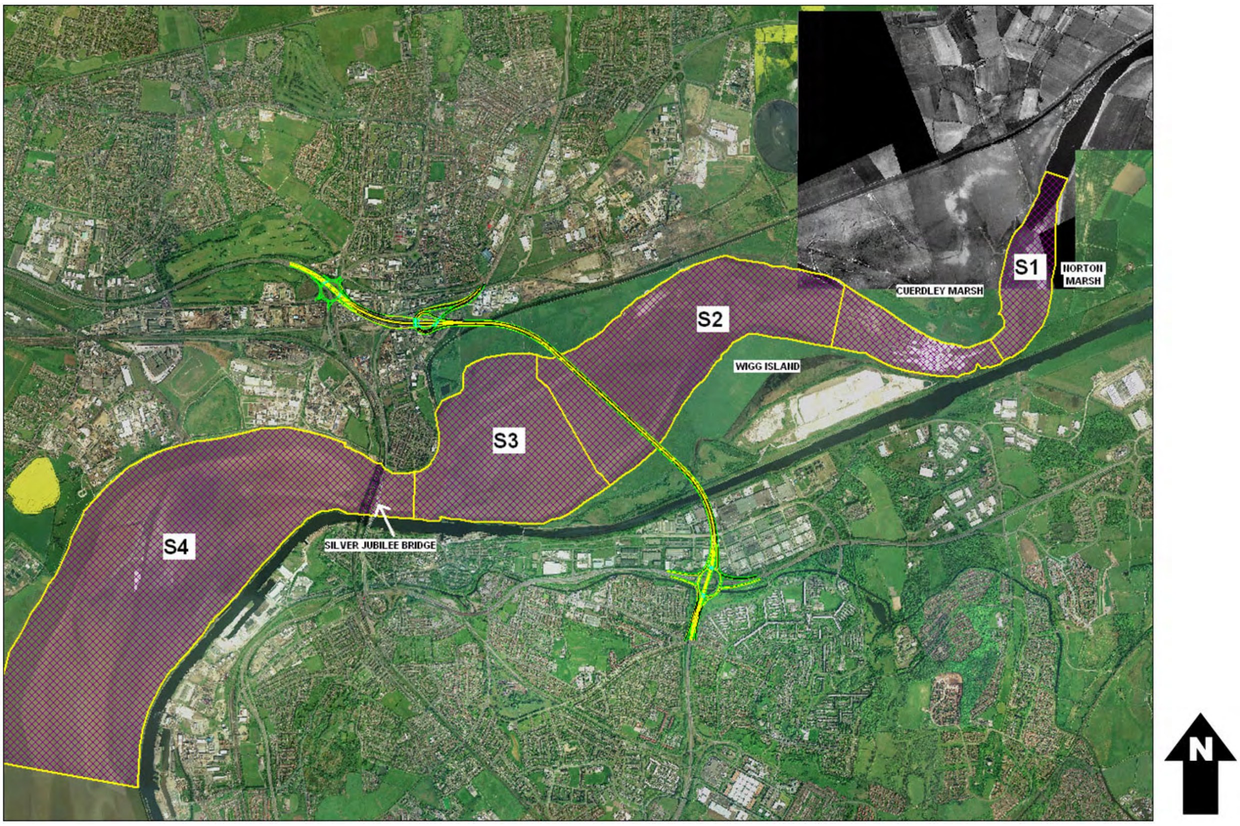
7.5.4 These surveys concentrated on the position of the sandbanks, channels and saltmarsh edges and the changes and development in these features over relatively short periods between surveys.

7.5.5 The two methods employed are complementary in that oblique aerial photography is rapid and repeatable but cannot be used to measure precise distances, whereas topographical surveys are a slower method of data collection, but provide accurate point location and distance data.

Oblique Aerial Photographic Surveys Methodology

7.5.6 For the purposes of observation and documentation of channel change, the Study Area was sub-divided into four broad sections (Figure 7.20).

Figure 7.20 - Location of the four sections within the Study Area



7.5.7 The sections start from the upstream extent of the Study Area to the downstream extent, illustrated in Figure 7.20, namely:

S1 - Area between Cuerdley Marsh and Norton Marsh (Norton Marsh);
S2 – Active area around Wigg Island encompassing the proposed New Bridge area of the Project and terminating east of Hempstones Point (Wigg Island downstream view);
S3 – Area upstream of the SJB at Runcorn Sands (Wigg Island upstream view); and
S4 – Area downstream of the SJB terminating at Hale Head (Silver Jubilee Bridge).

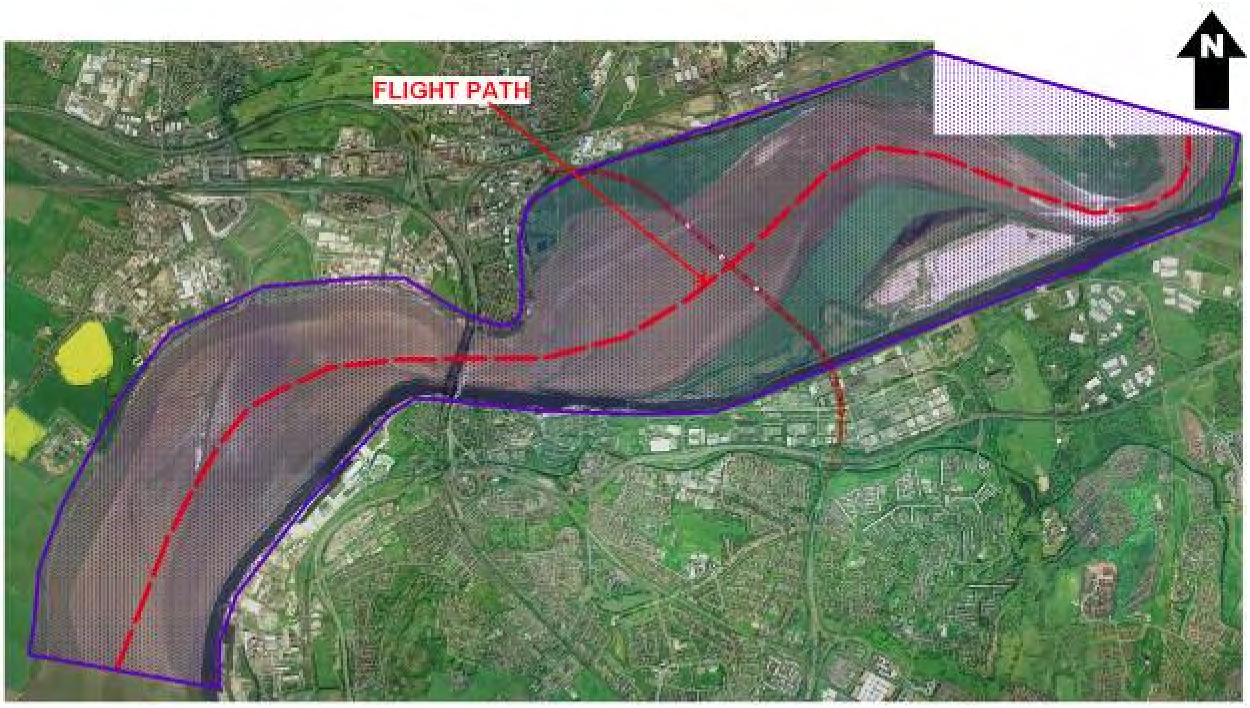
7.5.8 The proposed alignment of the New Bridge falls into the downstream part of S2. The names in parenthesis will be referred to as the section names for brevity. The proposed alignment of the New Bridge falls into the downstream part of S2.

7.5.9 S1, S3 and S4 were included in the aerial surveys 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 the most dynamic in terms of the changing patterns of the low water channels.

Aerial photographic flights

7.5.10 The aerial photographic surveys were planned to provide replicated flight paths over the Study Area from which images could be taken to record channel change. Flights were made around the time of low water to show the locations of the low flow channels. A small number of flights were also undertaken at high water to determine the extent of inundation on the saltmarshes. The flight path was replicated as far as weather conditions allowed and photos were taken from a similar position, angle and altitude (see Figure 7.21). Flights were only undertaken during good weather conditions with high cloud cover (i.e. not lower than 600ft). This ensured that, as far as possible, replicated views of the channel were taken on each flight.

Figure 7.21 - Flight path showing the spatial extent of the data capture of the oblique aerial photographs within the Study Area



7.5.11 In order to determine the frequency of channel change, the flights were undertaken according to the following basic schedule:

a. Every day for one week (25 April to 1 May 2005);
b. Every other day for the following two weeks (2 May to 15 May 2005);
c. Every week for the following two months (16 May to 14 July 2005);
d. Every month for the twenty three months (15 July 2005 to 21 March 2007).

7.5.12 The sequence of flights was used to establish the necessary frequency of surveys to capture the variability of the morphology of the Estuary within the Study Area. The observations on the early flights indicated that monthly surveys would adequately show the development of sand bars and channels.

7.5.13 Additional daily flights were undertaken during the topographic surveys and weekly flights during part of 2006. The full schedule is given in Appendix 7.3.

Views chosen for subsequent analysis

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

7.5.15 The five views are:

a. View 1 (Figure 7.22) of S1 is taken from the southern edge of the Estuary looking upstream across Norton Marsh;

b. View 2 (Figure 7.23) of S2 is taken from the northern edge of the Estuary and looks south towards the apex of Wigg Island. The New Bridge would cross this view;
c. View 3 (Figure 7.24), also of S2, looks northeast with Wigg Island visible on the right. The New Bridge would cross this view;
d. View 4 (Figure 7.25) of S3 is from the southern edge of the Estuary and shows the area immediately upstream of the SJB; and
e. View 5 (Fig 7.26) of S4 covers the area down-estuary of the SJB.

Figure 7.22 - View 1 – S1 Norton Marsh from the south west

Figure 7.23 - View 2 – S2 Wigg Island downstream view 01.06.2005

Figure 7.24 - View 3 – S2 Wigg Island upstream view (Hempstones Point and Wigg Island visible on the right) 24.04.2005

Figure 7.25 - View 4 – S3 Runcorn Sands (the area up-estuary from the SJB)

Figure 7.26 - View 5 – S4 Silver Jubilee Bridge

Image selection, rectification, digitizing and analysis

7.5.16 A database was established to hold the oblique aerial photographic record. For each aerial photograph, the following details were logged onto a database: date and time of the flight, description and location/orientation of the image, state of tide, altitude, weather conditions and the Study Area (S1; S2; S3 or S4).

7.5.17 The images of the representative views were selected from each flight and the position of the dominant channel documented. Images of representative views from subsequent flights 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.

Analysis of images

7.5.18 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, or control, to which later images were rectified.

7.5.19 Each subsequent flight provided several more images of each area and the best of these was selected, again based on ground clarity, area covered and angle for use in the analysis. Successive selected images were rectified to the original base image using points on the ground that were least likely to have moved between the images – for example, a road junction or pylon. The images could not be rectified to a flat grid system, so the scale varies between each image. The exercise allows comparison of images that were previously at different scales but does not permit distances between features to be measured accurately.

7.5.20 Once rectified, the outline of the ebb and flood channels, bars and saltmarsh were traced digitally, in order to identify any changes in the position of the low water channels or other features within the Estuary.

7.5.21 The photographic data and channel outlines were overlain in chronological order using ArcGIS software to track channel movements and to identify change. The images were analysed for morphological change and process, and features of interest were documented.

7.5.22 The information collected in the database 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.

Accuracy and Precision in Analysis of Images

7.5.23 Morphological changes can only be confidently identified provided these 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 effects relating to accuracy and precision can be identified:

a. Parallax error from oblique aerial 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; and

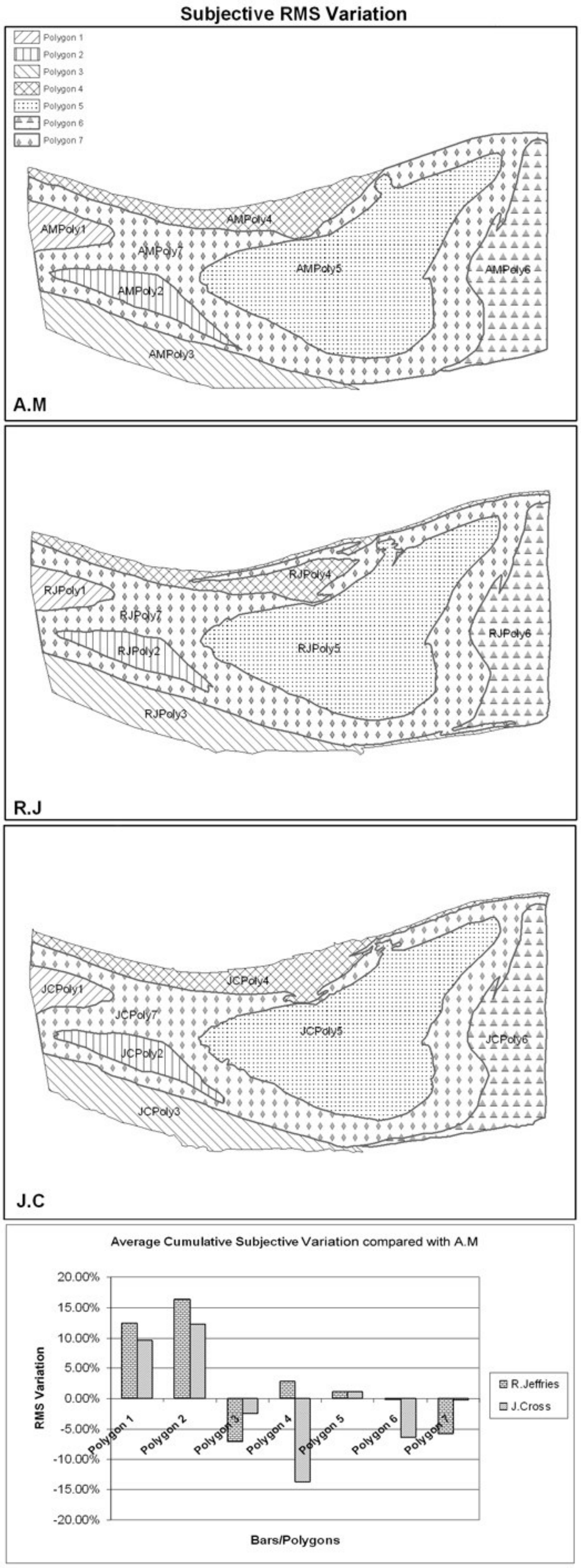
d. Tide-driven misconception. An area may appear different visually – even though no morphological changes have taken place - because the tide is at a different level.

7.5.24 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.

7.5.25 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.

7.5.26 Subjective (digitizing) variation was assessed by comparing the channel and bar polygons as digitized by three trained analysts. All operators had been trained to follow the boundary between water and sediment, thereby discriminating channels and bars. Figure 7.27 shows the average cumulative Root Mean Square (RMS) variation achieved from both the interpretation of the geomorphological bars and the accuracy in hand tracing.

Figure 7.27 - Subjective tracing variation



Topographic survey methodology

7.5.27 Topographic surveys were undertaken to provide a recent empirical survey of the entire Study Area and give an indication of the vertical extent of channel change. Generally, the survey area covered the downstream part of S2 and the whole of S3 as this was considered to be the area most likely to be impacted by the New Bridge.

7.5.28 The first survey was limited in spatial extent to Runcorn Sands because access using the initial survey methods and equipment was difficult to other areas of the Estuary. During later surveys, techniques (described below) were employed to access other parts of the Estuary, and the survey area was extended. The surveys were undertaken by a specialist company according to the following programme given in Table 7.8.

Table 7.8 - Record of Topographic surveys of Study Area

Date	Dates survey carried out
December 2004	Partial
February 2005	02.02.05 – 05.02.05
April 2005	27.04.05 – 30.04.05
May 2005	12.05.05 – 15.05.05
July 2005	11.07.05 – 14.07.05
October 2005	8.10.05 – 12.10.05
March 2006	28.02.06 – 03.03.06
April 2006	17.04.06 – 21.04.06
March 2007	21.03.07 – 23.03.07

7.5.29 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. 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 or dangerous to access had more sparse coverage. Each survey took 3-5 days to complete, depending on access and weather conditions.

7.5.30 The topographic surveys generated detailed geographic position and height data within the Study Area. The data were subsequently converted into a three dimensional representation of the Estuary bathymetry using ArcGIS.

7.5.31 The survey completed in February 2005 has been used as the base bathymetry for the 2005 Bathymetry model used in the hydrodynamic and morphological modelling (see Figure 7.7, paragraph 7.4.5).

7.5.32 Additionally, two fixed transects were established to provide a baseline from which repeat surveys were taken of the margins of the saltmarshes at Astmoor and Widnes Warth on the southern and northern banks of the Study Area at locations where the New Bridge will cross. This was to monitor saltmarsh erosion/accretion at the area in which the Project makes landfall, either side of the Estuary. These finer scale surveys have been tied in with the topographic surveys undertaken at a larger spatial scale. The results of this monitoring have been discussed in paragraph 7.4.53.

7.5.33 To provide a greater understanding of the short-term changes within the Study Area, the rectified and traced images of the oblique aerial photographs have been overlain and compared. The photographs were then examined and interpreted visually for other evidence of morphological change.

7.5.34 The results of this comparison for each of the sections (S1- S4) are shown in tables within Appendix 7.3. The tables provide 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 SJB. Figure 7.28 is an example of the data. A summary of the results is presented below.

Figure 7.28 – Example from tables of analysis of short term morphological change. Taken from Appendix 7.3

SI – Norton Marsh – Recording Channel Change

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

Limitations of short-term morphological assessment

7.5.35 Whilst every attempt has been made to arrive at a methodology to observe, describe and evaluate these short-term morphological processes operating in the Upper Estuary, the estuarine processes in the Study Area are chaotic.

7.5.36 In addition, estuarine morphology is the product of a number of complex and inter-related environmental parameters. These include geological controls, tidal regime, sediment dynamics, wind and wave climate, and fluvial flows as well as anthropogenic influences such as dredging and the construction of training walls. Such influences and interrelationships are inherently difficult to predict.

7.5.37 It is very difficult to provide a precise interpretation of the processes. However it is possible to look at the frequency of given channel positions occurring to provide an indication of likely future locations.

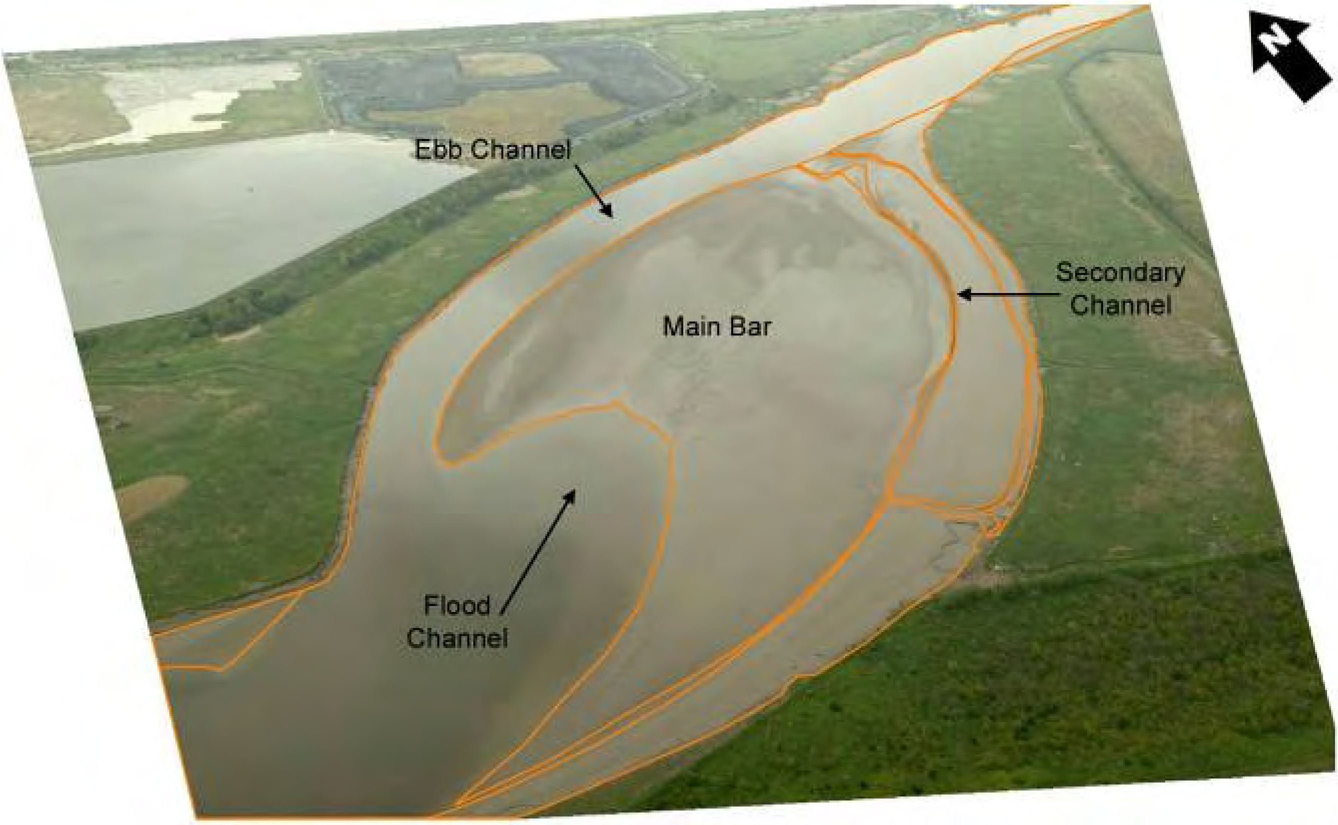
Results of morphological monitoring

7.5.38 The full results of the aerial photographic analysis are given in Appendix 7.3. Examples of the scale and rate of change of morphology that has been observed are described in the following paragraphs.

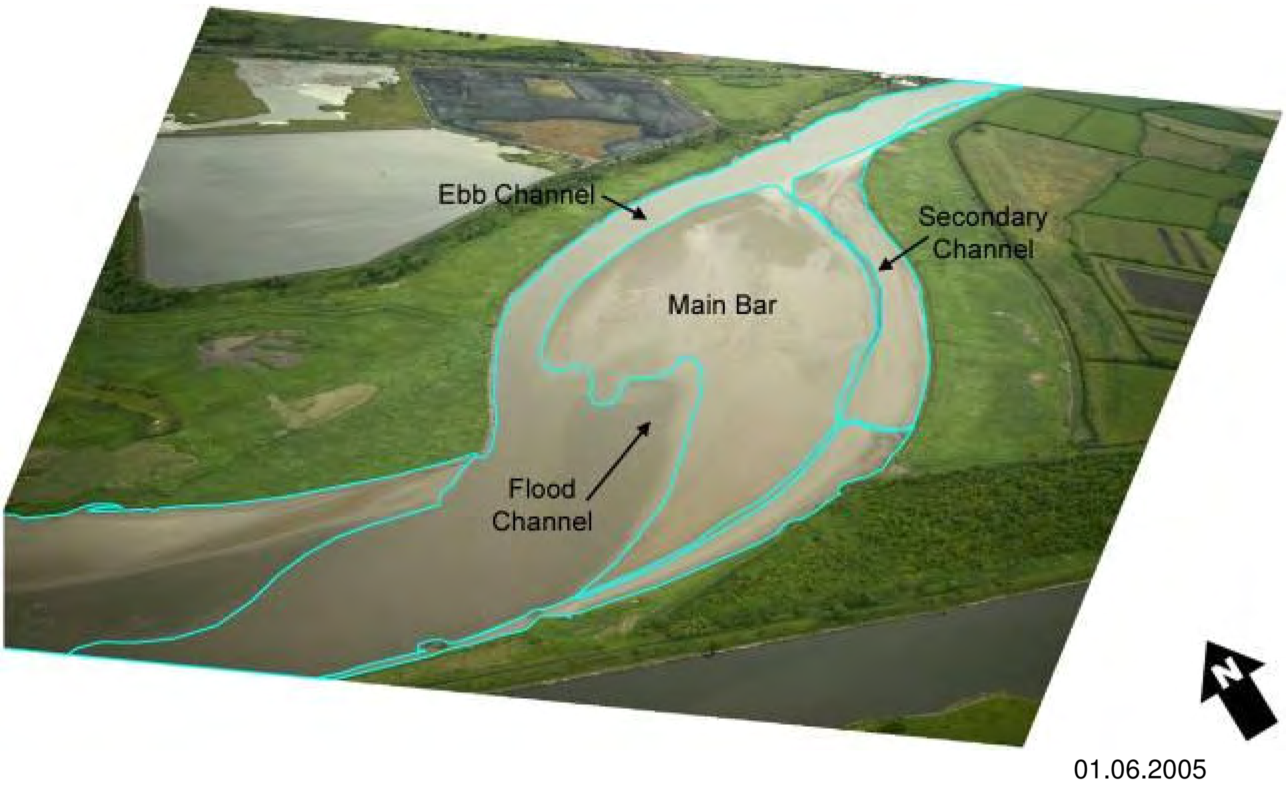
S1 Norton Marsh

7.5.39 Figures 7.29a and 7.29b show a sequence of aerial photographs covering the period 30 April 2005 to 14 April 2006. At Norton Marsh a low flow channel is consistently visible along the north bank; this was stable during the study period (March 2005 – March 2007). A large bar occupied the central part of the Estuary, and again this was stable during the study period. However, secondary channels were sometimes visible on this bar. A flood channel cuts into the bar. The only observed change was associated with 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.

Figure 7.29a - The location of low water channels at S1 Norton Marsh

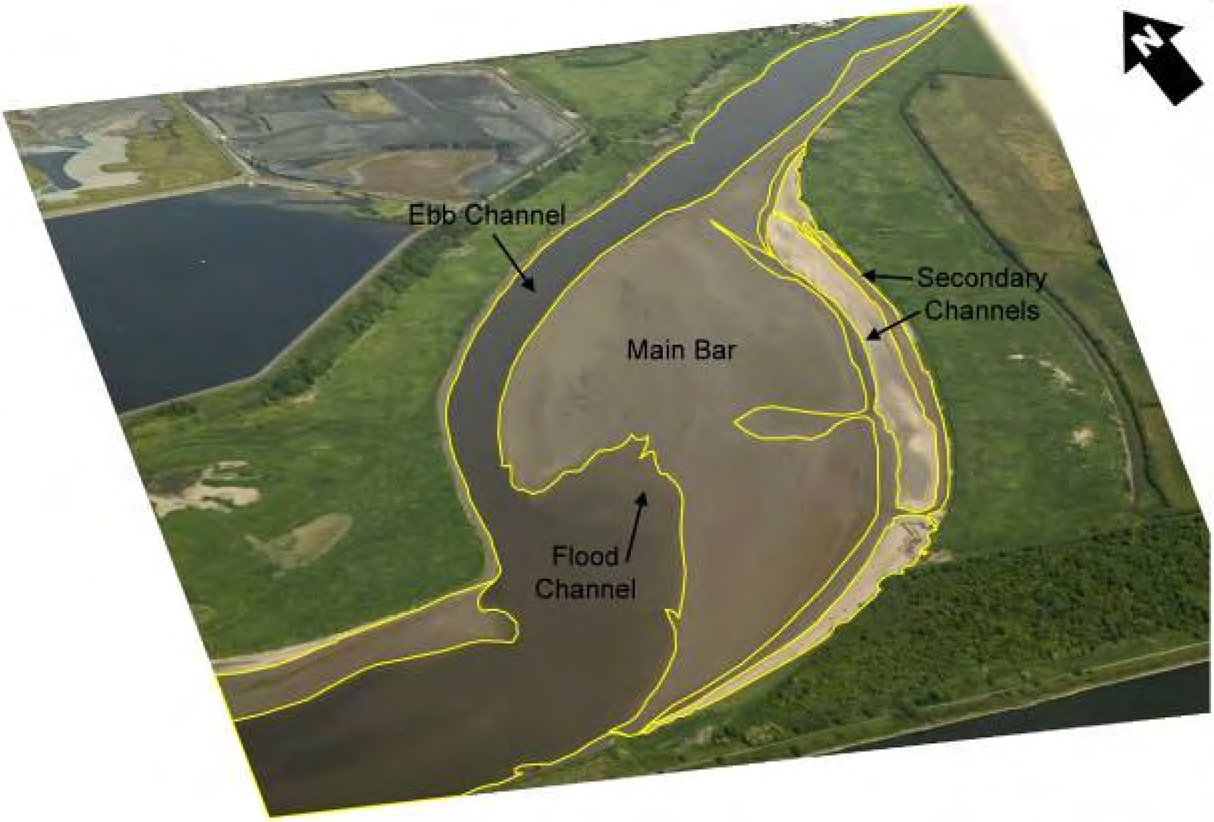


30.04.2005

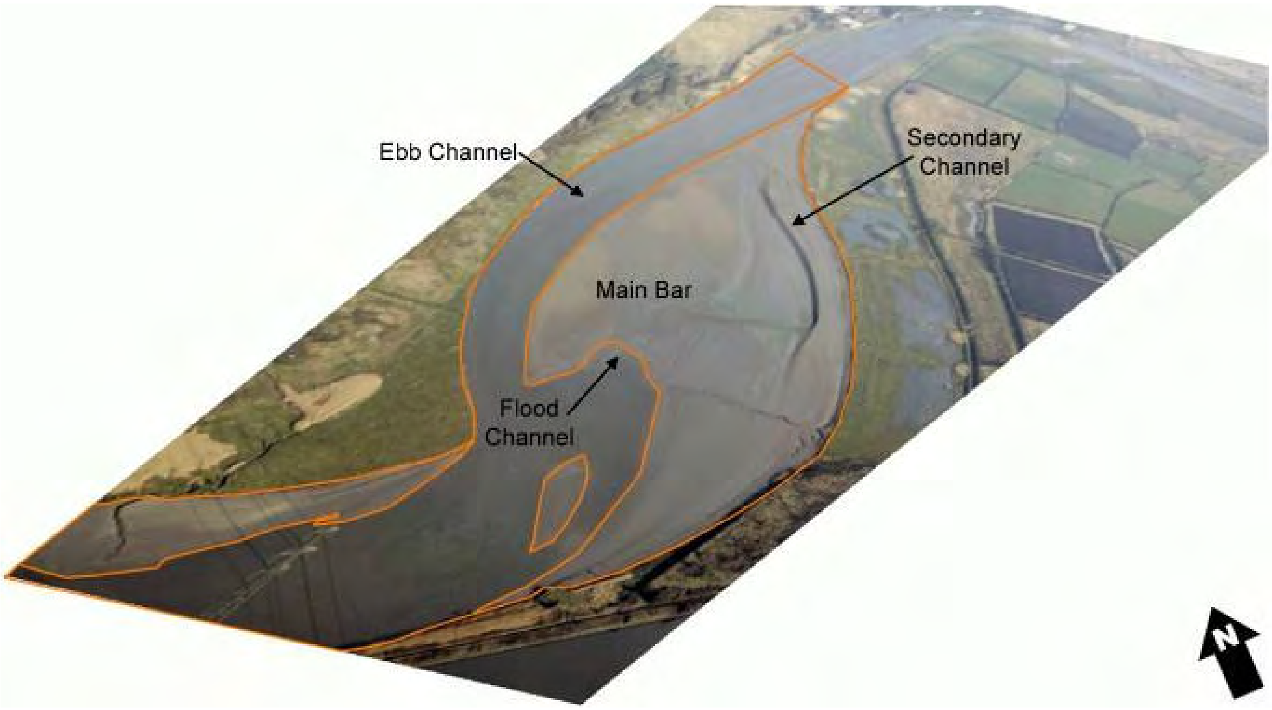


01.06.2005

Figure 7.29b - The location of low water channels at S1 Norton Marsh (Continued)



08.06.2005 (two secondary channels)



14.04.06

S2 Wigg Island – downstream view

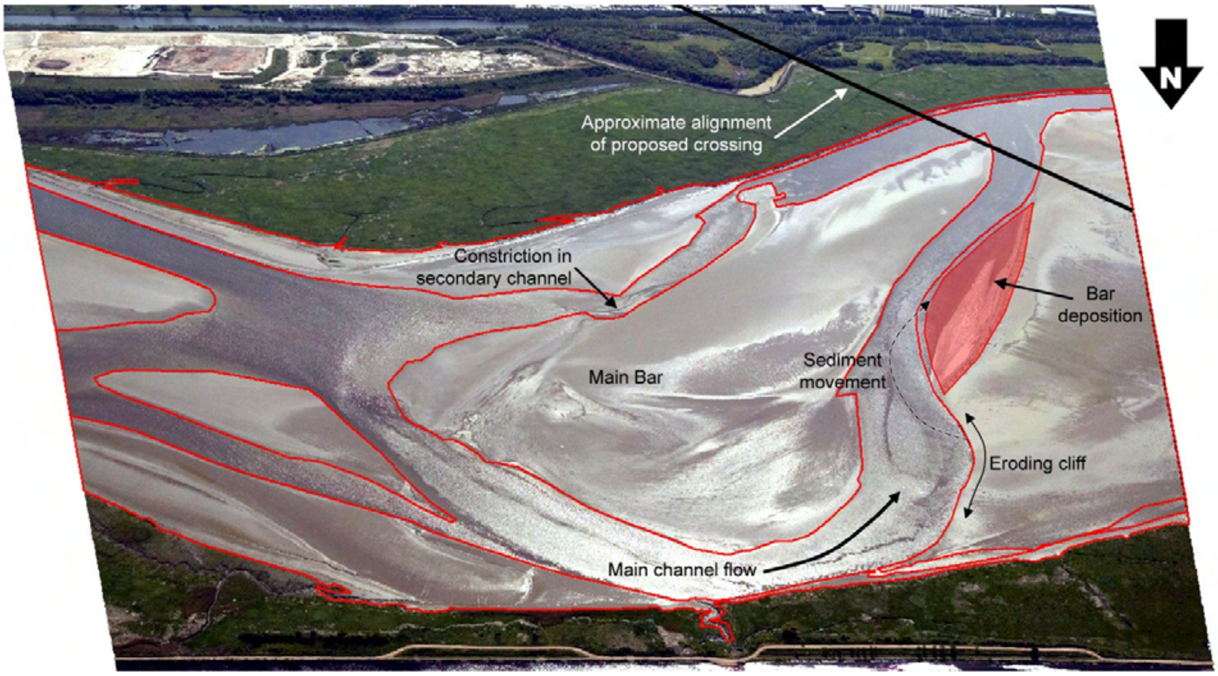
7.5.40 Figures 7.30a and 7.30b show a sequence of aerial photographs covering the period 12 May 2005 to 20 July 2005. It shows a dynamic ebb channel that was adjusting its boundary. Most flow was along the northern bank of the Estuary (bottom of image), where erosion is taking place along the outer bend of the meander. This erosion has several impacts: firstly it supplied a source of sediment to the channel which was moved downstream and some was deposited as a bar in the lee of a small headland. Secondly, the erosion (and associated downstream deposition) changed the overall shape of the channel, causing it to lengthen. This reduced the bed gradient. A second, smaller flood channel was visible on the opposite side of the main channel.

7.5.41 Over the two weeks prior to 1 June 2005, a progressive change in channel location and form has occurred. During this time the number of channels and bars within the area remained stable. But the main ebb channel was longer and a point bar has been deposited downstream of the erosion, leaving the former channel line – now an eroding cliff – behind. The secondary channel was now intruding into the main bar. The secondary channel that runs across the bar neck was wider.

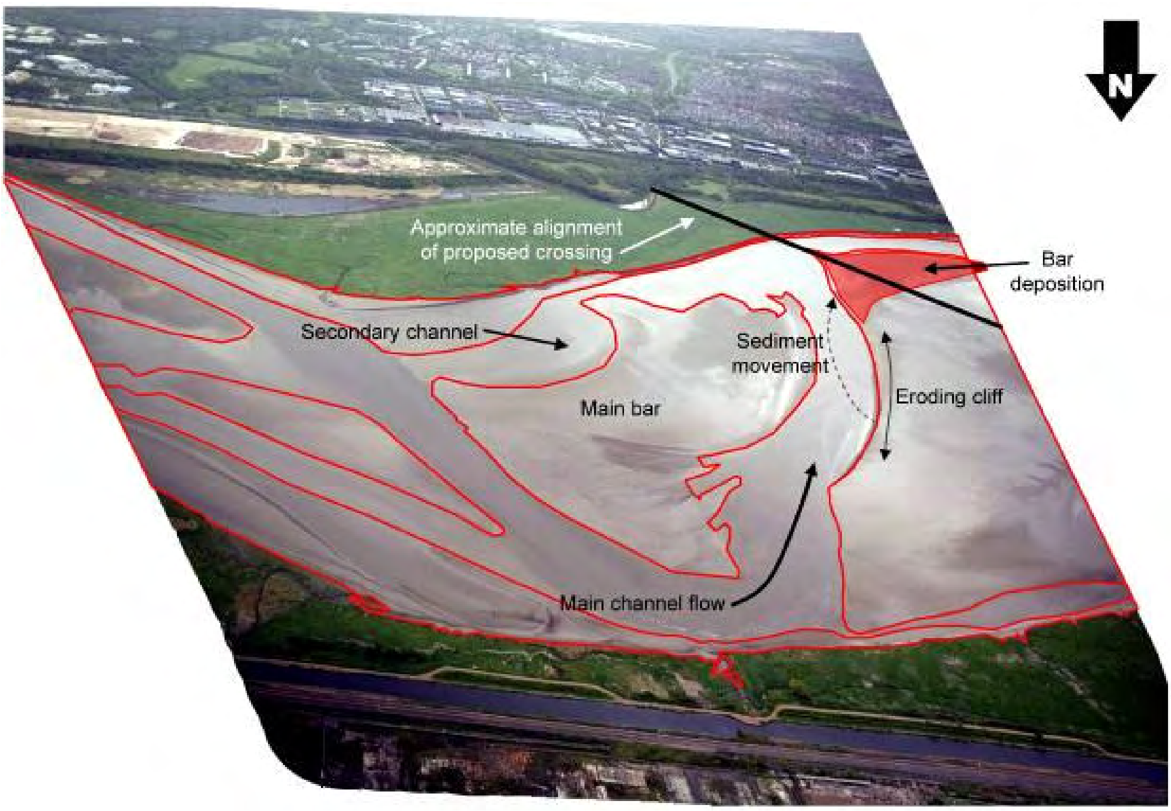
7.5.42 This process of channel lengthening continued for at least the next two weeks and then a major change occurred. The main ebb channel switched to a new location in the centre of the main bar, abandoning its former location next to the north bank. By 20 July 2005 the main channel has switched to a more central position.

7.5.43 As erosion progressed during the previous 6-8 weeks, the dominant ebb channel lengthened, and its gradient reduced. This also reduced stream power, which was 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 ran across the neck of the main bar. The consequent increase in stream power in this secondary channel would increase its carrying capacity until it became the main channel carrying the majority of the ebb flow. The channel continues to adjust its boundary and the cycle recommences.

Figure 7.30a - The location of low water channels at S2 Wigg Island downstream view



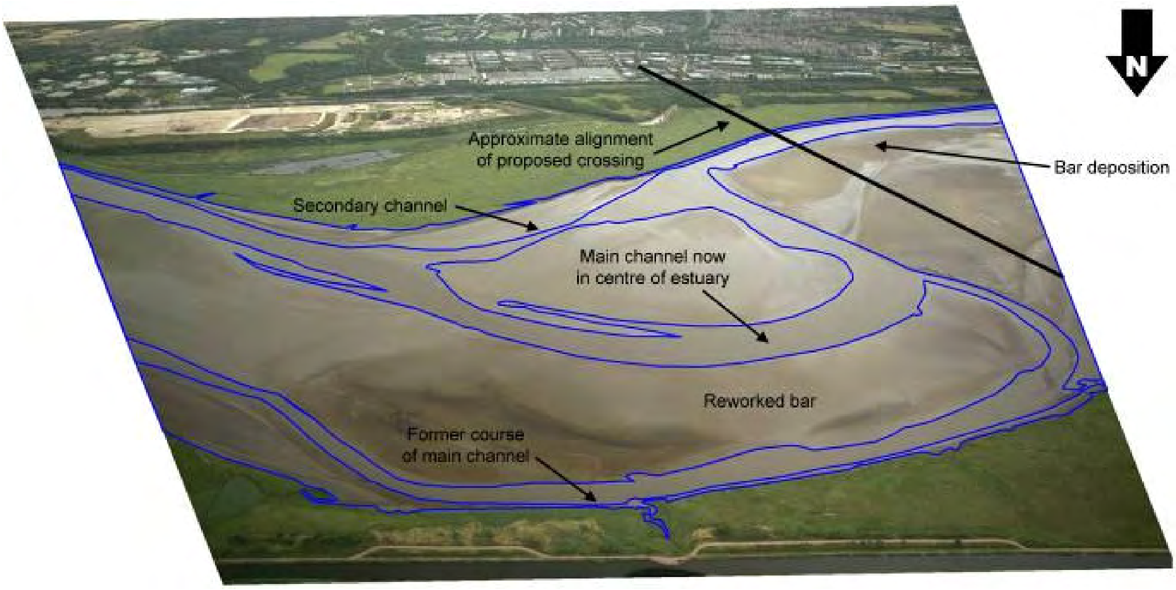
12.05.2005



01.06.2005

Figure 7.30b - The location of low water channels at S2 Wigg Island downstream view (Continued)

15.06.2005



20.07.2006

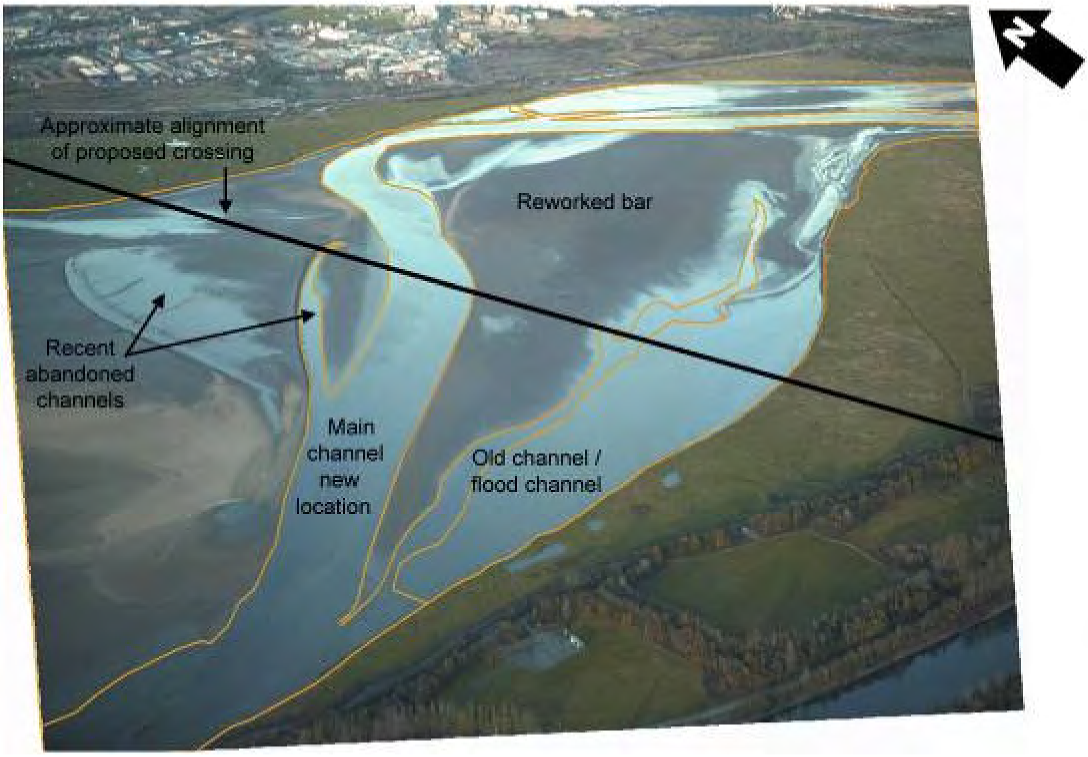
S2 Wigg Island – upstream view

7.5.44 Channel lengthening and switching were observed in several locations on a number of occasions. Figures 7.31a and 7.31b show a sequence of aerial photographs from the period 25 November 2005 to 19 June 2006. These demonstrate the scale of change that can occur.

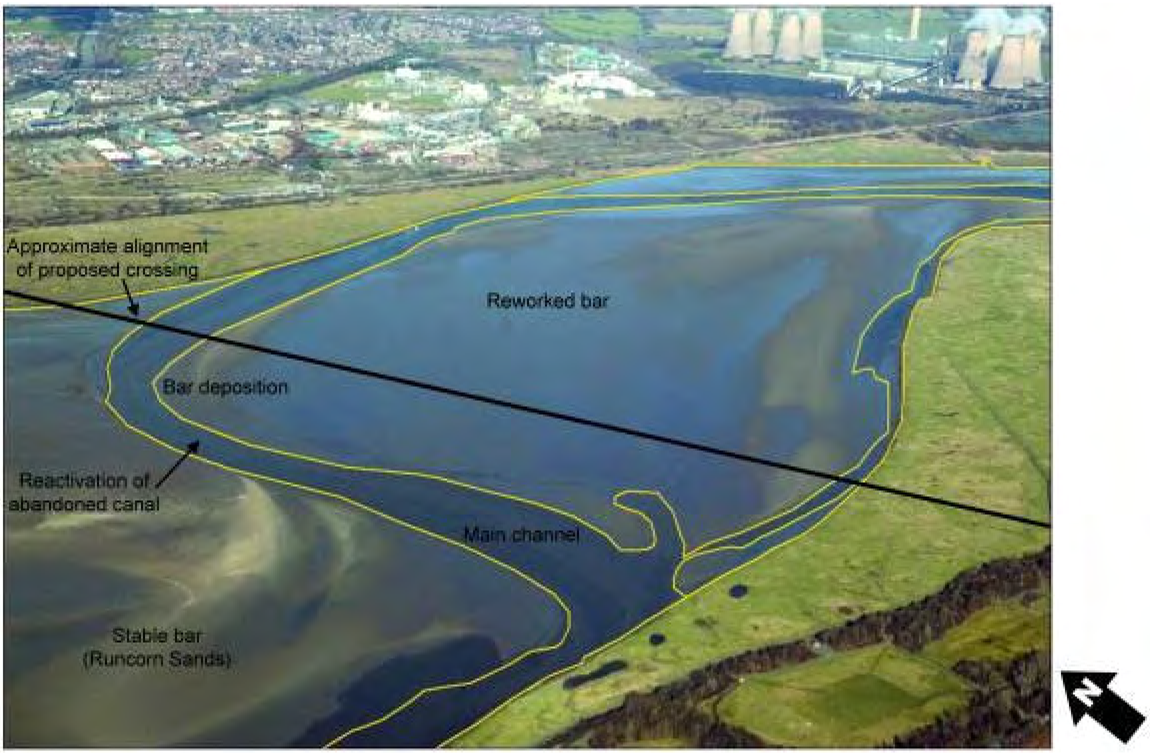
7.5.45 Prior to 25 November 2005, the main bar had appeared to be relatively stable. However, this image clearly shows a significant shift in the main channel forcing its way across the bar and depositing reworked material upstream. The main ebb channel had once more moved to the north bank of the Estuary. The main channel now cuts obliquely across to the southern bank, whereas it previously abutted the bank perpendicularly. The photograph 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. By 20 February 2006, this channel had reactivated and the zone of activity had moved down the Estuary. Subsequently, the photograph taken on 25 May 2006, 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. Finally, on 19 June 2006 the photograph shows evolution of this channel: an increase in sinuosity and construction of the inner meander and deposition of the bend point bar.

7.5.46 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. This suggests that the broad shape of the Estuary – rather than the detail of the low flow channel – controls the direction of the flood tide, which sweeps up the Estuary and across the bar. 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 7.31a - Low flow channels, S2 Wigg Island upstream view

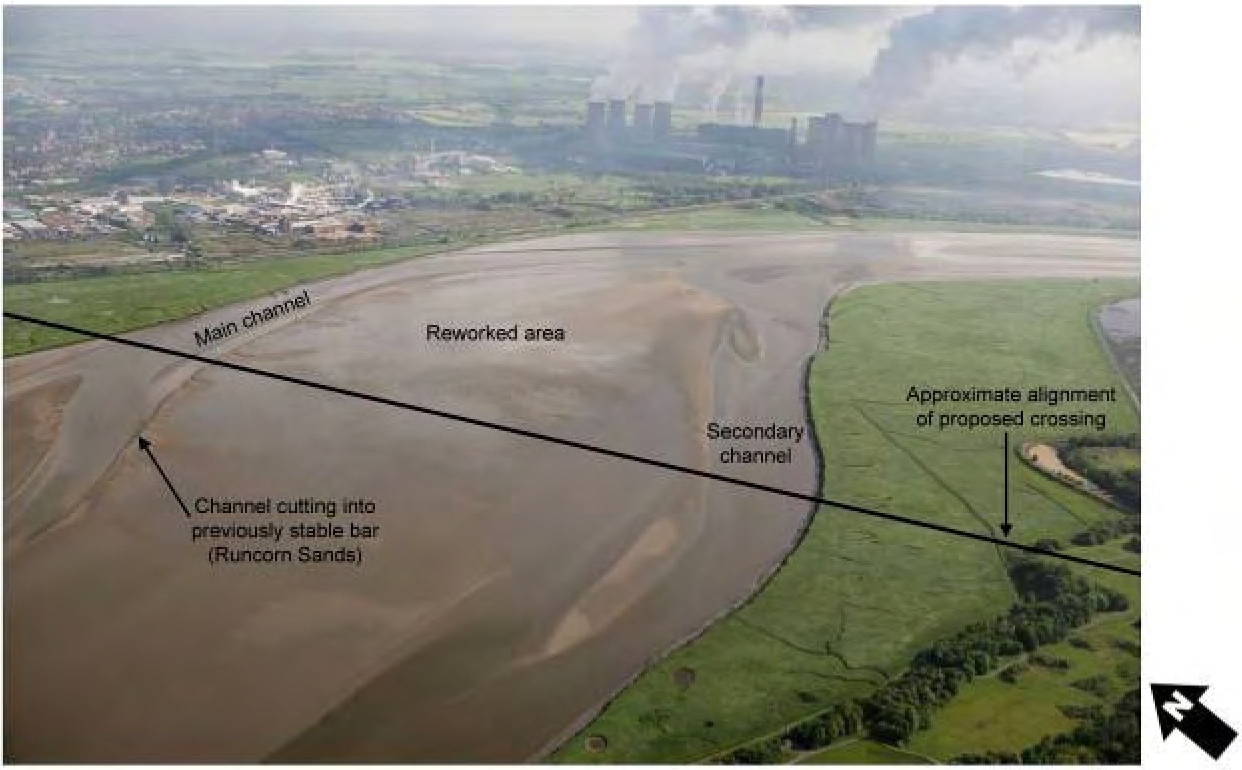


25.11.2005



20.02.2006

Figure 7.31b - Low flow channels, S2 Wigg Island upstream view (Continued)



25.05.2006

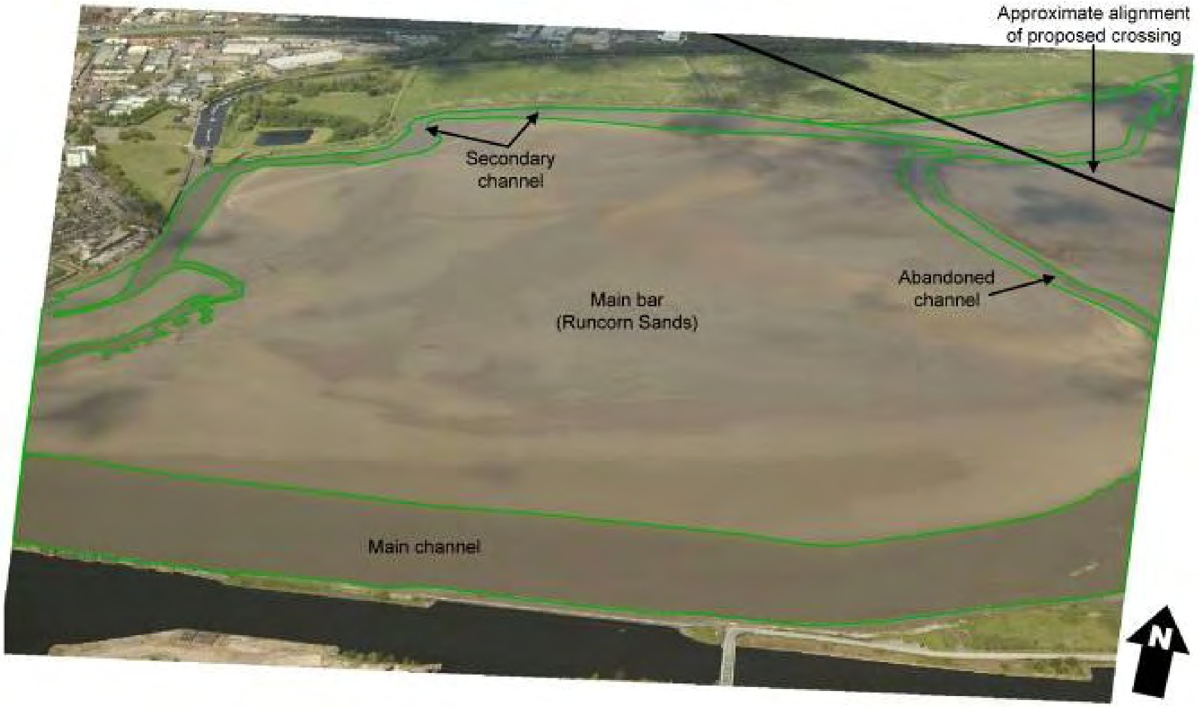
19.06.2006

S3 – Runcorn Sands

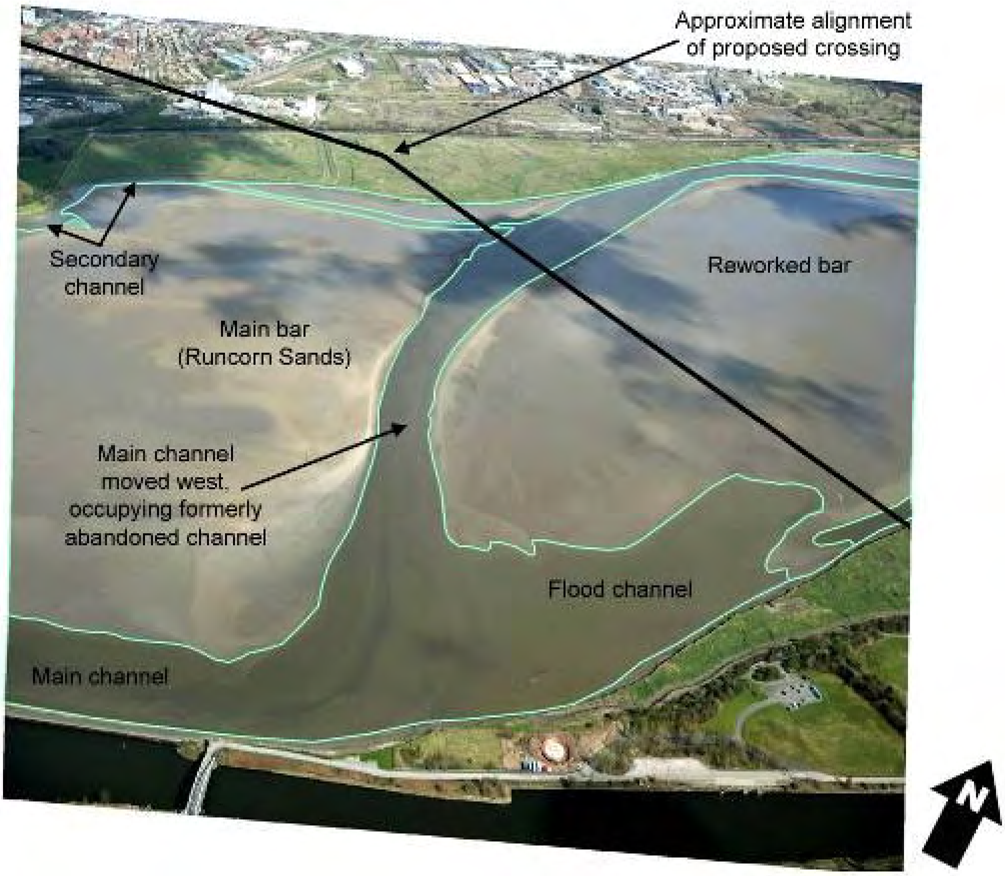
7.5.47 The overall pattern that emerges from this area is one of medium-term (approximately annual) stability, followed by a sudden change in ebb channel location (see Figures 7.32a and 7.32b). The most common condition from the aerial photographic record is of a large and relatively stable bar occupying the centre of the Estuary, flanked to the south by the main channel and to the north by a secondary channel (29 April 2005). Both of these channels carry flood flow and ebb flow. To the east on the 29 April 2005 image, lies an abandoned channel that shows evidence of slight reactivation.

7.5.48 However, the images taken between 14 April 2006 and 19 June 2006, show a major change in position of the main channel towards the west. This underlines the fact 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 7.32a - Low flow channels, S3 Runcorn Sands



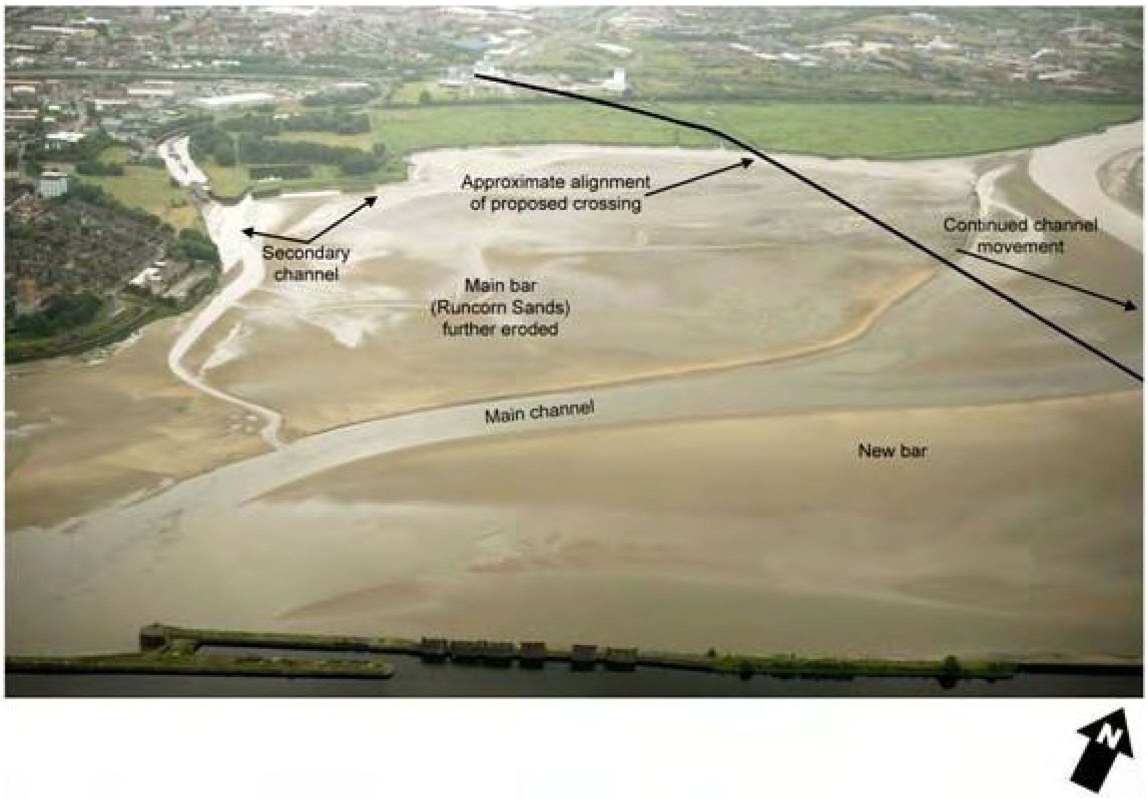
29.04.2005



14.04.2006

Figure 7.32b - Low flow channels, S3 Runcorn Sands (Continued)

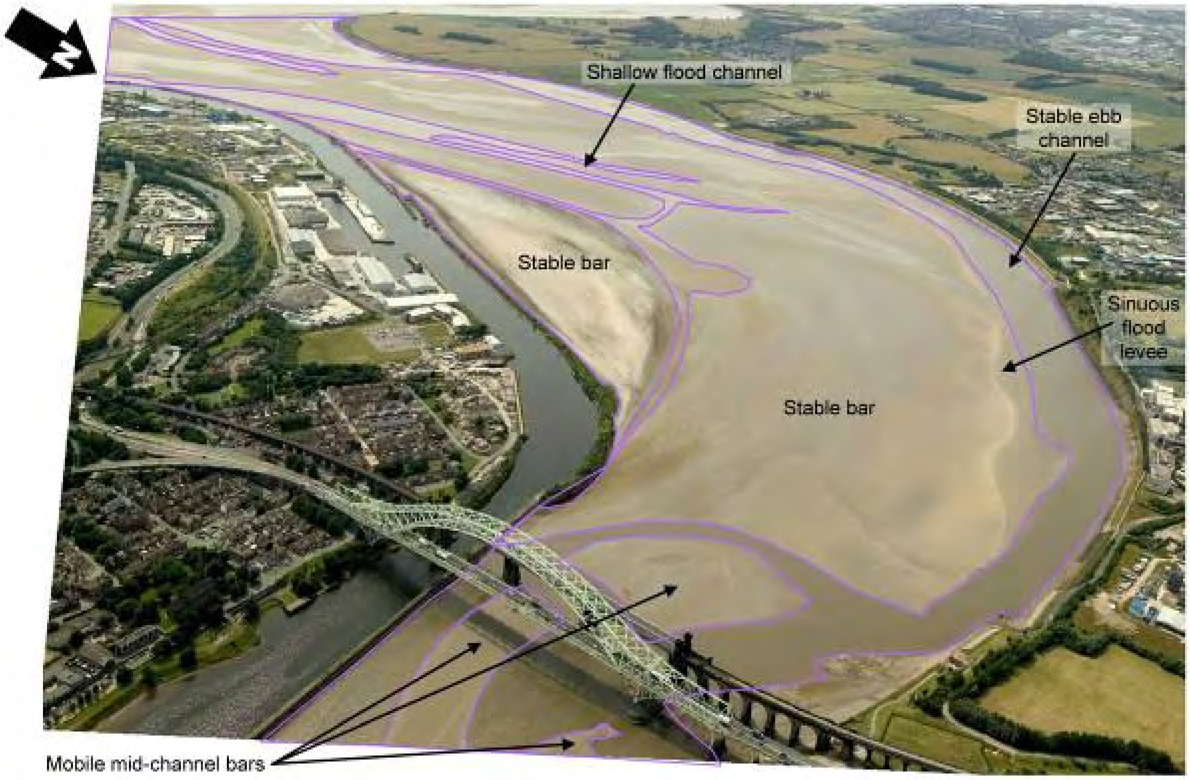
25.05.2006



19.06.2006

S4 – Silver Jubilee Bridge

Figure 7.33 - Channel locations at S4 Silver Jubilee Bridge 13.07.2005



7.5.49 Throughout the sequence of images available, the geomorphology of S4 is consistent and, when compared with other sections of the Study Area (especially S2), the majority of the area is relatively stable. A dynamic zone exists under the SJB, where multiple channels shift location at irregular intervals (Figure 7.33).

7.5.50 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:

a. Splitting and migration of the dominant channel;
b. Shifting of a mid-channel bar present beneath the SJB and Railway Bridge; and
c. Movement of the flood levee on the main bar.

7.5.51 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 7.9). The channel splits immediately downstream of the SJB. 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.

7.5.52 Downstream of the bridge these channels invariably coalesce – the exact location varies over time – to form a large ebb channel that shows infrequent channel movement, most frequently flowing along the north bank of the Estuary.

Table 7.9 - Change from single to multiple channel state at S4 Silver Jubilee Bridge

Date	Activity	Single	Multiple
29/04/2005	Single channel	6 weeks	
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		
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.		16 weeks
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		
19/09/2005	Single main channel: secondary south channel now cut off and mid-channel bar removed.	12 weeks	
03/10/2005	Similar pattern to 19/09/2005		
25/11/2005	Split of main channel, this time into dominant southern channel and secondary northern channel, split by a new mid-channel bar		15 Weeks
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		
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	

Relationship between Channel Change and Tides

7.5.53 In order to explore the relationship between the tidal cycle and channel change, the nature of the tides between the dates of two images displaying clear morphological change was investigated. 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.

7.5.54 Photographic images and tidal data cannot be directly compared. Consequently 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.

7.5.55 Based on the assumption that the energy that 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) following the spring and autumn equinoxes (21 March and September 23).

7.5.56 At Old Quay Lock the largest spring tide recorded by the water level recorder varies from 0.9 to 6.4mOD (range 5.3m); the smallest neap tide varies from 0.9m to 2.5mOD (range 1.4m).

7.5.57 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 June 2005 and 22 June 2005 with only the influence of a neap tide between these dates.

7.5.58 The highest tidal events were recorded on 31 March 2006 and 20 September 2005. 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.

Relationship between Channel Change & Meteorological Effects

7.5.59 As with the relationship between channel change and astronomically-driven tides, evidence of channel change and numeric data regarding meteorological conditions cannot be directly compared to determine whether any relationship could be found between meteorological effects and observed channel change.

7.5.60 This is made more complex with the inclusion of several additional variables. Whereas the astronomically-driven tide can be identified as a singular variable, meteorological effects may comprise of several different elements including 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.

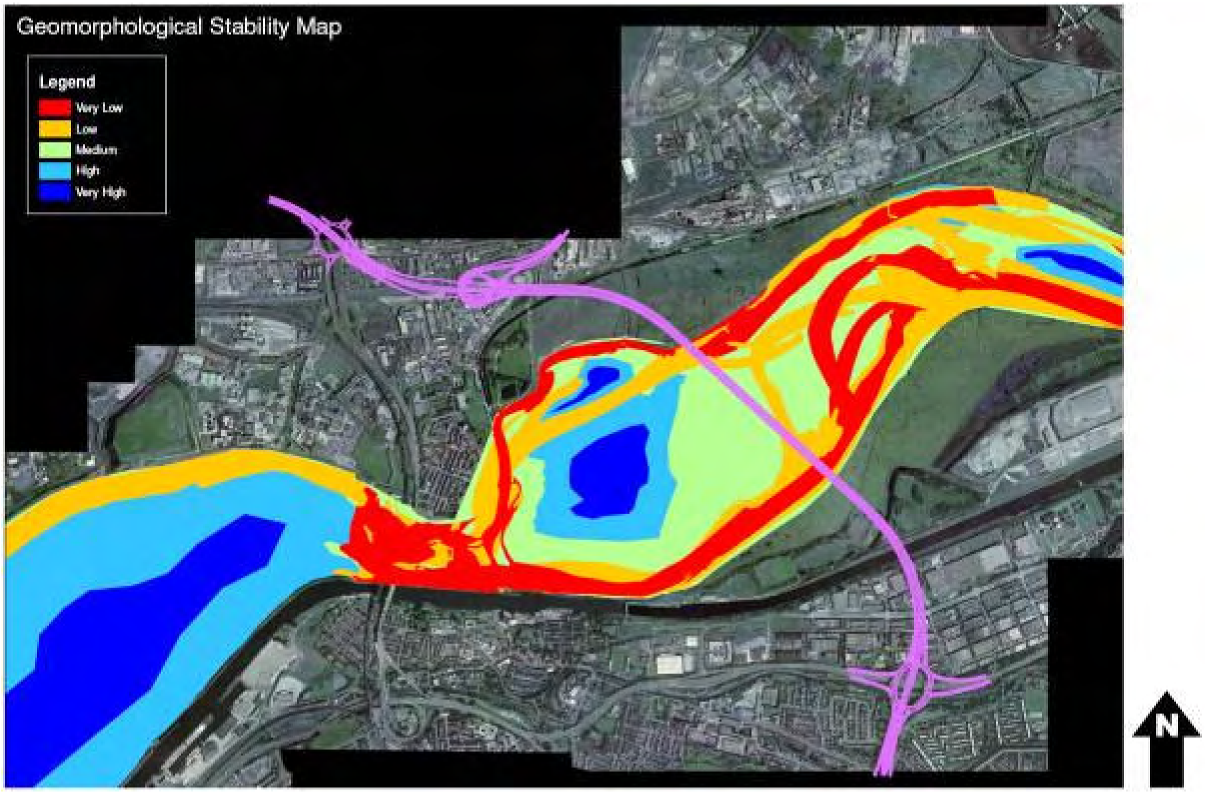
7.5.61 The pattern, influence and timing of these variables make distinguishing any relationship complex. It is extremely difficult to identify which (if any) of the meteorological variables may have caused any changes in channel morphology. It is possible that meteorologically-related change in channel morphology may be disguised by the energy of the incoming and outgoing tide.

Variation of Channel Position

7.5.62 By mapping the boundaries of different areas of morphological stability (i.e. where significant morphological change, such as channel movement, does not occur frequently), an assessment can be made of the relative stability of the areas where the New Bridge piers are proposed. Such a map needs to be based on geo-referenced information. Two geo-referenced data sources that cover the Upper Estuary were available to create a relative stability map: the channel locations derived from aerial photographs taken between 1945 and 2000; and the channel locations derived from topographic surveys undertaken between 2004 and 2006.

7.5.63 From each data source a polygon was taken that showed the water / sediment boundary. These polygons were overlaid and the number of occasions on which a given area changed gave an indication of how stable that area was. No area is completely stable as there is always a probability that morphological change will take place in such a dynamic system. From this analysis, a map was created that classifies the Estuary into zones of stability, ranging from areas of frequent channel movement (very low stability) to areas of infrequent channel movement (very high stability).

Figure 7.34 - Geomorphological stability zones within the Upper Mersey Estuary



7.5.64 The map shows relative stability: based on the available data, areas of 'high stability' are more likely to remain as sand bars and not be affected by the movement of migratory channels. This is not absolute however and these areas may be subject to some degree of change.

7.5.65 Each dataset used within the analysis provided a snapshot of part or all of the Upper Mersey estuary taken at a particular time. The physical processes that are being mapped move constantly within the Estuary, both across space and through time. The map must therefore be seen as a general guide of where change in the morphology of the Estuary occurs frequently and infrequently. In particular, the sharp boundaries between each stability class are an artefact of the model, and should not be used to infer that crossing a particular line within the Estuary will mean that a given area changes from 'stable' to 'very stable.'

7.5.66 The following general patterns can be seen:

a. Areas of instability tend to occur in zones parallel to the northern and southern banks, underneath the SJB, and in strips around Hempstones Point;
b. Areas of low stability are widespread in the area upstream of Hempstones Point, and tend to occur parallel to or around areas of very low stability – along the northern and southern banks, underneath the SJB, and in strips around Hempstones Point;
c. Areas of medium stability tend to occupy more central parts of the Estuary. Observations made with oblique photographs show that the areas of medium stability around Hempstones Point are, in fact, fairly active, and were reworked during 2005-2006; and
d. Areas of high and very high stability tend to occur in the widest parts of the Estuary.

Bathymetric Volume

7.5.67 An assessment has been made of the bathymetric volume of the Study Area. This was based on four surveys which covered the same area and are therefore directly comparable. The volume was calculated as the volume of the Estuary between the measured bathymetry and Mean High Water Spring tide levels. The results are set out in Table 7.10 below.

Table 7.10 - Surveys and Bathymetric Volume

Date of Survey	Bathymetric Volume (m3)
September 2005	5,151,650
March 2006	5,286,740
April 2006	4,891,680
March 2007	4,857,870

7.5.68 The observations cover an eighteen month period. The most significant change occurs 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, it is not possible to determine whether there is any trend towards infilling of the Estuary at this location.

Implications for Construction

7.5.69 The analysis of the short-term changes in channel position provides some guidance for the construction works in terms of suitable positions for temporary structures and difficulties that will need to be managed.

7.5.70 The short term monitoring demonstrates the speed with which the morphology of the Study Area can change. The database of images of S2 and S3 in particular provide a baseline against which monitoring through the construction phase can undertaken. Evidence of channel movement lengthening along the northern or southern saltmarsh edges should be carefully monitored. Changes of this type would potentially impact on the interface between the stone causeway and the aligned jetty.

7.5.71 The degree of channel movement that has been observed has implications for the design of the temporary cofferdams for the tower construction. As channels migrate, the depth of mobile material and depth of water adjacent to these structures will change quite rapidly and the assessment of the structural integrity of these temporary structures will need to account for this phenomenon.

7.5.72 There are similar implications for construction to those identified from the analysis of the long term morphology record. In addition, the rapid sudden loss of saltmarsh identified during the morphological monitoring (paragraph 7.4.52) underlines the need for the careful positioning and monitoring of any temporary structures. It is important that these structures do not impinge on the saltmarsh edge or increase the loading on it. This is particularly important for the interface between the stone causeway and the aligned jetty. In order to avoid this problem, the interface should be set back a sufficient distance on the saltmarsh.

Implications for Operation

7.5.73 There are similar implications for the operation of the New Bridge resulting from both the long term and short term morphology records. The retreat of sections of saltmarsh edge emphasises the need to ensure that the design of pier bases in proximity to the edge allows for the possibility that they may be within the Estuary during the lifetime of the structure.

7.5.74 The rate of change of the short term-morphology has implications for the design of the permanent works. The depth of scour used for the design of the tower pile cap needs to include the likelihood of towers being within channels as these migrate to new locations within the Estuary.

Summary

7.5.75 A dataset of the results of analyses of oblique aerial photographs and a limited set of topographic surveys has been established. This has enabled short term changes in the Study Area to be assessed for the period since 2005.

7.5.76 Generally, the results of this work show:

a. The short term patterns of change tend to mimic those observed over the longer-term which have been described in Section 7.4;
b. There is some evidence that a sequence of several strong spring tides can induce significant channel movement although this is by no means a reliable trigger for all the changes that have been observed;
c. The bathymetric volume of the Study Area can change quite significantly over a relatively short period but for the period since 2005 there is a small reduction in volume;

7.5.77 A stability plot was produced of the likelihood of channels being at specific locations within the Study Area. This is similar to the plots produced from the mobility analysis of long-term data sets. Although the mechanism and development of new channels is observed in more detail by the short-term assessment, the net result in relation to channel position relates closely to the long-term results. This evidence suggests that 'snap-shots' of channel position used in the long-term assessment is a valid approach even if significant differences occur between these 'snap-shots'.

7.6 Computational modelling: establishing the model

Introduction

7.6.1 The morphological analysis detailed above was designed to capture data on large scale morphological change, such as movement of the main channels, which could be analysed to describe, in general terms, how morphological processes operate in the Study Area. The computational modelling described in this section is the first element of the assessment of the effects of the New Bridge.

7.6.2 In order to provide a more specific assessment of the magnitude and extent of effects from the construction and operation phases of the New Bridge, some form of model was required. Whilst interpretation of the existing data is essential for understanding processes operating in the Estuary at present and in the past, in order to distinguish what are complex patterns and to apply these processes to future changes, a model is necessary. Models are a simplified version of reality but, well designed and carefully interpreted, they can be used to provide an insight into how the Estuary may react to future changes.

7.6.3 A calibrated and tested physical model of the Study Area was not available. To construct and calibrate such a model would require considerable resources to achieve the same level of accuracy as is now available from computational models. Mathematical models are now frequently employed for such studies and this was the main modelling approach chosen (see also Section 7.12 for use of a simplified physical model).

7.6.4 Two high resolution computational models were constructed to determine the impact of the New Bridge on the Estuary; one for hydrodynamic and the other for morphological assessment. Details of the model setup and specification used for the operation phase of the project can be found in Appendix 7.4 (ABPmer Report No. 1151, Phase II Modelling Study) to this Chapter, while details of the hydrodynamic modelling of the construction phase is provided in Appendix 7.6 (ABPmer Report No 1180 Phase II Modelling : Construction Options).

7.6.5 The two high resolution models were developed using the software Delft-3D; a hydrodynamic model and a morphological model. Delft-3D allows for a 2D or 3D approach. In complex environments such as the Mersey, several processes contribute to deviations of the velocity profile from a logarithmic one, including density gradients, wind driven currents, and other factors. A 3D model like Delft-3D can therefore resolve many more of the physical processes occurring than a simpler 2D model. This is at the expense of computational time. The hydrodynamic model allowed water level, bed shear stress (the frictional force exerted on the sea bed by the water flowing over it) and speed to be investigated. A slightly lower resolution model was used for the morphology which also looked at movement of sediments around the Estuary. Two different models were necessary to allow the required intensive calculation of the hydrodynamic model over a spring-neap cycle and the calculations of the longer-term change required with the morphological modelling.

7.6.6 The New Bridge has been modelled with towers of 10m diameter. The temporary jetty structure has been modelled as a 6m wide deck on top of pairs of 0.5m diameter piles, 5m apart, at 12m centres, with finger jetties extending to 30m cofferdams at each tower location. The piles for the cranes required for construction have not been modelled although it is expected that these will be placed in the line of usual flow in front of or behind the cofferdams and thus avoid significant increases in hydrodynamic effects.

7.6.7 The main issues addressed in the modelling study for both construction and operation phases of the bridge are summarised below:

a. Impacts on flood defence;
b. Impacts on intertidal areas and saltmarshes;

c. Changes to estuary morphology;
d. Assessment of the potential for channels to ‘attach’ (remain permanently located) to structures and thus change the chaotic character of sediment movement within the Estuary;
e. Estimates of scouring around proposed structures;
f. Assessment of the potential impacts on the SPA site downstream of Runcorn designated due to the large areas of saltmarsh and extensive intertidal sand and mud-flats which provide feeding and roosting sites for large populations of waterbirds;
g. Assessment of the potential impact on existing structures, in particular the Manchester Ship Canal; and
h. Investigation of the changes in morphology due to naturally occurring events in order to place any changes predicted in the context of the magnitude and rate of natural change.

Methods

Hydrodynamic modelling: Structure of the model

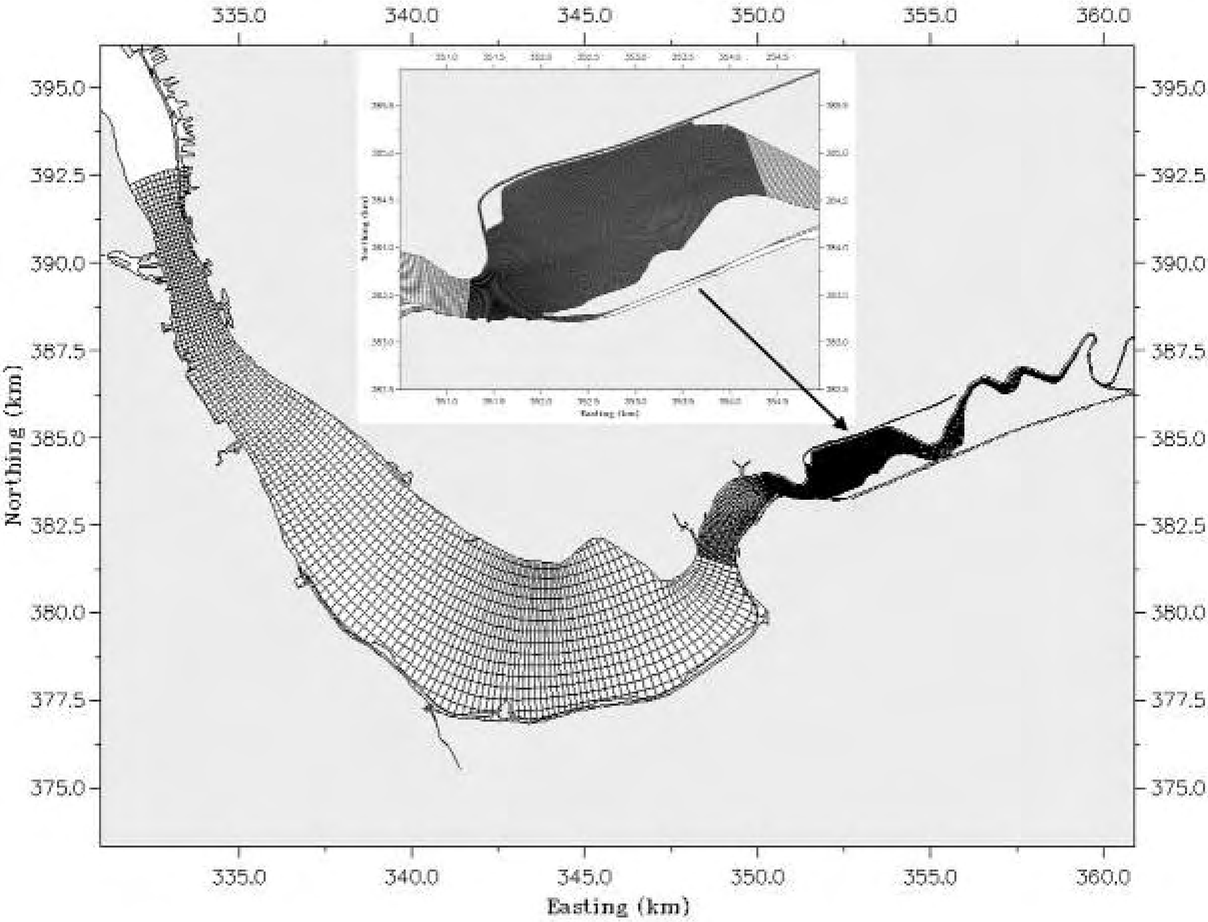
7.6.8 The key hydrodynamic parameters that were investigated during the modelling work were water level, bed shear stress and speed. Bed shear stress is the frictional force exerted on an area of seabed or riverbed by the current flowing over it. It is therefore an important quantity in the study of sediment transport processes, because it represents the flow-induced force acting on the bed sediments.

7.6.9 The hydrodynamic modelling work has been undertaken using the Delft-3D software specifically with the Domain Decomposition module in use. This software has been used for all the studies of the Project. Delft-3D is one of a number of similar software packages for three dimensional modelling of hydraulic processes in estuaries.

7.6.10 The Domain Decomposition module of Delft-3D allows a model grid to be sub-divided into several smaller model domains (sub-domains). The sub-division is based on the horizontal and vertical model resolution required for adequately simulating the key physical processes under consideration. This allows optimisation of the computer modelling power to be focused in areas that specifically require a greater detail of output data.

7.6.11 For the hydrodynamic model, there are five dynamically nested groups (sub-domains) which each have an input and output into the neighbouring nest of cells (Figure 7.35). On the horizontal plane, the model has cell sizes down to a 3m x 3m grid in the Study Area, and has ten layers in the vertical plane through the water column. A time step of 0.05 minutes was used. Modelling undertaken at this resolution of data requires long simulation run-times.

Figure 7.35 - High resolution curvilinear model grids for the Estuary Phase II modelling study. Inset shows grid resolution in area of the New Bridge



7.6.12 The model covers the Estuary from the Narrows to the tidal limit at Howley Weir. The downstream input to the model is an open tidal boundary across the Estuary in the vicinity of Gladstone Dock (See Figure 7.1 for locations). The upstream inputs are fluvial flows from the River Mersey catchment usually incorporated as a constant flow. These inputs can and have been modified on certain model runs to represent tidal surges, extreme fluvial flows as a constant flow and as a time varying flow (hydrograph). However, for the majority of model runs, a constant fluvial input of $36m^3/s$ has been used. This represents the 1:1 year discharge at Howley Weir.

7.6.13 Results from the hydrodynamic model have been presented as changes brought about by the New Bridge relative to a baseline case.

7.6.14 The spring-neap cycle has been used as the key simulation period. During this period the greatest and smallest water flow, speed and water levels are witnessed. Simulating more than one spring-neap cycle for the hydrodynamic assessment would not add to the accuracy or reliability of the output results.

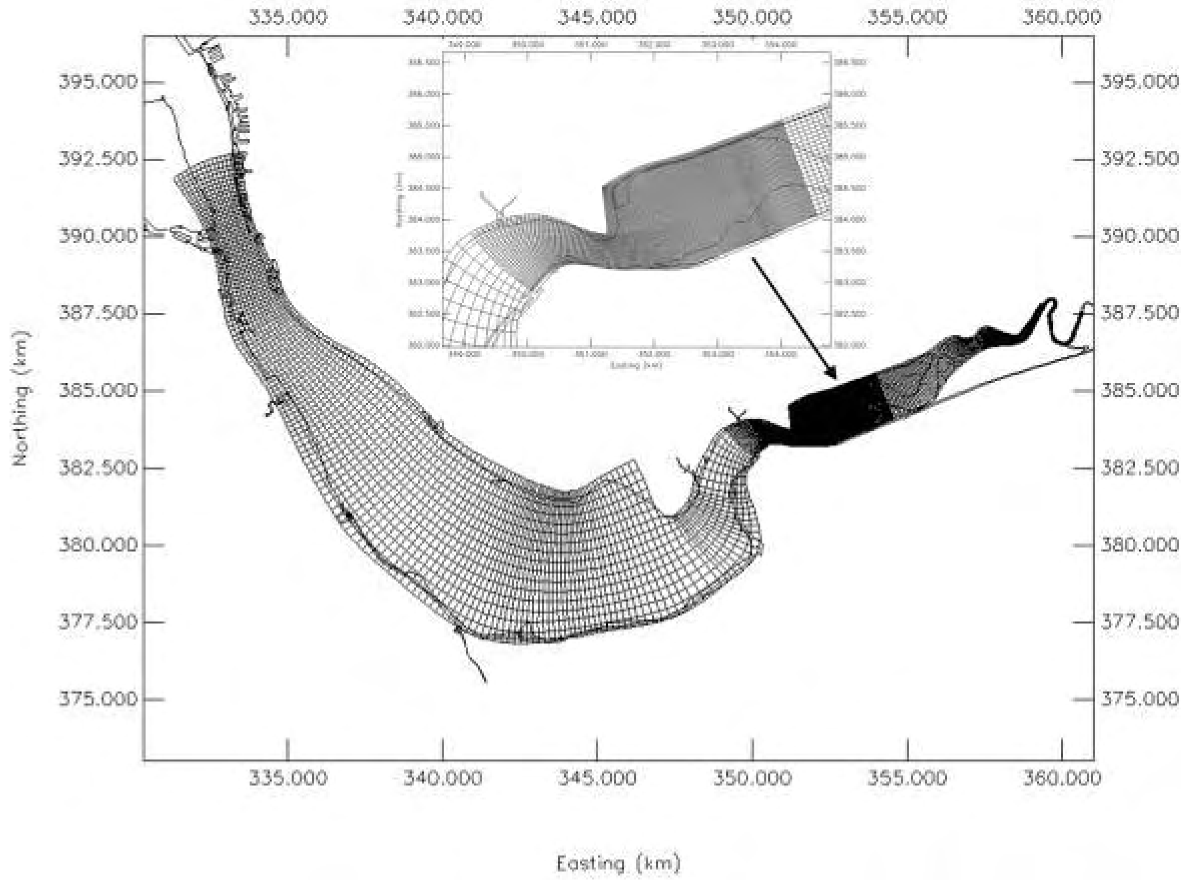
7.6.15 The proposed structures are modelled by changing the roughness coefficients of those cells in the model which coincide with the location of the structure. Given that the cells used to model the Study Area are typically 3m by 3m, then for structures such as the 500mm piles, the roughness has to approximate the influence to flow of the pile.

Morphological Modelling: Structure of the Model

7.6.16 The morphological model of the Estuary is based on a three domain calibrated Delft-3D-FLOW hydrodynamic model of the Estuary (see Appendix 7.4). All hydrodynamic parameters are identical to those assessed in the more detailed five domain model used to assess hydrodynamic change. The initial bathymetry and sediment distribution map was set up using data provided by the EA, the British Geological Survey (BGS), The University of Southampton, Gifford and ABPmer.

7.6.17 This model uses a grid cell size of the order of 20m by 30m in the Study Area and 8 layers through the water column (Figure 7.36). A time step of 0.3 min was used.

Figure 7.36 - Morphological curvilinear model grids for the Estuary Phase II modelling study. Inset shows grid resolution in area of the New Bridge



7.6.18 The morphological model uses the same baseline information as the hydrodynamic model, but is run independently. It then additionally calculates the bedload sediment transport for sand and silt fractions.

7.6.19 Morphological developments take place over a long time scale ranging from hours to years. Modelling such detail for long periods leads to lengthy simulation times. This can be overcome by applying a "morphological time scale factor" whereby the speed of changes in the morphology is scaled up to represent a longer period. Morphological scaling is undertaken by simulating the spring-neap cycle changes and extrapolating the change over a suitable period such as one year; a scaling factor of 25. This however does not incorporate natural variability in the system such as fluvial floods or tidal surges. The 'scale up' technique adopted within the morphological model is a well recognised approach (Ref. 26). It is generally accepted that the model is only used to predict morphological change for periods up to a maximum of 5 years.

However, levels of uncertainty can grow exponentially over time, hence as the time scale is extended the confidence in the predictions diminishes. The Estuary, and particularly the Study Area, is a dynamic environment and the predicted rapid adjustment of the system required a shorter time scaling factor. A period of one year was used.

7.6.20 The spring-neap tide cycle covering the period 1 January 2003 to 16 January 2003 was selected, as a typical event, for use in the models. The initial period of adjustment or “spin-up” of the simulation was 15 days. During this period the bed level was updated without any morphological scale factor. The resulting changes in bed elevation from this period of modelling were then adjusted by the scaling factor to produce the 1-year simulation.

7.6.21 The dominant sediment type was chosen using particle size analysis from the field survey and borehole data. A sand fraction with a d_{50} grain size of 150 µm was applied in the morphological modelling.

Sediment Transport

7.6.22 For riverbeds consisting of sands (non-cohesive sediments) the movement of sediment depends on the physical properties of the individual grains, such as size, shape and density. For riverbeds made up of silty and muddy materials, the cohesive forces between the sediment particles become important, leading to a significant increase in sediment resistance to erosion. Flocculation of sediment particles is the result of particles adhering together as they come into contact with each other and the resulting aggregations are called flocs. Floc behaviour will be different to that of its constituent particles. Consolidation and biological activity at the bed may also influence the critical shear stress values required to initiate sediment movement.

7.6.23 Seasonal variations in sedimentation are considered sufficiently small to be masked by the variances arising from the acknowledged limitations of sediment transport models.

7.6.24 In order to initiate transport of sediments, the fluid stresses have to overcome the inertia of the particles on the riverbed. Once particles are in motion they can move in several ways, which can be generalised as bedload and suspended load.

7.6.25 The bed shear stress is an important factor in determining whether or not deposition of suspended particles or erosion of bed sediments will occur. Deposition takes place when the bed shear stress drops below a critical value, whilst re-suspension occurs when the bed shear stress exceeds a critical value. In cohesive sediment transport other bed processes such as consolidation and bioturbation also influence movement.

Bed Material

7.6.26 The sediment distribution map (Appendix 7.4) was used to establish the locations for the sediment types used in the morphological simulations.

7.6.27 The distribution of material within the Estuary can be divided, generally, into sands, silts and rock. Within the Narrows (seaward end of the Estuary) the bed consists of a large area of rock, with a small amount of sand at the Estuary mouth. Within the Inner and Upper Estuary much of the bed is made up of sand material with small patches of mud mainly dispersed along the shoreline intertidal region. Beyond Fiddler’s Ferry towards Howley Weir the Estuary bed begins to be dominated by fine silts, however, data in this region is scarce.

Baseline bathymetry for computational models

7.6.28 For the majority of the model runs, the baseline bathymetry was that derived from the 2002 survey data supplied by the EA. This data was collected using both LIDAR and conventional sonar surveys and was readily available for initial option studies. Analyses using this data helped gain an understanding of the Estuary, and directed what information should be collected in future surveys. This bathymetry will be referred to as the 2002 Bathymetry in subsequent Sections of this Chapter.

7.6.29 It is recognised, however, that the bathymetry is constantly changing and that any survey is merely a 'snap shot' in time. In recognition of this a second set of bathymetry was obtained from topographic surveys of the Estuary completed in February 2005. This bathymetry will be referred to as the 2005 Bathymetry in subsequent Sections of this Chapter

7.6.30 Repeating model runs with both sets of bathymetry reduces the possibility that results are a consequence of the starting point bathymetry; rather, they are a consequence of the processes operating. If results for both sets of starting bathymetry are similar it can be assumed that the results represent what would happen based upon the processes operating and that the initial starting bathymetry, which is somewhat arbitrary due to the chaotic nature of the morphology, is not a major influencing factor.

7.6.31 The outputs considered for each scenario tested are the *differences* between two runs using the same bathymetry (one run with and one run without the New Bridge), in order that the start and end points may be directly comparable.

Water levels and fluvial flow rates

7.6.32 Tidal water levels in the Upper Estuary have been derived from long-term tidal monitoring points in the Outer and Inner Estuary, as well as two monitoring points set up in the Study Area specifically for this study (see paragraph 7.6.36)

7.6.33 Analysis of fluvial flow data from six gauging stations has been undertaken to assess the return period of fluvial flows into the Estuary. The records used correspond to the following stations:

a. The River at Irlam Weir;
b. The River at Westy;
c. River Weaver at Pickerings Cut;
d. Sankey Brook at Causey Bridge;
e. Ditton Brook at Greens Bridge; and
f. River Gowy at Picton.

7.6.34 Analysis undertaken for the fluvial discharge identifies that the daily baseflow in the Upper Estuary is of the order of $20m^3/s$. Fluvial inputs are typically 1% of the total inputs to the Estuary. For the baseline models other than the extreme fluvial events, a constant fluvial input of $36m^3/s$ was used.

Tides

7.6.35 For the purposes of hydrodynamic modelling, a tidal input needed to be established for the downstream boundary of the model. This tidal information was derived from a water level time-series obtained from the tide gauge at Gladstone Dock. Further details are provided in Appendix 7.4.

7.6.36 A continuous record of tidal levels within the Study Area has been obtained since February 2002 and is continuing. This was needed for calibration of the computational model for the hydrodynamics study. Accurate tide level information was needed upstream and downstream of the Study Area. Two water level recorders were established located at Old Quay Lock and close to Randall Sluices (Wigg Island) (Figure 7.37). A continuous record (15 minute interval) of tidal level has been obtained from these recorders for the period from 19 February 2002. In addition to water level, water temperature and water conductivity are also recorded. There have been several short gaps in the recording of temperature and conductivity over the period. These recorders remain in operation. An example of the record is given in Figure 7.38. Using a constant flow equivalent to a 1:1 year event in the model adds a greater fluvial input to the Study Area than would be expected, and is thus a conservative approach.

Figure 7.37 - Location of analysis points for assessment

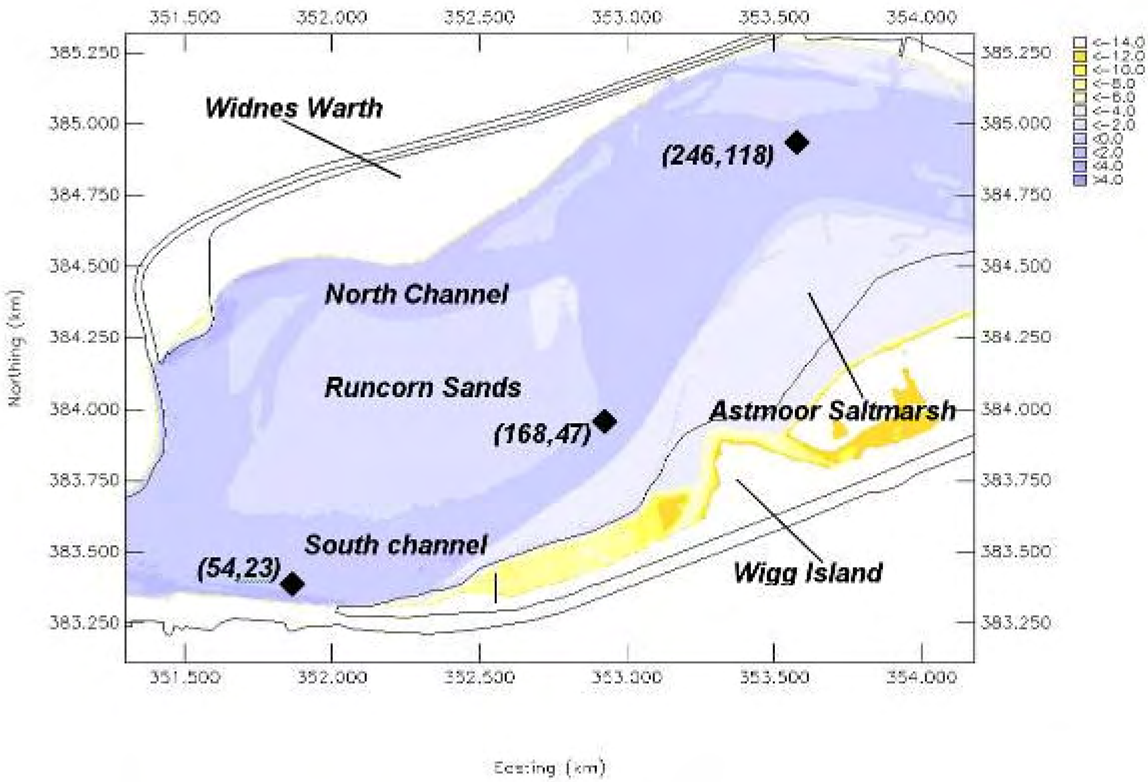
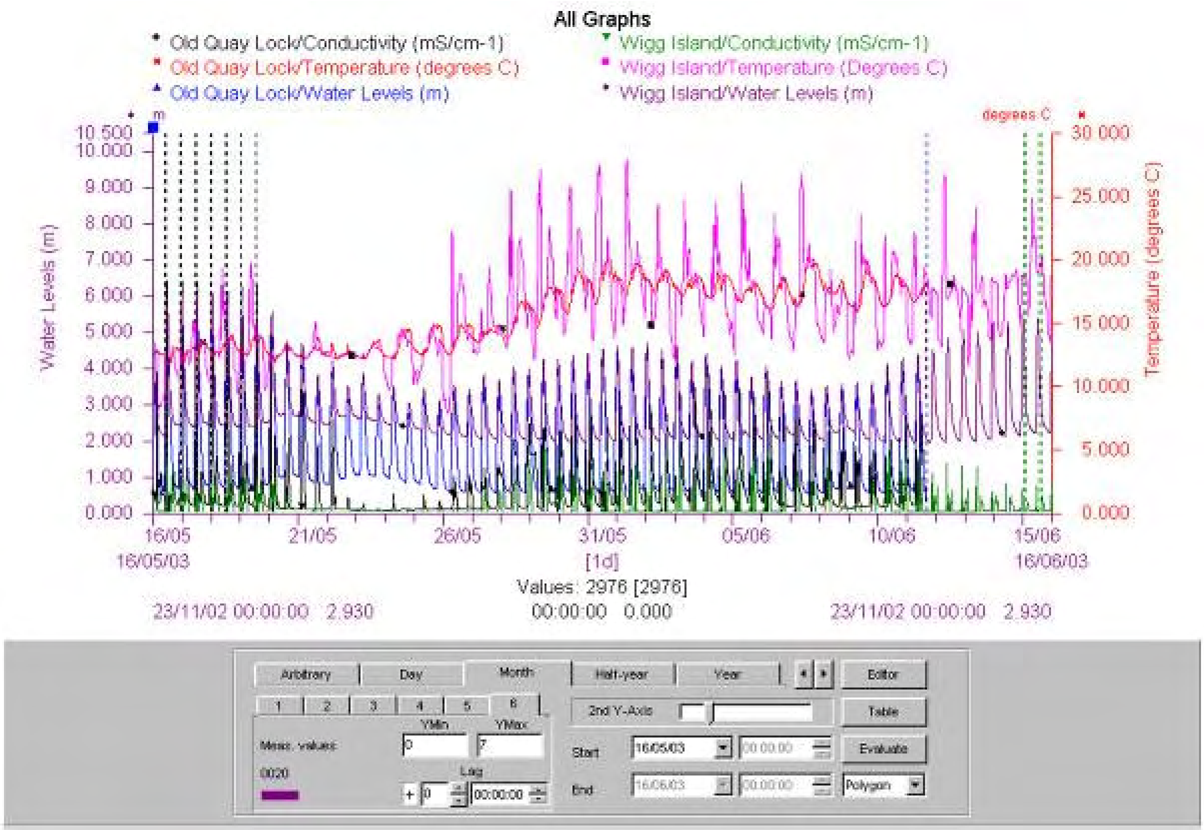


Figure 7.38 - Tide gauge output for May/June 2003



Extreme Events

7.6.37 Some of the highest storm surges in the UK are found on the West Coast in Liverpool Bay. Such surges can reach around 2m in height and can increase tidal currents by up to 0.6m/s (Ref. 27). Tidal surges are likely to lead to increases in water levels and water currents in the Estuary. The character of surges on the west coast of the UK is different to those observed in the North Sea. The most effective wind direction for producing large surges is from the south and southeast, which corresponds with the Ekman transport theory with motion to the right of the wind and the resulting build-up of coastal sea levels. The extreme tidal levels at Gladstone Dock were obtained from the EA (North West Region) Report (Ref. 28) of extreme sea level predictions. These values were then subjected to an analysis of Maximum Likelihood (MLE) to fit a General Extreme Value distribution, to give a return period level of 6.20m for a 1:200 year event at Gladstone Dock. The shape of the tidal curve used in the model was determined from a recorded surge event at Gladstone Dock. Whilst this event was lower than the required 1:200 years return period the shape of the curve was used to construct the required event of a return period level of 6.20m. Further details are provided in Appendix 7.4.

7.6.38 The 1 in 200 year fluvial event was identified by applying a Gumbel distribution to the annual maximum discharge recorded at gauging stations. This gave a 1 in 200 year return period event flow of 229m3/s, which was used in the modelling. Combining the effects of a 1:200 tidal surge with a 1:200 fluvial event in certain of the model runs represents a highly unusual condition for the Estuary; an extreme set of circumstances coinciding.

Climate Change

7.6.39 A consideration of the potential impacts of the New Bridge would be incomplete without some consideration being given to the possible impacts of climate change. Current best practice is to allow for rise in sea level and increase in rainfall. The Flood Risk Assessment shows that tidal water levels are expected to rise by 0.98m over 100 years in the area around the New Bridge. It is however extremely difficult to predict what changes to the morphology of the Estuary will occur as a result of this water level rise. Research shows that there may be a process of Estuarine Transgression (Ref. 29), but the specific characteristics of the River with the geological narrowing at the entrance to the Estuary and the hard structures lining much of the length of the Estuary may limit this process. The potential impacts of climate change on the Estuary are complex.

7.6.40 In this assessment, the possible changes have been considered only in relation to how these might affect this assessment of the hydrodynamic and morphological changes predicted from the New Bridge. Climate change is only relevant in considering the operation phase and not the construction phase, which will be completed before climate change can give rise to any large changes.

7.6.41 The potential increase in fluvial flow is allowed for in that best practice is normally to consider a 1 in 100 year event with climate change allowance (Ref. 30). In this assessment, the 1:200 year fluvial event has been used. The water level rise is similarly partly covered by the fact that in this assessment the 1:200 year tidal surge event has been modelled. In fact, the assessment has been extended to consider the combined affects of a 1:200 year tidal surge occurring at the same time as a 1:200 year fluvial event which gives a more robust result. It has been shown that the impact of the New Bridge in a 1 in 200 year tidal surge event is minimal and the day to day maximum water levels will not exceed the level modelled, albeit they will be present for longer.

7.6.42 A higher general water level may lead to increased accretion within the Estuary giving a significantly different morphology or alternatively could lead to a general increase in the presence and distribution of deeper water within the Estuary. The New Bridge's towers and piers are all approximately vertical sided and will extend above the water level, with or without climate change allowance. Thus the New Bridge will have a similar impact for the same depth of water, irrespective of what level this has relative to the New Bridge. However, if the changes are such that the water becomes deeper, the affects are unlikely to be significant given the minimal impacts predicted from the modelling of the 1 in 200 year surge plus 1:200 year fluvial event. In the extreme case a 1 in 200 year surge event with allowance for climate change will have a higher water level than anything that has been modelled. However, to extend the analysis in this way goes well beyond what is normally considered prudent for the assessment of the impacts of climate change given the degree of uncertainty that must exist over the hydrodynamics and morphology of the Estuary so far into the future. Finally, it should also be recognised that any effects from such events will be limited by the short term nature of the event itself.

Hydrodynamic Modelling: Calibration and Validation

7.6.43 A detailed description of the calibration and validation of the hydrodynamic models used in this study is provided in Appendix 7.4. Water level predictions from the models were compared with those obtained from tide gauging stations along the length of the Estuary. In addition, tidal current measurements from selected sites were used to provide further calibration points. Where necessary, parameters within the models were adjusted to improve the fit to these known records.

7.6.44 The validation exercise is to test the calibrated model against other known and recorded events to determine its 'fitness for purpose'. In this case, the calibration of the model was done using spring events and the validation used recorded neap events. An acceptable fit was achieved when compared to the EA guidelines for such models (Ref. 31).

Morphological Modelling: Calibration and Validation

7.6.45 The morphological model was calibrated for the period December 2002 – January 2003 (see Appendix 7.4). Measured suspended sediment concentrations from various points within the Narrows and Fiddlers Ferry were used to calibrate and then validate the model. These data were obtained from HR Wallingford (Ref. 32) and the EA.

Modelling Simulation

7.6.46 A summary of the sequence of modelling simulation runs for the construction and operation phases are given below:

a. Baseline model

   i. Spring-neap cycle[3,4]
   ii. High fluvial flow (1:200 year event) and spring tide[3]
   iii. High fluvial (1:200 year event) and corresponding 1:200 year surge event[3,4]

b. Mersey Gateway Alignment – construction phase

   i. Spring-neap cycle[3,4]
   ii. High fluvial (1:200 year event) and corresponding 1:200 year surge event[3,4]

c. Mersey Gateway Alignment – operation phase

   i. Spring-neap cycle[3,4]

Modelling Limitations and Assumptions

7.6.47 The Delft-3D model software used is comparable with other software available. All of the software is based on similar principles and should therefore predict results of a similar magnitude and extent.

7.6.48 Limitations in the accuracy and precision of the output from the different models used are consistent throughout as the same inputs for bathymetry, tidal and fluvial flows, and other physical parameters are used. To remove 'noise' within the model outputs, cut-off levels of a change of less than 0.01m in water levels, less than 0.01m/s in speeds and less than 0.02N/m^2 in bed shear stress were adopted.

7.6.49 The near surface and near bed speeds are similar in all iterations of the model in both magnitude and spatial extent, and as such have not been discussed independently.

7.6.50 It is generally accepted that the morphological model under predicts the scour holes created adjacent to the New Bridge piers. The physics associated with the changes of direction of flow impinging on a structure such as the New Bridge tower and the development of the vertical flows and vortices that lead to scour are not fully represented in the Delft-3D model.

7.6.51 Changes in bed shear stress mimic the locations of changes in near-surface and bed-surface speeds as one is a function of the other. It is important to determine the thresholds, extents and the magnitudes of these changes in bed shear stress as they provide a useful tool to assess how much impact the Project has on sediment within the Estuary.

7.6.52 It is important to note that the hydrodynamic modelling results displayed within this report and in Appendix 7.4 show the worst case scenario for the Estuary for the particular tidal regime

[3] 2002 Bathymetry
[4] 2005 Bathymetry

modelled. Although the model has been run for the spring-neap cycle, the results show the changes in parameters as a result of the proposed structure for the spring tide only. These are only snapshots in time and as such only provide an indication of the magnitude and extent of any impact, but not the duration of that impact.

7.6.53 Due to the vast amounts of data produced by the model (time steps of 0.05 minutes and 0.3 minutes for the hydrodynamic and morphological models respectively), results were abstracted every 60 minutes to produce the output file for analysis. These snap shots in time in the results are the output from the closest 60 minute time step to the high water, low water, peak flood and peak ebb. As such, it is possible to find in the results directional changes in speeds and bed shear stresses at high water when it would be expected there would be no movement in the water column.

7.6.54 Due to the continuous movement of materials within the Estuary, the bathymetry is only applicable perhaps until the next tidal cycle. The Estuary bathymetry is thus constantly changing and every tidal cycle has the potential to change the channel locations and positions of sand bars, albeit generally within certain limits.

7.6.55 After the initial morphological model simulation, some areas of the model indicated zones of large erosion and deposition (greater than +/- 10m). A possible explanation of this is related to the initial distribution of sediment. Areas given an unrealistic thickness of sediment will under the hydrodynamic conditions scour or deposit material that in reality would not be there. During the calibration procedure, sediment seen to erode significantly within the simulation period was removed as it was assumed that this material would have eroded and hence should not be included.

7.6.56 The initial thickness of the sand layer in the morphological model was set at approximately 1m. This was based on the assumption of a non-erodible sediment layer below the surface. Subsequent borehole data provided by Gifford and the BGS indicated that the depth of the sand material along some areas of the intertidal is in excess of 4m. The base model was revised to include a 4m thickness of available bed material and the model was run for a spring-neap cycle to establish an adjusted bathymetry. This adjusted bathymetry was used as the base model for all subsequent morphological model runs.

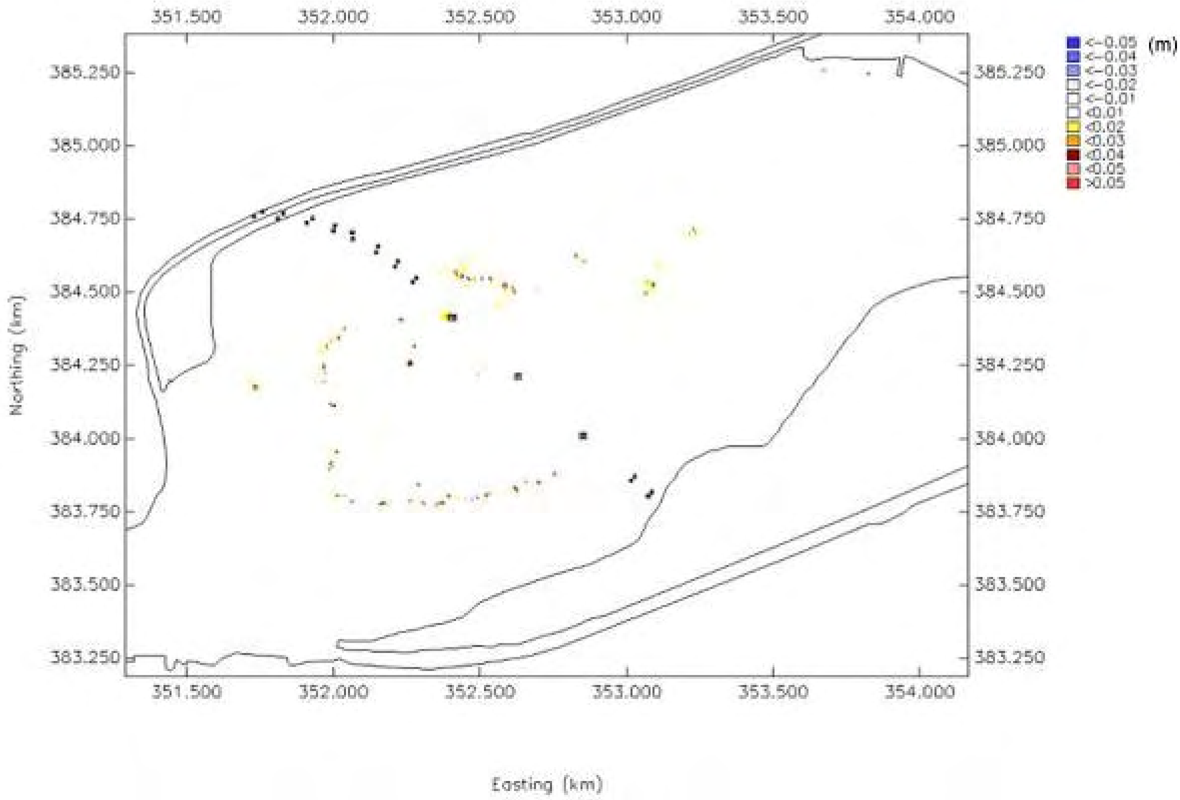
7.6.57 The estimation of sediment transport is complex and the results from the morphological model need to be interpreted with care. Account must be taken of the spatial variability of the various factors affecting sediment movement, and consideration given to the effects of processes not included as parameters within the model (for example biological activity).

Tidal Phase changes

7.6.58 Apparent changes in water level that are identified in the hydrodynamic modelling results are, in part, due to shifts in the tidal phase, as seen in the one hour time step outputs of the model, rather than real physical changes predicted by the model. Without an understanding of the way in which the model makes comparisons and the outputs it produces, it is easy to interpret the results in the wrong way.

7.6.59 Results of the hydrodynamic modelling indicate that the physical barrier created by the proposed New Bridge structures, delays the ebb tide leaving the Estuary, creating a change in timing of the tide (by only a few minutes). The front of the incoming flood tide meeting this delayed ebb tide results in a change in speeds and bed shear stress in comparison to the baseline situation. The uniqueness of this Estuary, with a very short flood and long ebb, creates this reaction to what is a short delay in tidal propagation. However, it is important to note that the results observed for water level for example are as a result of this delay in tidal propagation and, were the model results to be extracted at a different time (i.e. a few minutes later to compensate for the delay of the blockage) this phenomenon located on the front of the flood wave would not be present. Trying to adjust sampling of results to the exact time does not work since this time changes spatially within the model. Thus, within the model results are an artefact of the timing of the outputs rather than real changes, as demonstrated in Figure 7.39. This curved feature downstream of the New Bridge is observed in most of the outputs from the hydrodynamic model. This issue and its impact on results are discussed in more detail in Appendix 7.7.

Figure 7.39 - Example of changes in water level as an artefact of phase shifting rather than actual change



7.6.60 This figure is one of a number of figures that are generated from the computational model. In each figure the areas of change are colour coded based upon the legend attached to each figure. In a number of cases (e.g. 7.48A, 7.49A, 7.49B, 7.54A, 7.58A, 7.59A, 7.59B and 7.64A) these figures contain little or no colour indicating that there is little or no difference between the scenarios modelled. For example Figure 7.64A indicates that there is no difference in near surface speed between the baseline case and the situation when the New Bridge is in place for the condition of low water on a spring tide.

7.7 Computational modelling: Baseline Model Results

Introduction

7.7.1 An assessment has been undertaken of how hydrodynamic conditions vary for three scenarios, these being:

a. Spring-Neap Cycle;
b. Extreme Fluvial (1:200 year event); and
c. Extreme Events (combined fluvial and surge events, both 1:200 years).

7.7.2 In this Section the results of the Spring-Neap Cycle modelling and Extreme Events will be discussed. These two conditions represent day to day conditions and a worst case scenario respectively, thus allowing impacts of the New Bridge to be assessed.

7.7.3 Extreme climatic conditions have been simulated to help understand how these events impact on the Estuary dynamics and how these may affect the bathymetry. Extreme fluvial flows estimated to be equivalent to the 1 in 200 year event coupled with a spring tide have been simulated. In addition, the 1 in 200 year fluvial flow coupled with a 1 in 200 year tidal surge has been simulated.

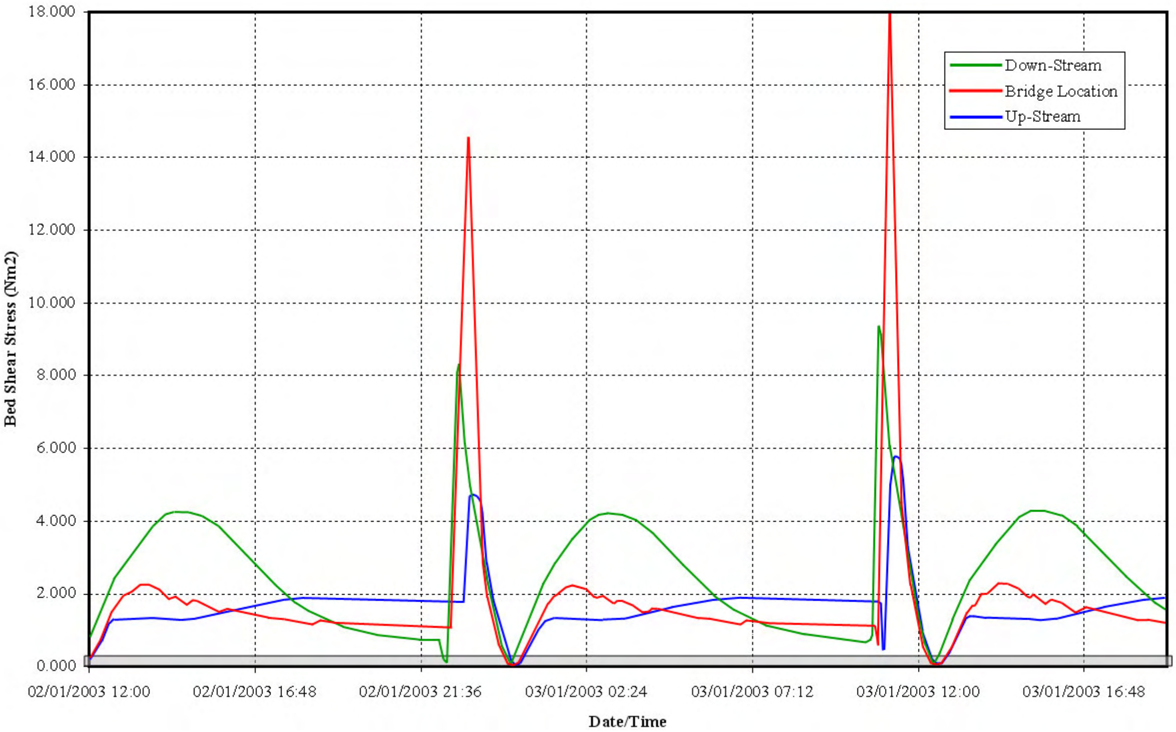
7.7.4 The approach with the modelling of the extreme events was to apply the surge to a spring tide i.e. in effect assessing the impact of this event over one tide, and for fluvial events to apply these over a spring tide since the duration of such events is typically measured in hours rather than days. Applying these events in this way would maximise any impacts associated with water level change or erosion or deposition. For the chosen extreme events this is thus a worst case approach.

7.7.5 These three scenarios are assessed at three locations as identified in Figure 7.37. All baseline event simulations are described in detail in Appendix 7.4.

7.7.6 In order to understand the degree and significance of change, the percentage change should be considered as well as the extent of the change. A change in the near-surface speed of 0.2m/s at one location for example might represent a 10% change whilst at another location the same change in near-surface speed would represent only a 5% change.

7.7.7 A bed shear stress assessment is a straightforward method of identifying whether the bed material is likely to be moved and if so at what point during the tidal cycle. The "threshold of motion" is the minimum force which will liberate sediment from the bed. Figure 7.40 identifies the grey area as the "threshold of motion", in the order of $0.25N/m^2$, for the silt material present in the Estuary.

Figure 7.40 - Bed shear stress variations and the threshold of motion for a spring tide



7.7.8 It should be noted that, when viewing modelling output, an increase in bed shear stress will not necessarily liberate more bed material as the threshold is likely to have already been exceeded. Assessing a percentage change in bed shear stress should not therefore be used as the sole measure to assess the extent of change in this situation for the reasons described above and graphical representations should be interpreted with caution.

Hydrodynamic Model Outputs: Spring-Neap Cycle

7.7.9 The baseline case for the hydrodynamic model is shown in Figures 7.41 and 7.42. These are outputs for bed shear stress since this is the driver for mobilisation of bed material and the cause of changes in morphology.

Figure 7.41 - Actual bed shear stress (Nm^{-2}) in the baseline case for low water (A) and peak flood (B) on a spring tide

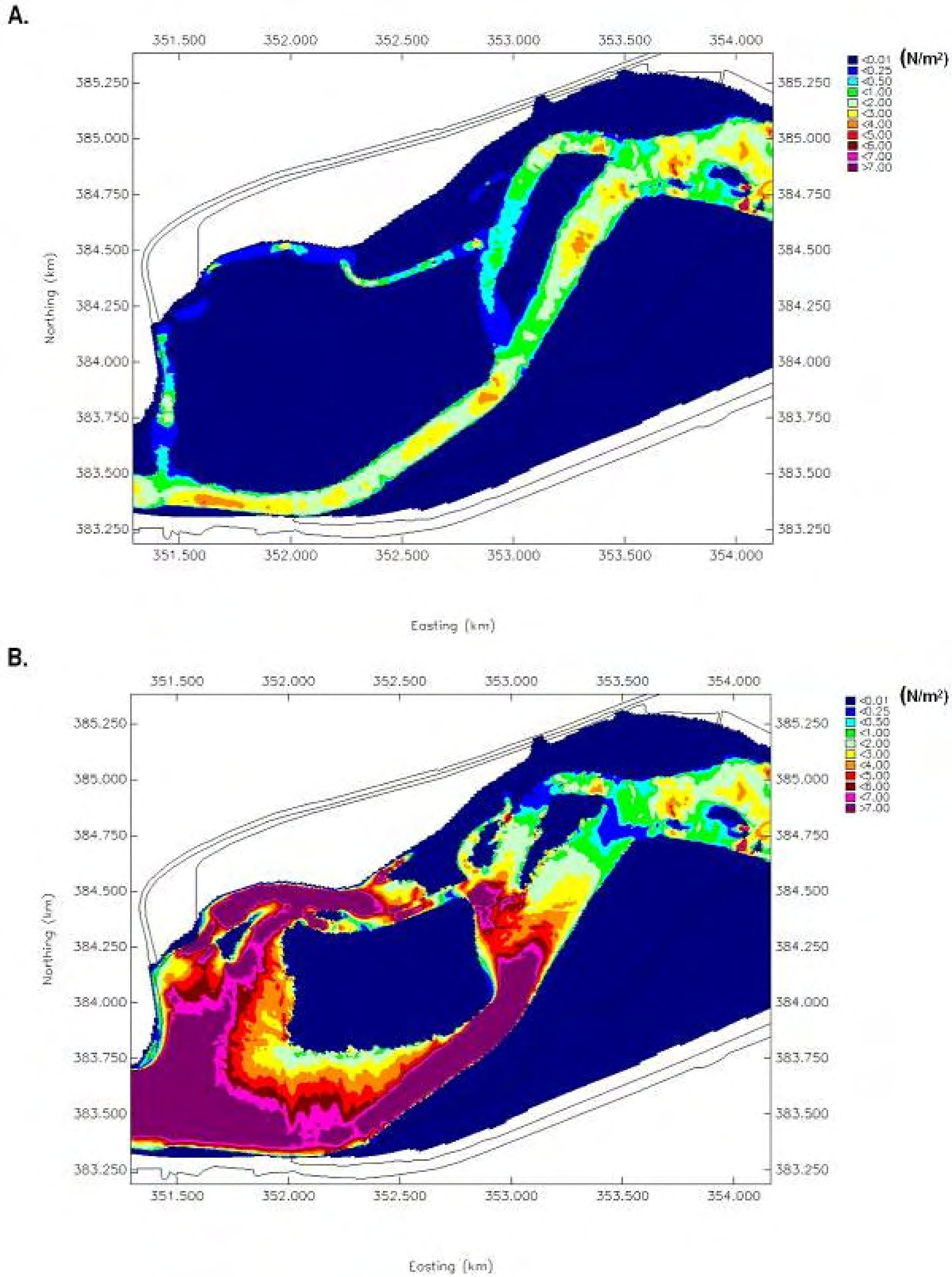
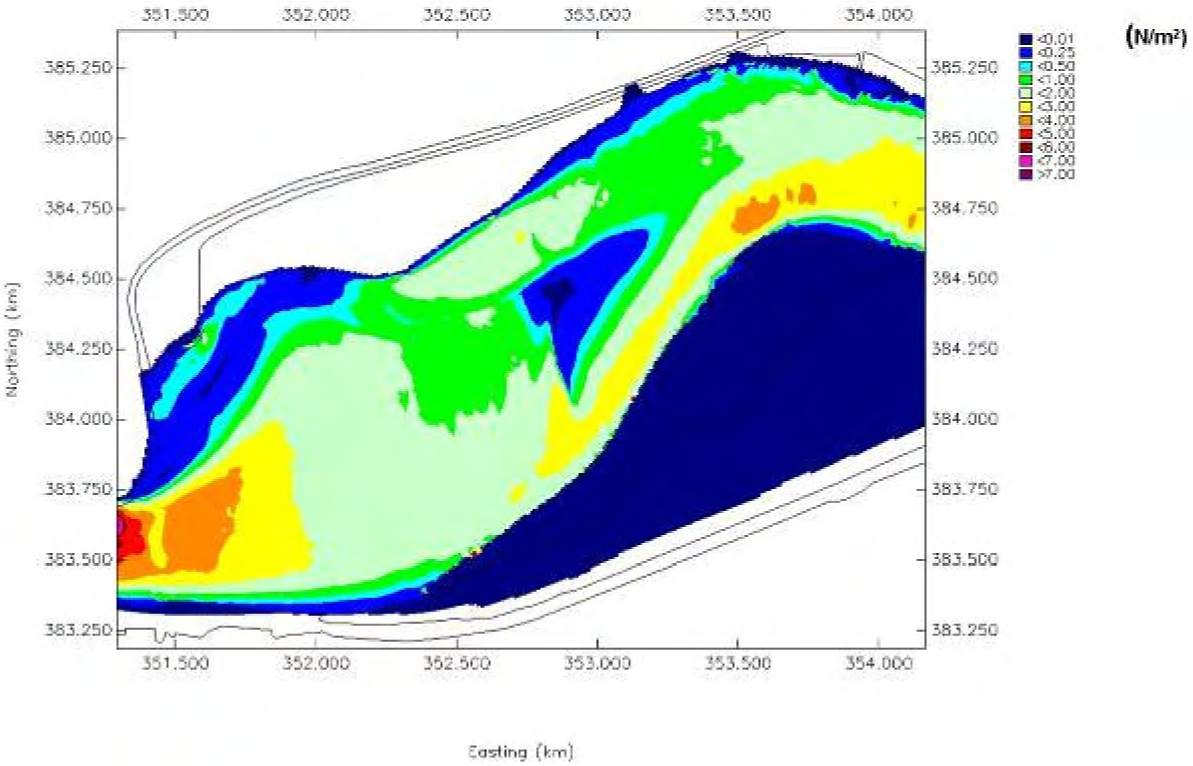
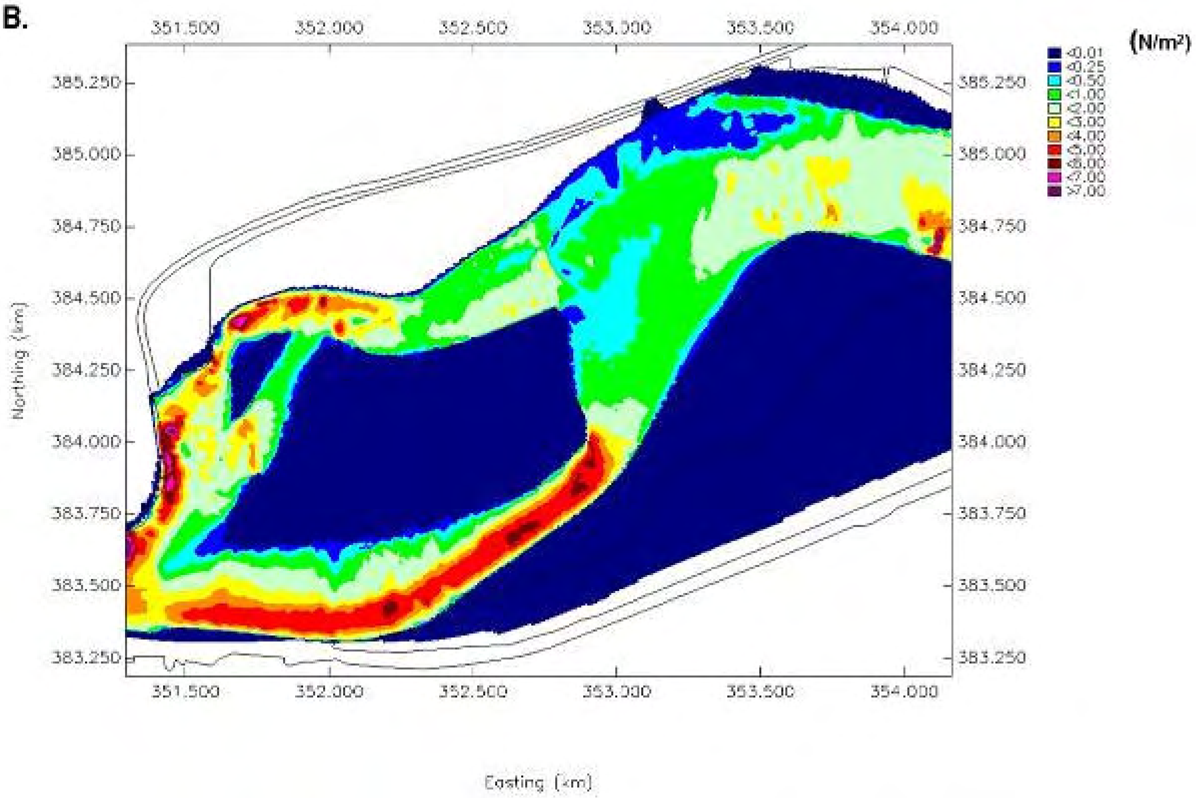


Figure 7.42 - Actual bed shear stress (Nm^{-2}) in the baseline case for low water (A) and peak flood (B) on a neap tide

A.



B.

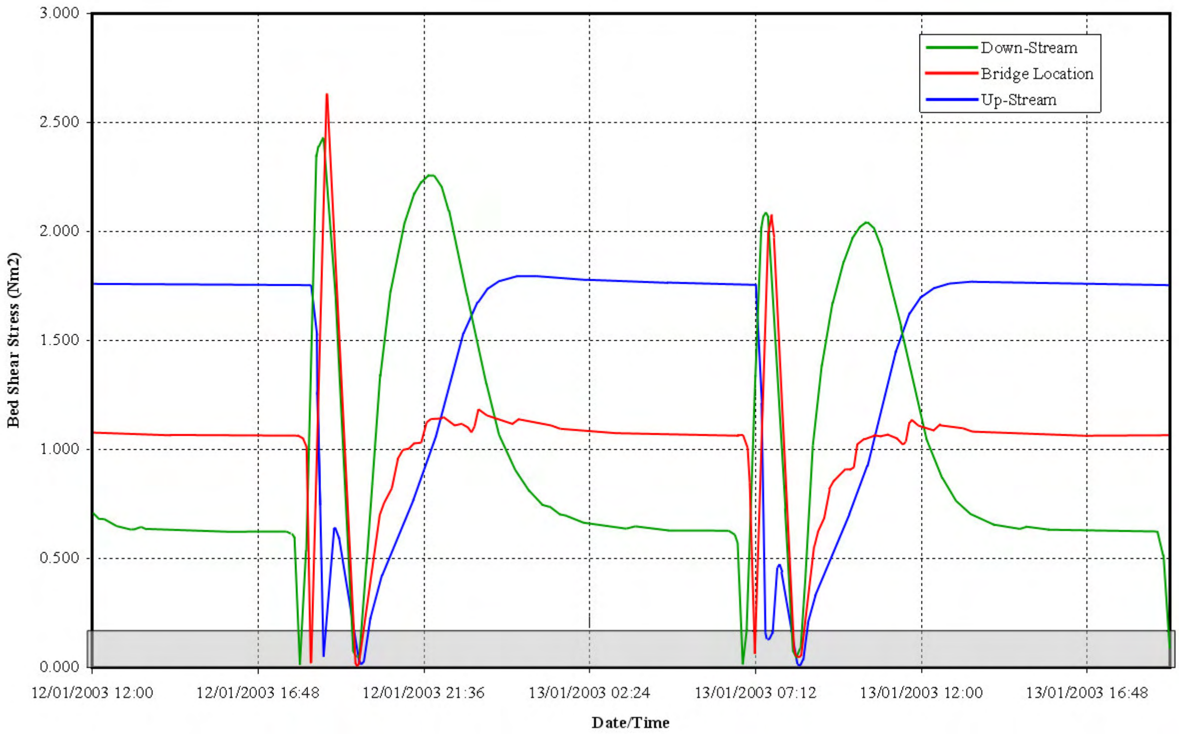


7.7.10 Figure 7.40 shows that at the bridge location, a spring tide exerts a shear stress of up to $18N/m^2$; approximately 70 times that required to mobilise the bed material. There are only two short periods during the tidal cycle that the shear stress is not sufficient to mobilise this material.

The figure identifies that for all three locations, bed shear stress is almost permanently above the threshold level, and as such, the liberation of silt into the water column is almost constant during the spring tide cycle.

7.7.11 Figure 7.43 identifies the potential for mobilisation during a neap tide. As explained in paragraph 7.7.7 the "threshold of motion" is in the order of 0.25N/m^2 for the silt material present in the Estuary. At the New Bridge location, a neap tide exerts a shear stress in excess 2.5N/m^2; approximately 10 times that required to mobilise the bed. Indeed, there are only four short periods during the cycle that the shear stress is not sufficient to mobilise the bed.

Figure 7.43 - Bed shear stress variations and the threshold of motion for a neap tide



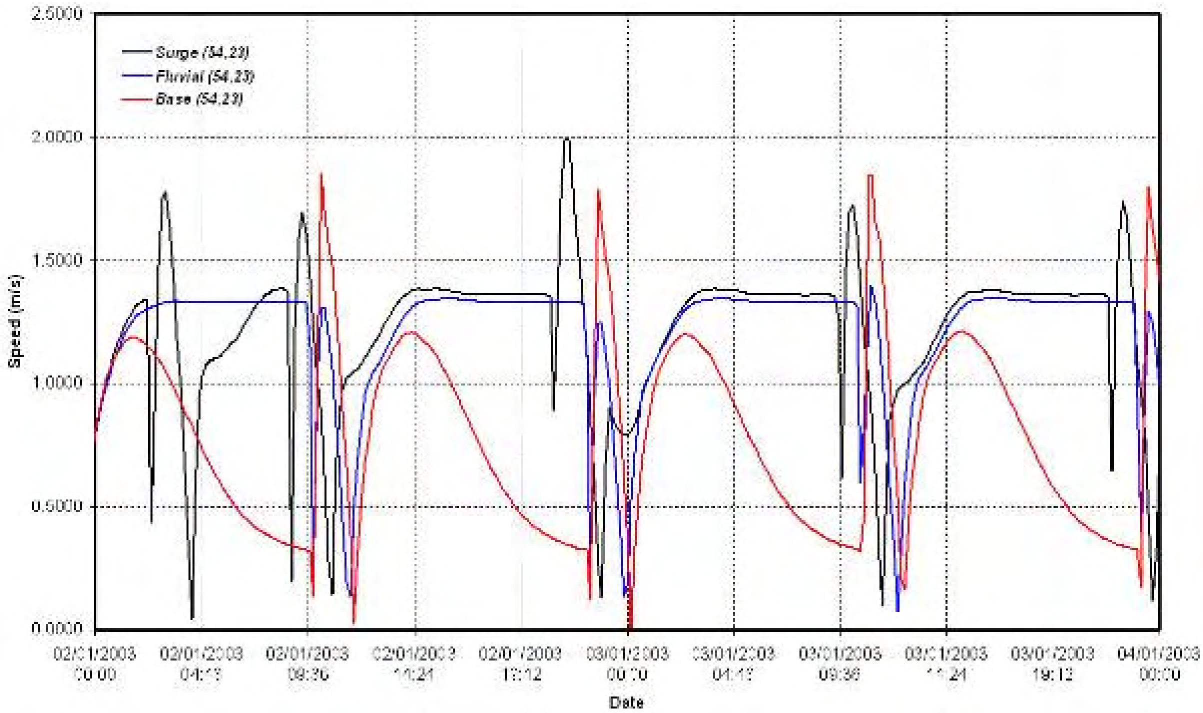
7.7.12 It should be recognised that these plots show actual shear-stress values and are the first element of the assessment for the impacts of the New Bridge. By running the same model with the New Bridge in place, a similar plot is produced. However, in the following Sections, the plots are of the *differences* in shear stress, not the absolute values as shown on these figures.

7.7.13 The figures demonstrate the wide range of shear stresses that apply within the Estuary and how these change, both in magnitude and location, between low water, high water, peak flood and peak ebb. Given how much greater these values are than the threshold values for the mobilisation of bed material, the figures explain why the Study Area has a chaotic and highly mobile morphology.

Hydrodynamic Model Outputs: Extreme Events with 2002 Bathymetry

7.7.14 Figure 7.44 identifies that, in the vicinity of Old Quay Lock there is little difference in peak near-surface speed between the baseline, shown in red (1.8m/s) and the extreme surge with extreme fluvial event, shown in black (2.0m/s). Extreme fluvial flows, shown in blue, have a peak near-surface speed of approximately 1.3m/s.

<u>Figure 7.44 - Near surface speed at position (54,23) for baseline extreme fluvial and extreme surge and fluvial events</u>



7.7.15 Figure 7.45 identifies near-surface speed in the approximate position of the New Bridge and Figure 7.46 indicates near-surface speeds in the vicinity of Hempstones Point on the northern edge of the Astmoor saltmarsh.

<u>Figure 7.45 - Near surface speed at position (168,47) for baseline, fluvial and extreme surge and fluvial events</u>

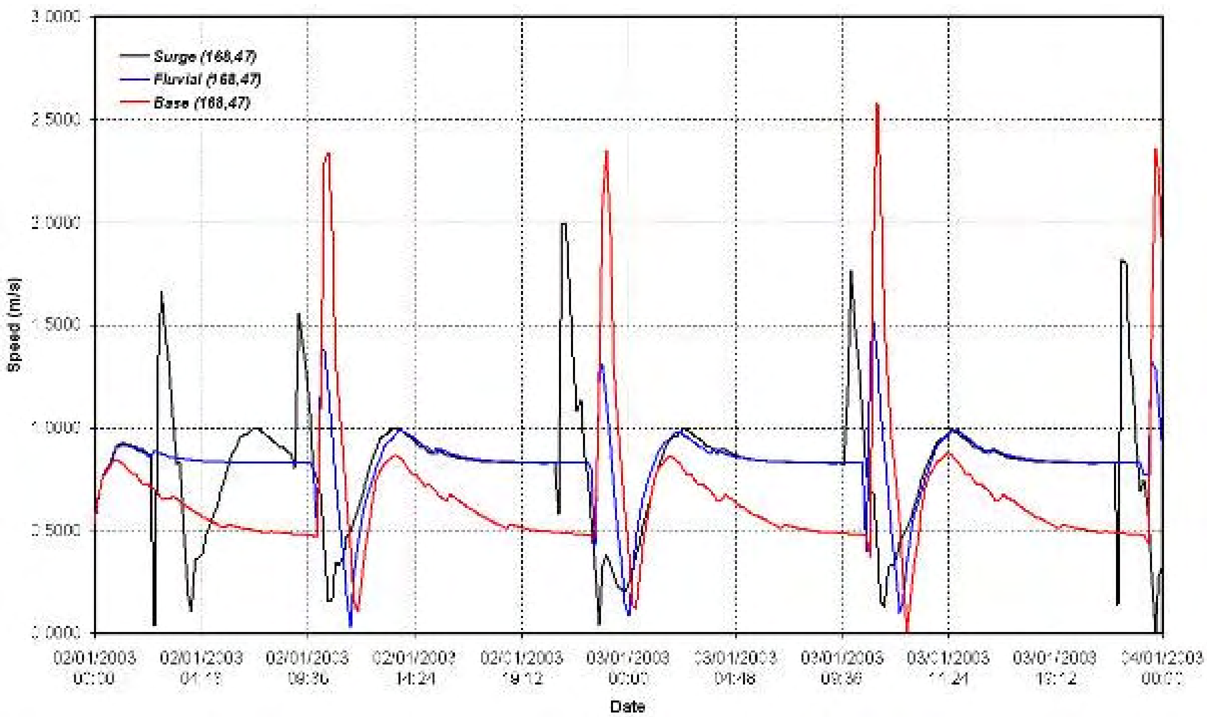
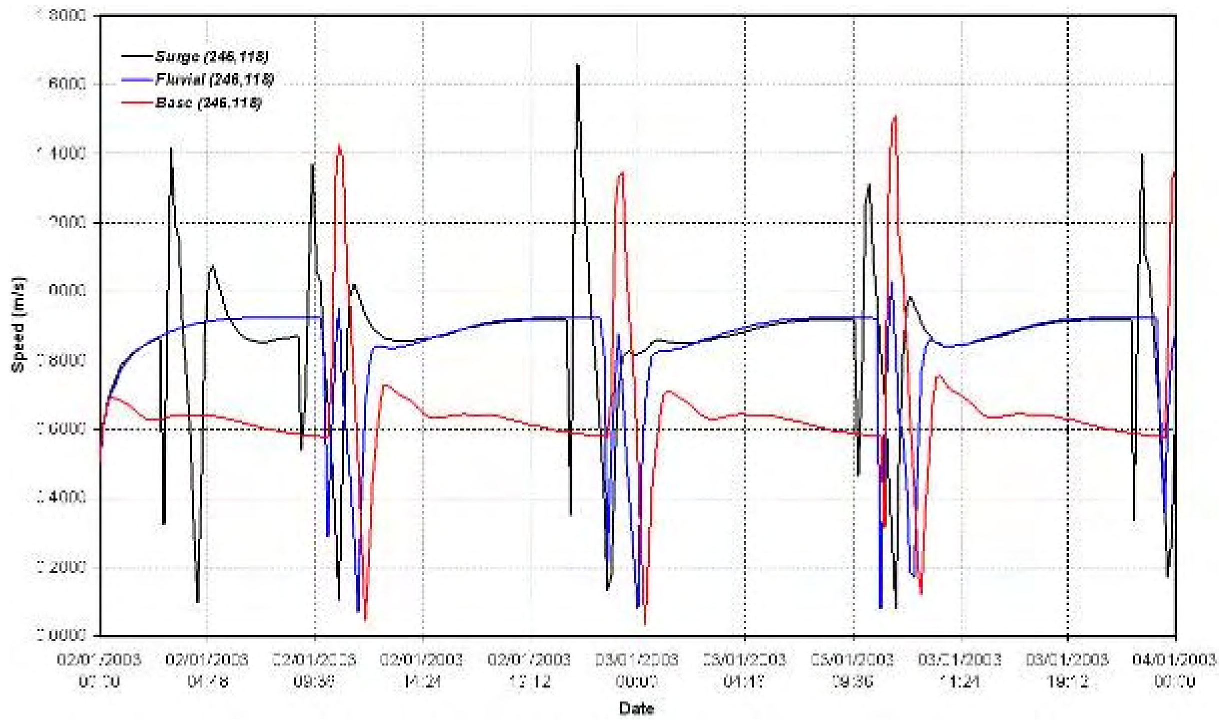


Figure 7.46 - Near surface speed at position (246,118) for baseline, extreme fluvial and extreme surge and fluvial events



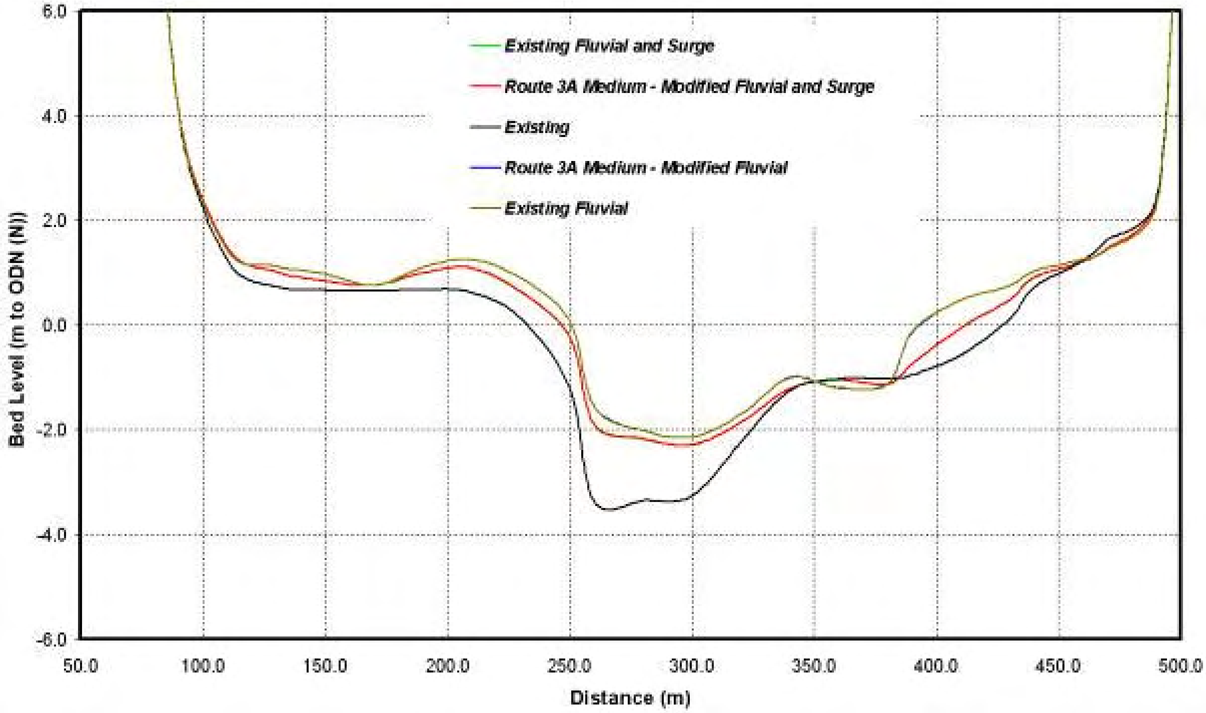
7.7.16 At the location of the New Bridge it is interesting to note that the peak baseline speed is greater than that of the extreme surge with extreme fluvial event. This perhaps reflects the differences caused by a great depth of water for the extreme events having the effect of marginally reducing peak velocities at what is the widest part of the Estuary compared with the more normal water depths under a spring tide. Baseline speeds peak at a value in excess of 2.5m/s. A 10% change in this location would therefore require a difference in speed of 0.25m/s

7.7.17 Figure 7.46 indicates near-surface speeds in the vicinity of Hempstones Point on the northern edge of the Astmoor Saltmarsh. The peak speeds here are generally less than at the proposed crossing point, with the greatest speed occurring for the extreme surge coupled with the extreme fluvial event having a value of approximately 1.7m/s. Peak baseline speeds reach 1.5m/s.

Morphological Model Outputs: Extreme Events with 2002 Bathymetry

7.7.18 The most interesting morphological outputs of the baseline cases assessed relate to the extreme events. A series of cross-sections were produced from the morphological output files to compare changes in bathymetry. These cover the Study Area and can be seen in Appendix 7.4, an example is shown in Figure 7.47.

Figure 7.47 - Cross section B from the morphological model (Appendix 7.4)



7.7.19 The cross-sections demonstrate the extent and degree of change that can be caused to the morphology by extreme events. It should be recognised that this is an example based upon one particular initial bathymetry and the results would be different for different initial bathymetry. However, the power of the events and the impacts these have on the bathymetry would yield similar magnitudes of change.

7.7.20 The results shown in these cross-sections indicate changes in morphology in places of up to several metres in depth. When assessing the impacts predicted for the New Bridge, this degree of naturally induced change should be recognised.

Summary of Computational Baseline Results

7.7.21 The results of the baseline model are given in absolute values, whereas subsequent plots of parameters such as bed-shear stress or morphology associated with the impacts of the New Bridge are the *differences* of the two conditions i.e. with and without the New Bridge.

7.7.22 A wide range of shear stresses that apply within the Estuary are identified. How these change, both in magnitude and location, between low water, high water, peak flood and peak ebb has been described. Given how much greater these values are than the threshold values for the mobilisation of bed material, the shear stresses explain why the Study Area has a chaotic and highly mobile morphology.

7.7.23 The effects of the extreme events on the morphology of the Study Area, when compared with a spring neap cycle, without the New Bridge in place, can be substantial in terms of changes to the bathymetry these events cause. The maximum erosion and deposition depths and the percentage of the Study Area where changes in sediment level occurred taken from computational results given in Appendix 7.4, are displayed in Table 7.11.

Table 7.11 - Impacts of Extreme Events on Baseline Bathymetry

Bathymetry modelled	Duration modelled	**Maximum erosion**	**Maximum deposition**	**Extent of plan area which changes within the Study Area**
Baseline extreme 2002	15 days	2.26m	2.58m	40.5%
Baseline extreme 2005	15 days	2.43m	2.22m	37.7%

7.8 Computational Modelling: Construction and Operation Results

Introduction

7.8.1 This Section describes the results of the modelling of the proposed situation, during and following construction of the New Bridge. The potential effects of the New Bridge on the hydrodynamics and morphology of the Estuary are considered in detail within this Section.

7.8.2 The potential for the New Bridge to change the existing regime has been investigated in a number of different ways as described above. These investigations have looked at both the situation when the New Bridge is under construction and the situation when it is operational. The Construction option investigated is an Aligned Jetty Construction method with 30m diameter cofferdams at each tower location (refer to Section 7.2).

Results of Computational modelling for Construction Phase

7.8.3 For the construction phase, the hydrodynamic model was run for a spring-neap cycle and an extreme event (fluvial and tidal surge). Both events were run using both the 2002 and 2005 bathymetry.

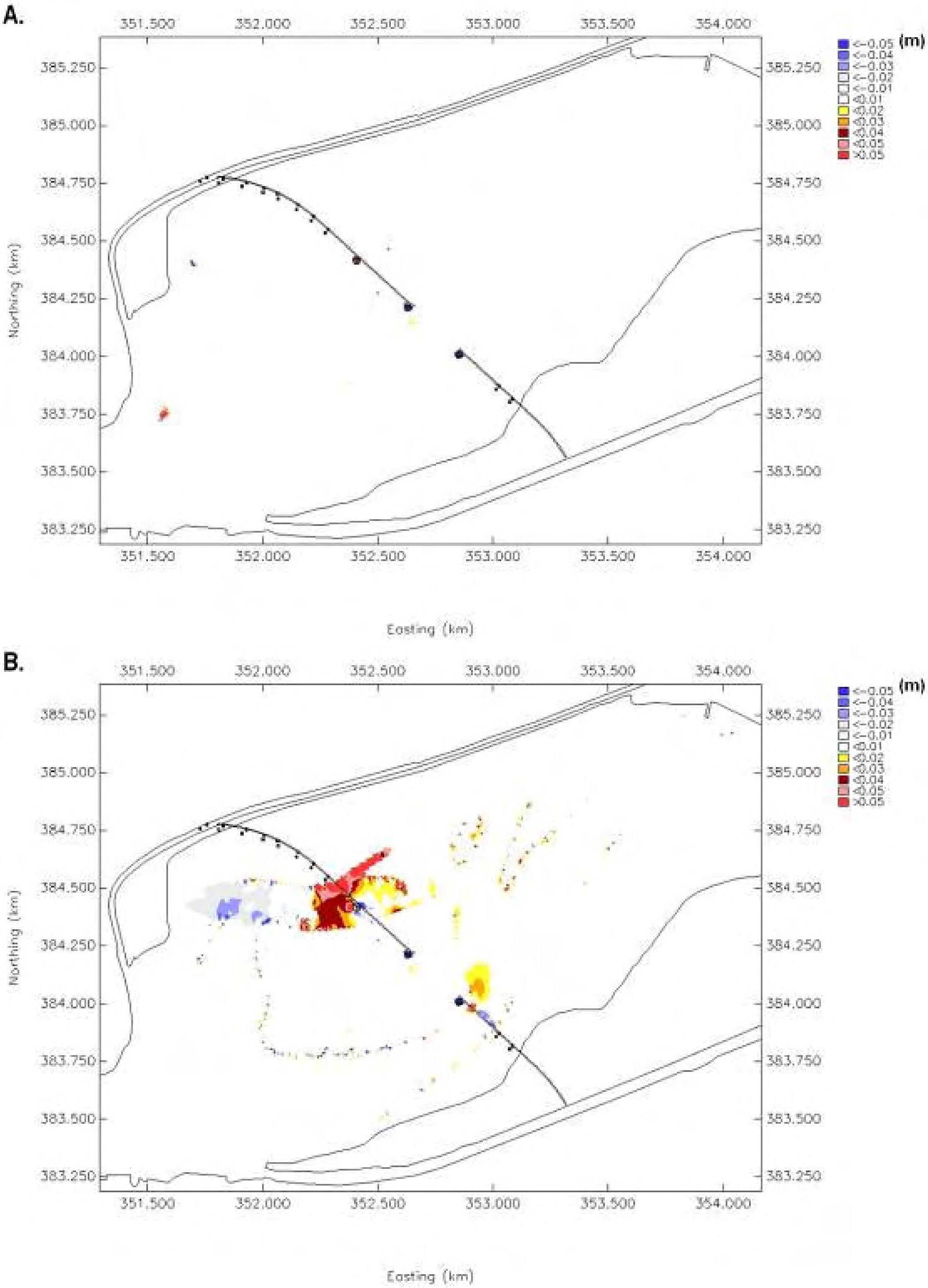
7.8.4 As with the operation phase, the results described below focus on those relating to water levels and morphology. Further detail on these and results for water speeds and near bed shear stresses are included in Appendix 7.6.

7.8.5 This Chapter focuses on the possible effects on the Estuary associated with changes in bed level and changes in water level which may be caused by the New Bridge. The results relating to speeds of water flow and bed shear stress have not been described in detail, as they do not have a direct effect on morphology, but are needed to allow changes in morphology to be identified, and thus provide background to the results that are detailed below.

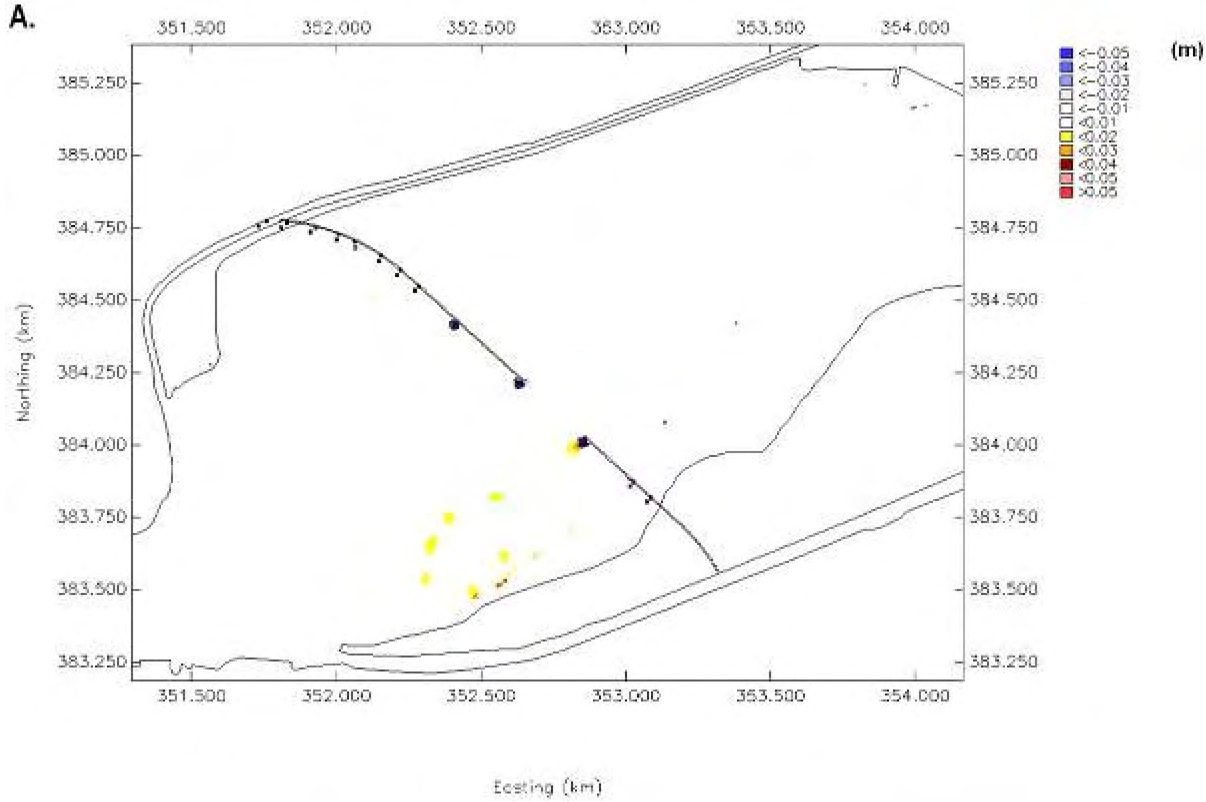
Hydrodynamic Model Outputs: Spring-Neap Cycle with 2002 Bathymetry

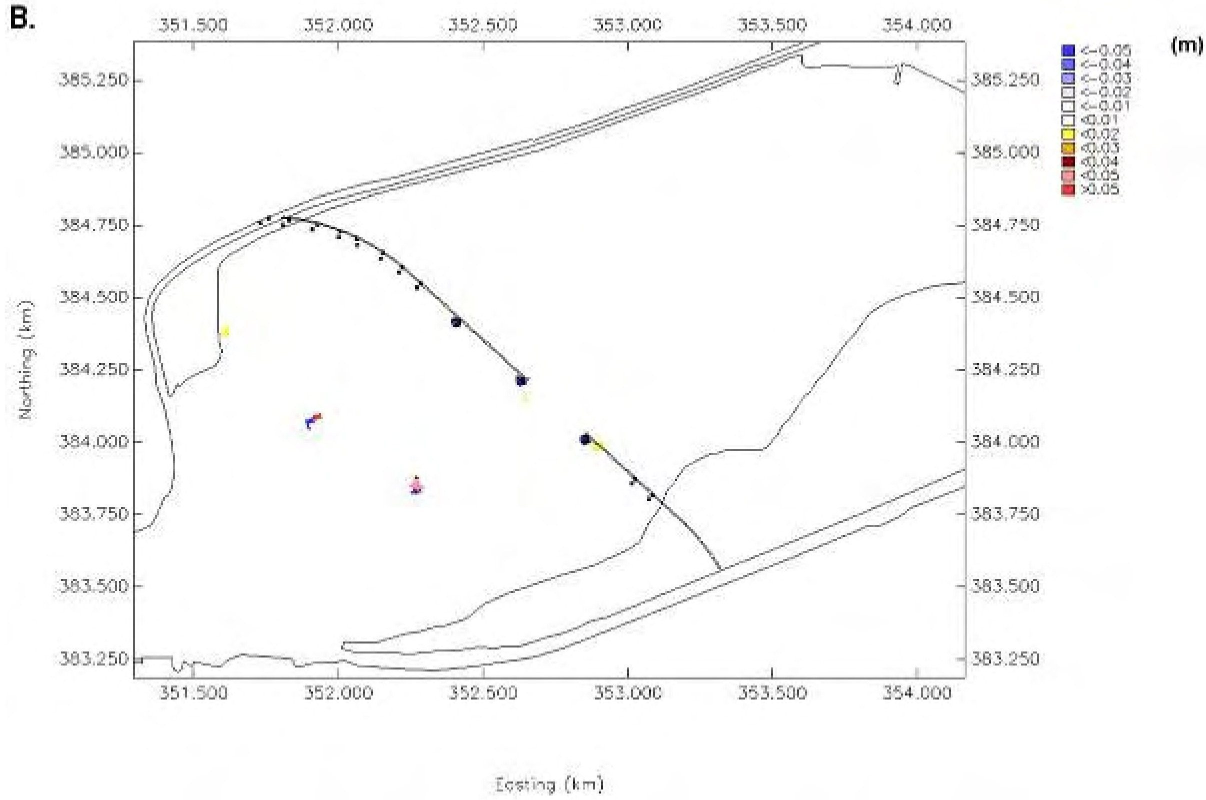
7.8.6 During peak flood water the aligned jetty option is found to have generally elevated water levels in both the north and south channels (Figures 7.48 and 7.49). The extent and magnitude of this blockage effect is greatest in the north channel. The maximum changes were identified during the peak flood tide with maximum increases in water level around the piers of 0.07m. A slightly higher change of 0.08m is measured in the intertidal areas and within the channel this reduces to 0.03m. During the peak ebb smaller changes were observed in the intertidal areas (0.04m) and around the piers (0.01m), but there was no change recorded in the channel. It should be recognised that these predicted changes occur during the periods of peak flood and peak ebb flows and not at high water.

Figure 7.48 - Differences in water level (m) between the New Bridge and the baseline case for low water (A) and peak flood (B) on a spring tide – Jetty construction option



<u>Figure 7.49 - Differences in water level (m) between the New Bridge and the baseline case for high water (A) and peak ebb (B) on a spring tide</u>





7.8.7 Throughout the tidal cycle there are areas of increased and reduced water speed caused by the presence of the piles and cofferdams obstructing flow. These changes correspond to an increase in bed shear stress at all stages of the tidal cycle. During the peak flood the largest changes occur in the immediate locality of the cofferdam and pier structures. In contrast during the peak ebb there is a general increase in bed shear stress within the north and south channels. There is also a reduction in bed shear stress between Old Quay Lock and the Runcorn Gap which could lead to a build up of sediment.

7.8.8 It is important to note that the modelling of the deck of the jetty assumes that it is high enough over the water surface to prevent it causing any blockage to flow and at a level to prevent it being inundated during high spring tides and tidal surges.

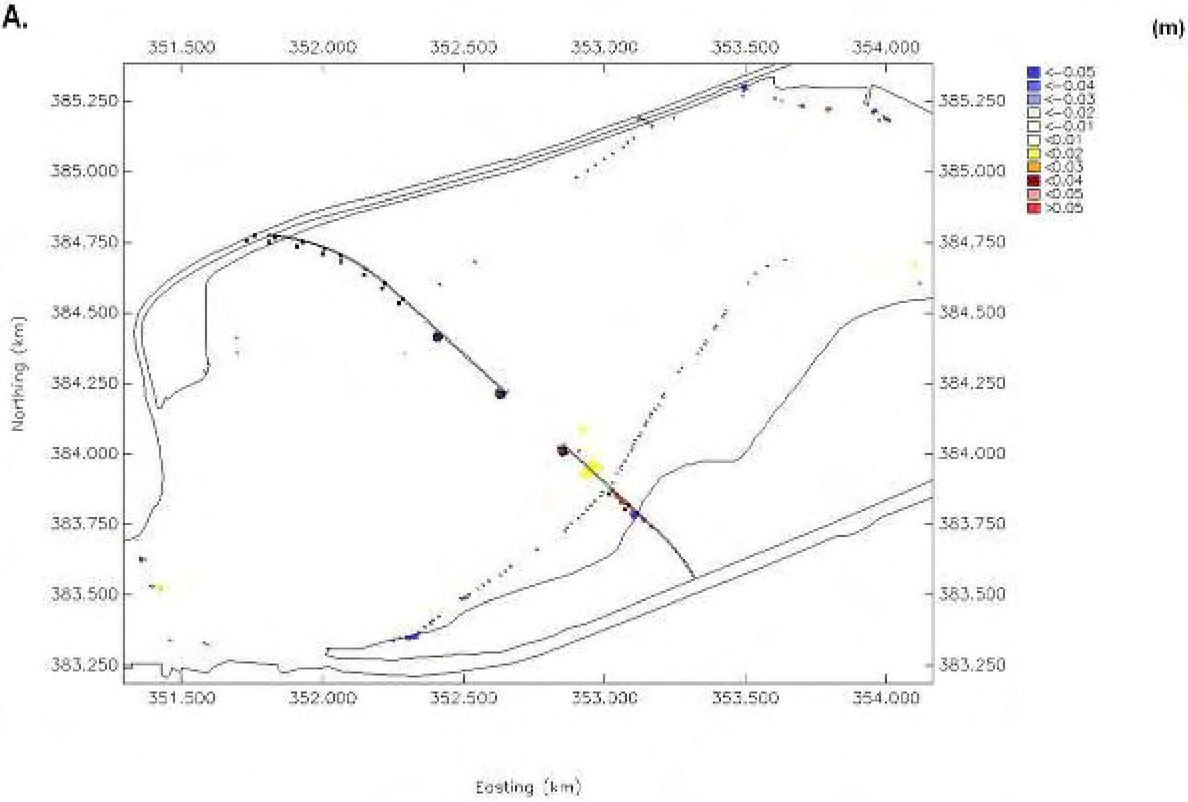
Hydrodynamic Model Outputs: Spring-Neap Cycle with 2005 Bathymetry

7.8.9 The 2005 Bathymetry allowed determination of whether the magnitude or spatial extent of the change being predicted during the modelling was dependant on the particular chosen initial bathymetry.

7.8.10 During this standard spring-neap cycle for the 2005 Bathymetry, as with the 2002 Bathymetry, the only state of the tide with any significant change in water levels is during the peak flood (see Figures 7.50 and 7.51. Around peak flood the model shows a small backwater effect occurring in the south channel (less than 0.02m). The maximum change around the piers is 0.06m with a maximum reduction in water level of about 0.14m. The changes observed continue downstream from the New Bridge, but there are no significant areas of water level change downstream of the Runcorn Gap.

Figure 7.50 - Differences in water level (m) between the baseline case for low water (A) and peak flood (B) on a spring tide

A.



B.

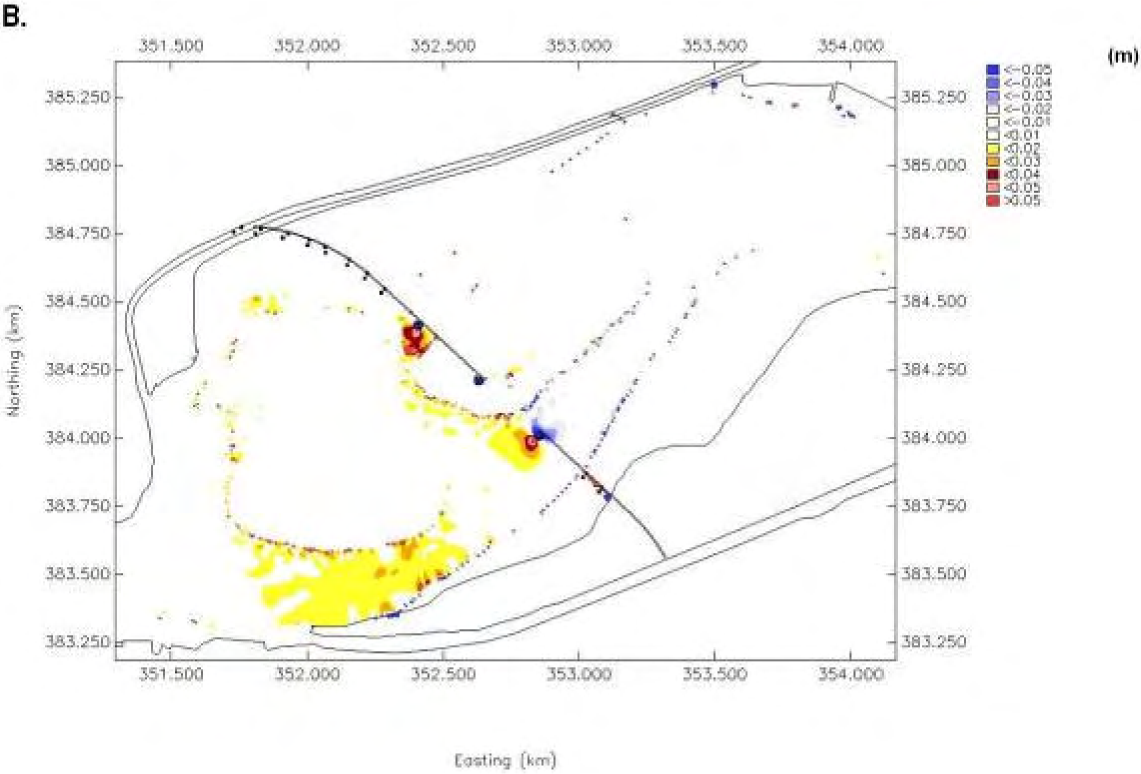
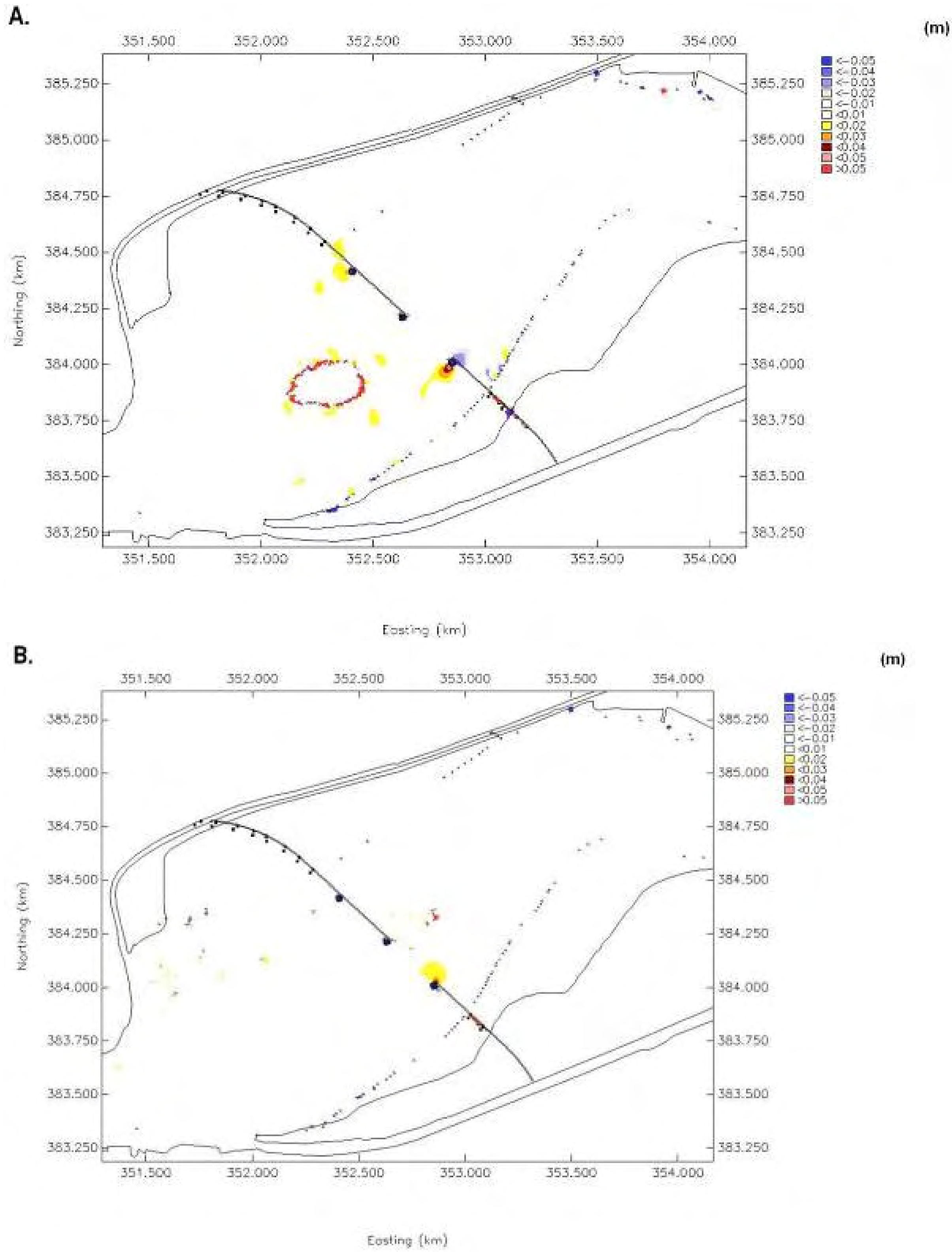


Figure 7.51 - Differences in water level (m) between the baseline case for high water (A) and peak ebb (B) on a spring tide



7.8.11 At high and low water there are minimal changes which are mostly local to the New Bridge structure (maximum 0.28m at low water). In both cases there are minor changes observed along the intertidal areas which are due to minor phase changes in the timing of movement of the tide as it propagates within the channel.

7.8.12 As with the original bathymetry, the aligned jetty in the 2005 Bathymetry has minimal impact during low water. Between peak flood and peak ebb there are also comparable increases in speeds between the three towers and decreases in speeds in the lee of the structures. However, the 2005 Bathymetry has greater changes in speed extending throughout most of the low water channels in the Study Area during peak flood. As would be expected with this alterative bathymetry the greatest effect on water speeds is caused by the presence of the most southern cofferdam.

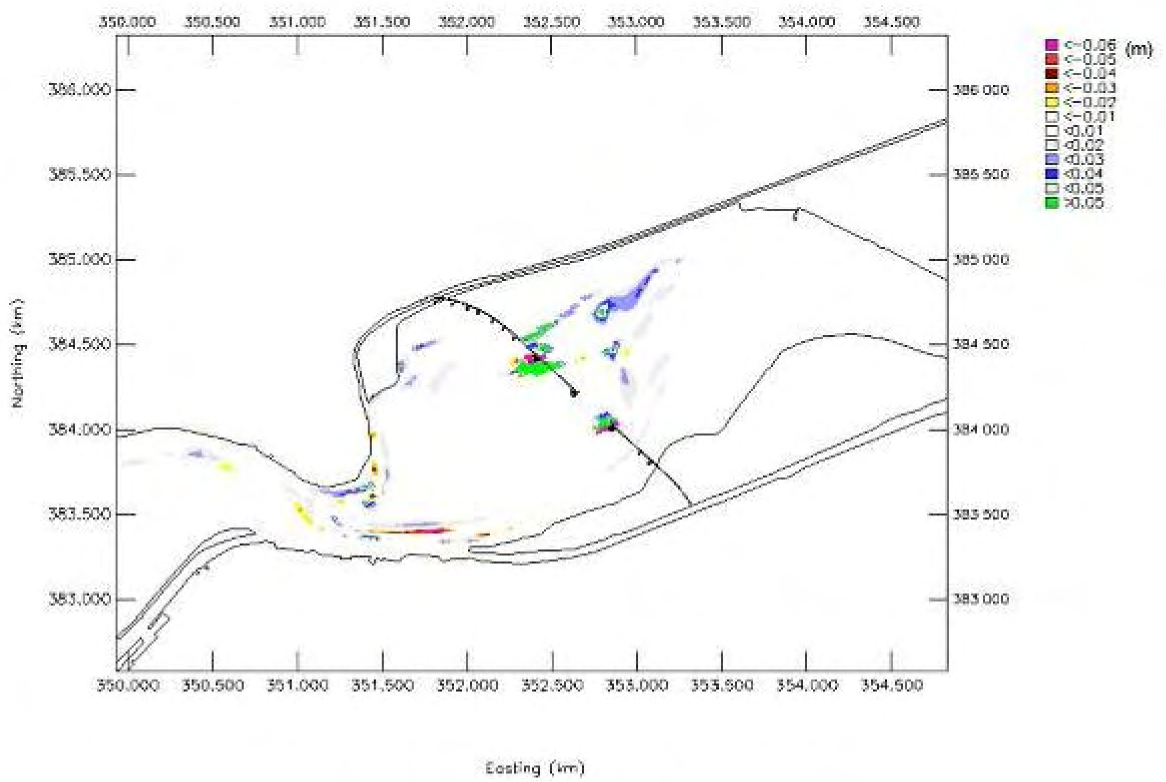
7.8.13 Changes in bed shear stress give a good indication of the impact that the Project has on the sediment system, in particular changes in suspended sediment. As such, with the 2005 Bathymetry, there are significant increases in bed shear stress principally in the vicinity of the low water channels and the gaps between the New Bridge piers.

7.8.14 During high water these changes in bed shear stress are comparable to the original bathymetry. During peak ebb the spatial coverage of the impact varies to the patterns predicted within the original bathymetry with less change in the Runcorn gap area. This is reflected in the morphology outputs.

Morphological Model Outputs: Spring-Neap Cycle with 2002 Bathymetry

7.8.15 In general the greatest changes predicted for the construction phase are local to the cofferdams and in particular the structure located close to the north channel where erosion of 1.4m is predicted. Local to this area of erosion is a large area of accretion (>0.05m) extending around the area of predicted erosion. No change is predicted around the central tower location. (See Figure 7.52).

Figure 7.52 - Morphological changes (m) for construction option – aligned jetty method over 12 month period with 2002 Bathymetry

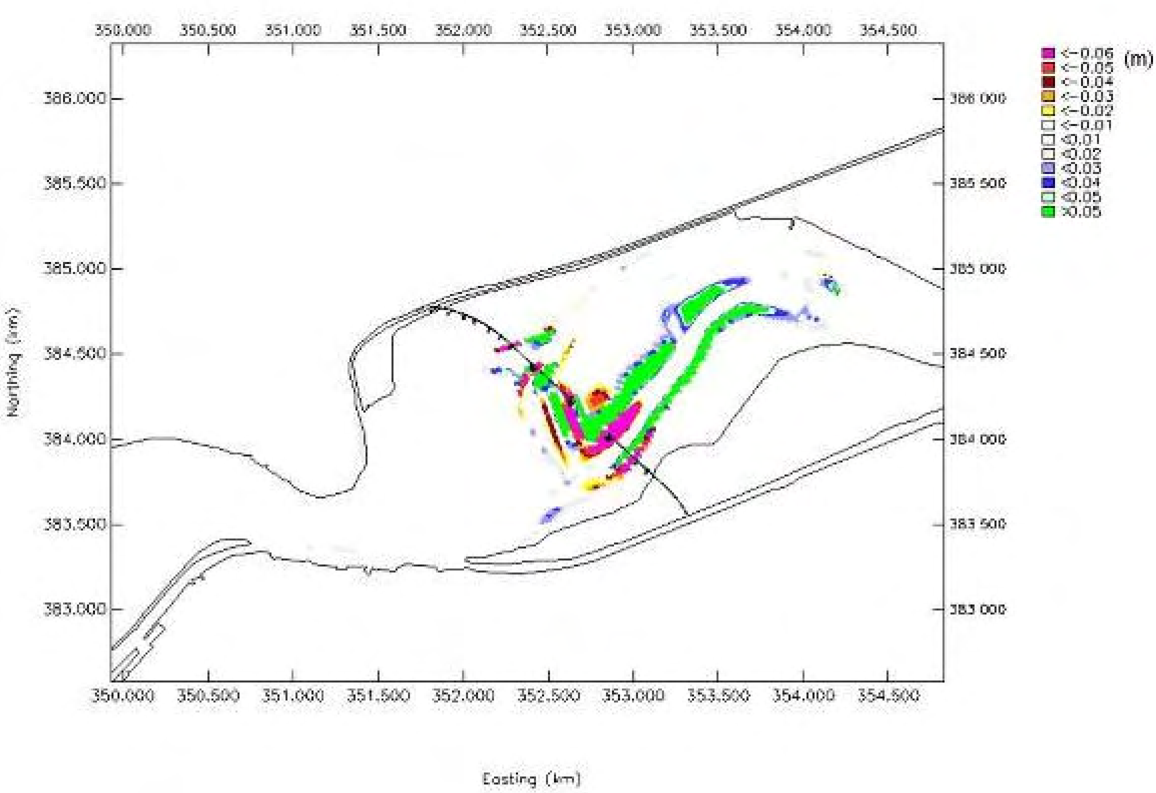


7.8.16 Areas of sediment accretion (0.04m ± 0.02m) are predicted to occur upstream of the New Bridge within the North Channel. There are no significant changes predicted downstream of the New Bridge that could impact on the existing structures and SPA.

Morphological Model Outputs: Spring-Neap Cycle with 2005 Bathymetry

7.8.17 The results of the morphological model for the aligned jetty with the spring neap cycle run for one year show a predicted increase in erosion adjacent to the cofferdams within the north and south channels (around 1.3m and 1.4m respectively). This is illustrated in Figure 7.53. The largest area of erosion occurs forward and behind the southern cofferdam, along the south channel and extending towards the central cofferdam.

Figure 7.53 - Morphological changes (m) for Construction Option – Aligned jetty method over 12 month period with 2005 bathymetry



7.8.18 An increase of 0.4m ± 0.2m in bed elevation is predicted along the margins of the south channel. This extends form Reed Island up to the New Bridge crossing site. The extent of change is slightly greater than predicted using the 2002 bathymetry. However the change in bed elevation is not significantly different. An increase of 0.1m is predicted downstream of the central cofferdam. No difference in bed elevation is predicted downstream of the immediate areas of the New Bridge crossing.

Hydrodynamic Model Outputs: Extreme Events with 2002 Bathymetry

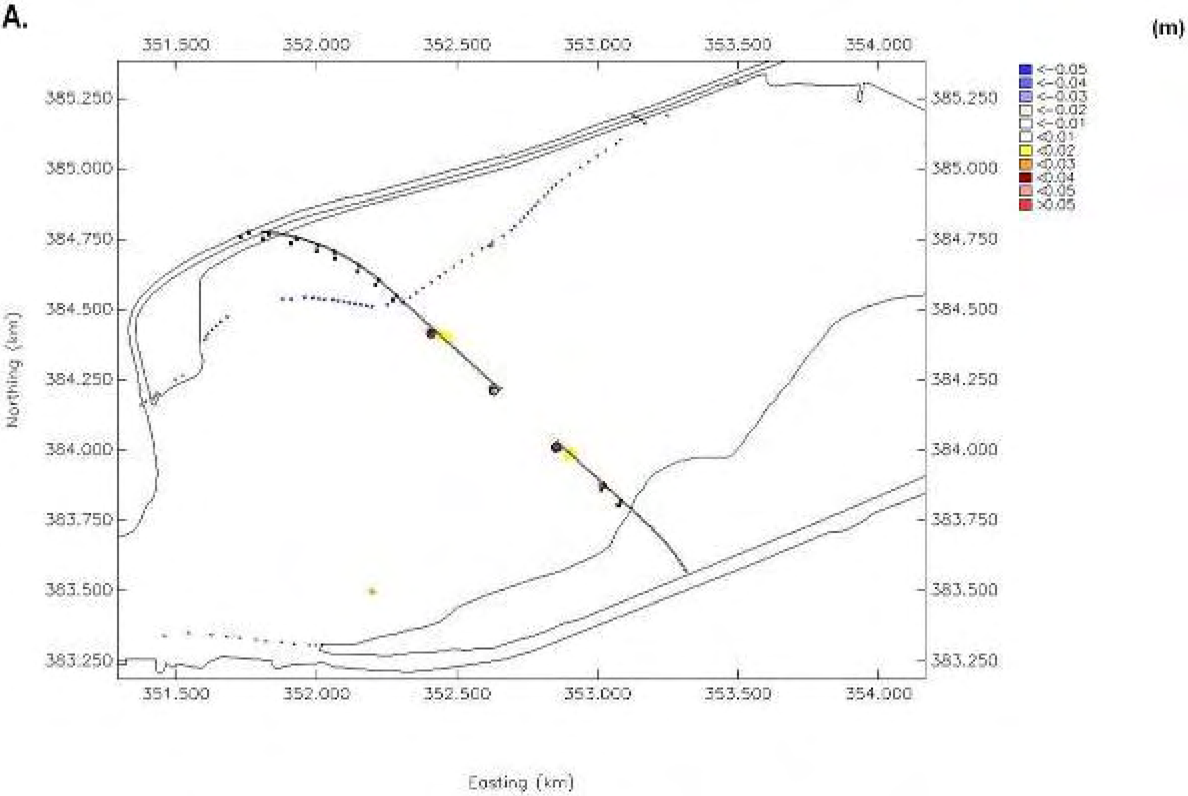
7.8.19 It is possible to draw some level of comparison between the results of the Extreme Events (combined 1:200 year fluvial and surge events) and the standard Spring-Neap Cycle. However, the duration of the modelling is different (standard spring-neap fifteen days and extreme event four days) and therefore the spatial extent of this change is much reduced as the event only lasts a few days.

7.8.20 Around low water in an extreme fluvial and surge event the changes in water level are primarily linked to the channel area around the jetty and tower structures and do not exceed 0.02m

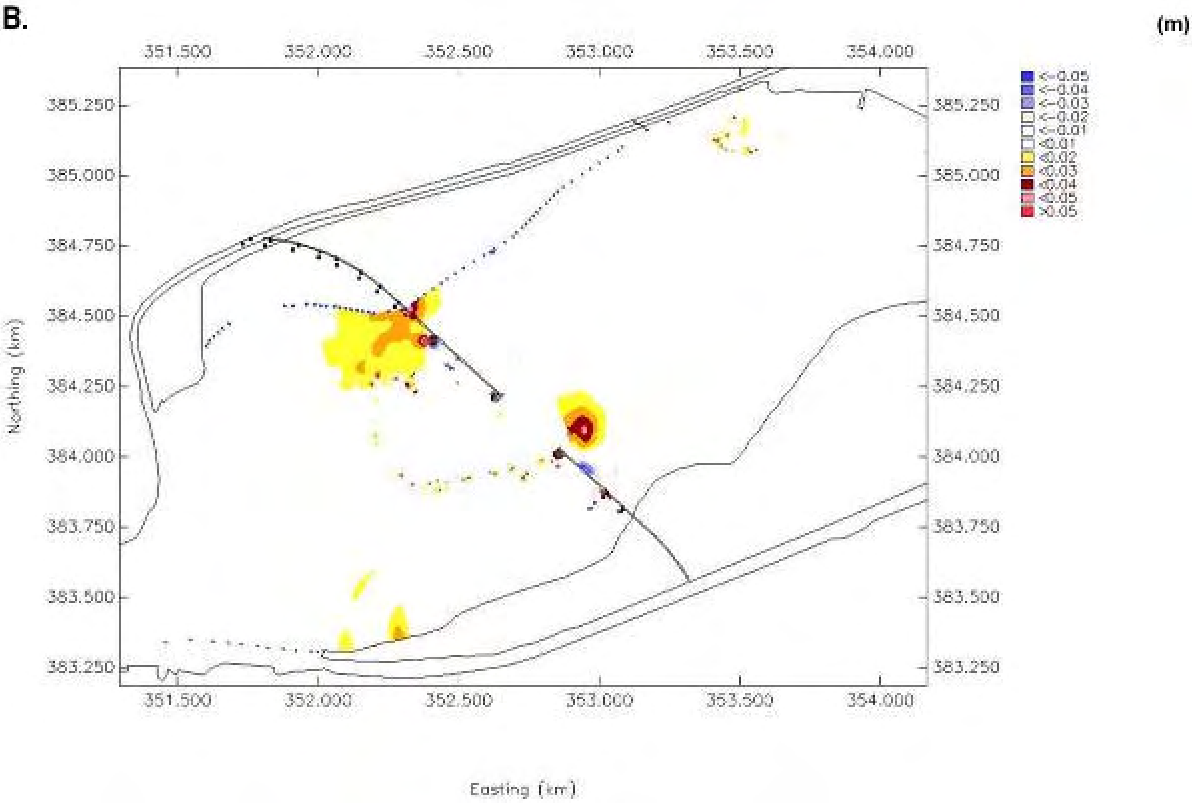
(Figure 7.54). Any changes observed along the intertidal area are due to minor phase changes in the timing of the movement of the tide as it propagates within the channel.

Figure 7.54 - Differences in water level (m) between the Aligned Jetty Construction Option and the baseline case for an extreme fluvial and surge event at low water (A) and peak flood (B)

A.



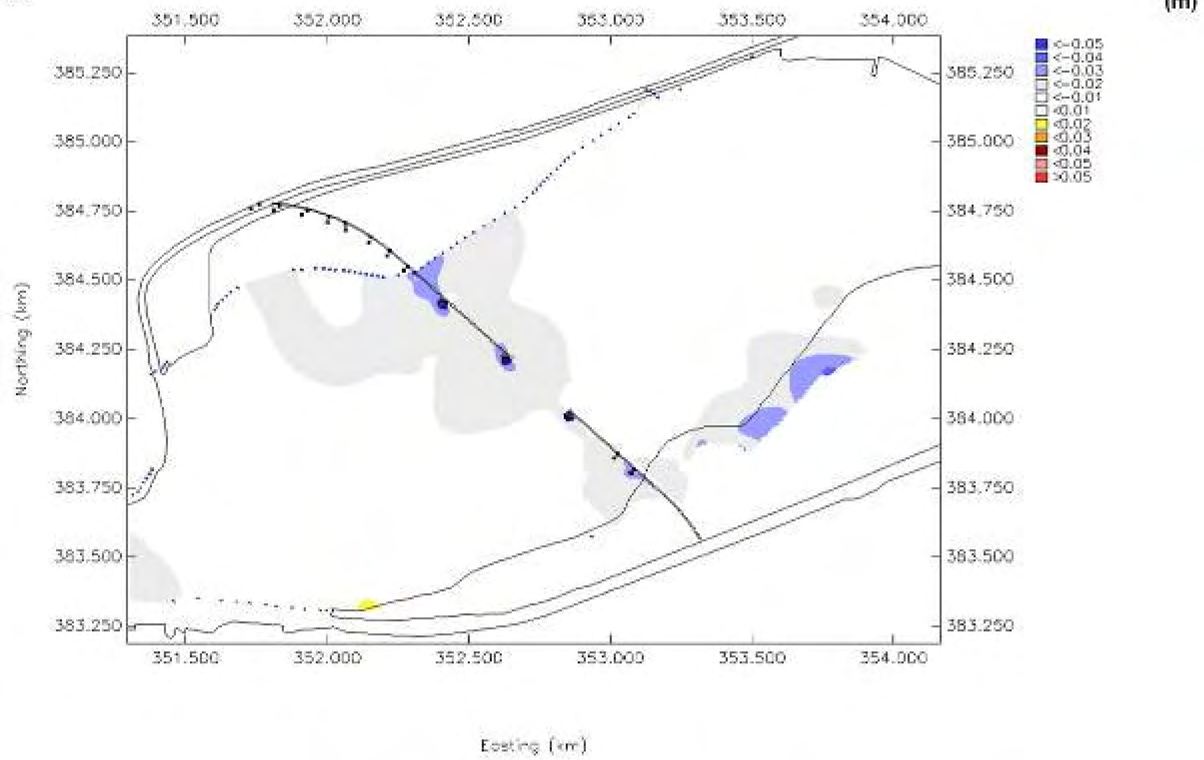
B.



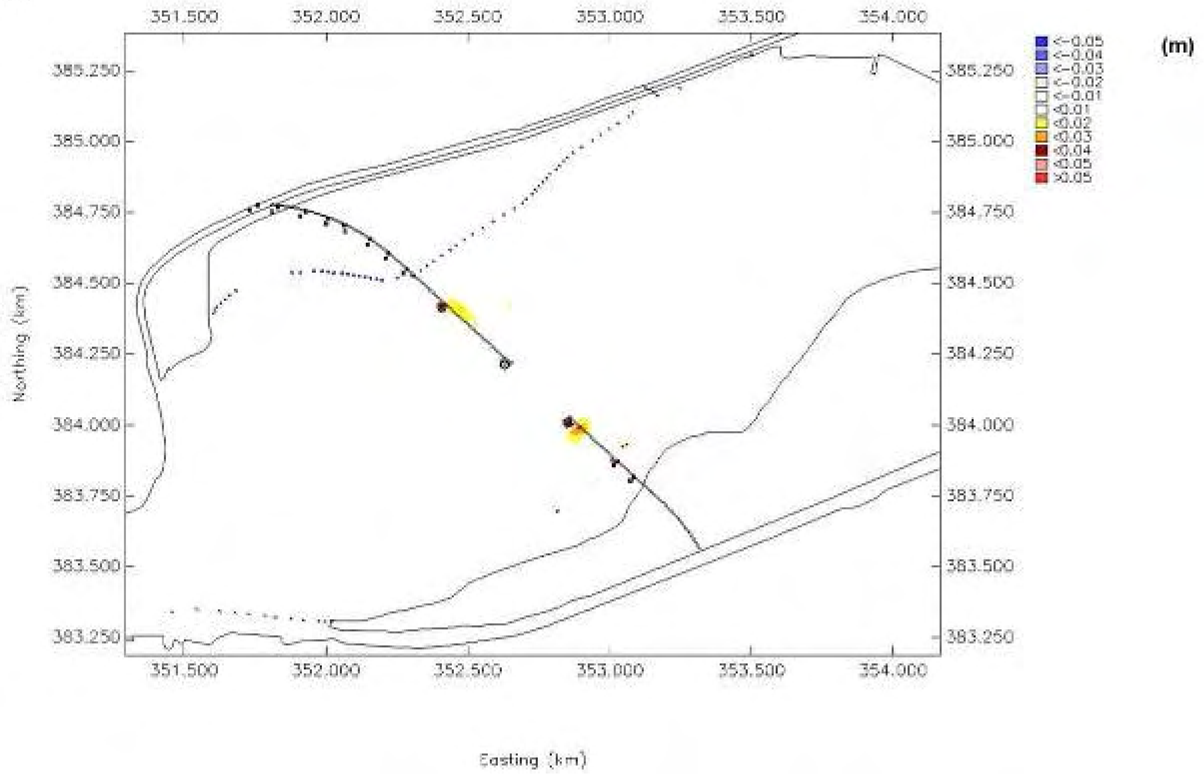
7.8.21 During the peak flood tide there is a small backwater effect indicated by water level change which is focused on the areas adjacent to the north and south cofferdams and the low water channels. The maximum change around the piers is 0.06m and within the channel this reduces to 0.04m. There is a residual effect around high water as shown in Figure 7.55A, but this has dissipated by around the time of peak ebb flows.

Figure 7.55 - Differences in water level (m) between the Aligned Jetty Construction Option and the baseline case for an extreme fluvial and surge event at high water (A) and peak ebb (B) on a spring tide

A.



B.

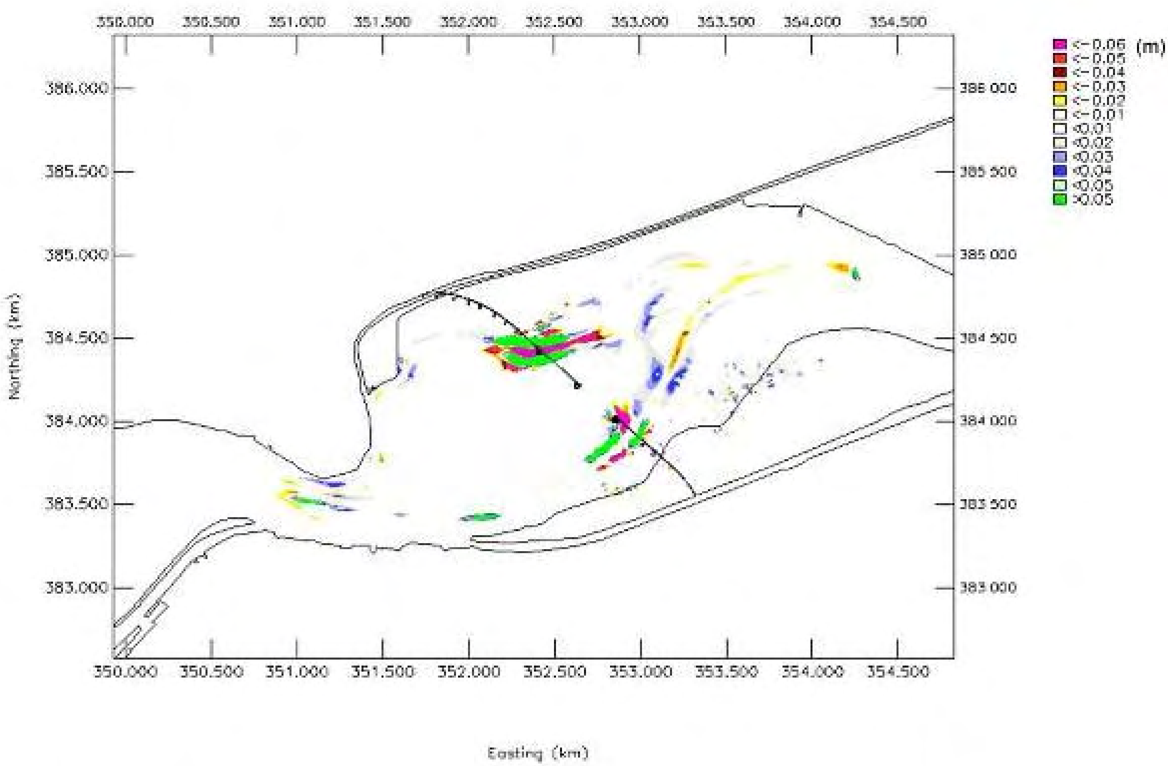


7.8.22 During this extreme event there are changes to the near-bed and surface water speeds and bed shear stress at all states of the tide. During peak flood, the short flood tide, combined with the increased tidal surge and restrictions due to the cofferdams, creates a change in velocities. During high water, due to the cofferdams and subsequent backwater effects, additional areas will be inundated.

Morphological Model Outputs: Extreme Events with 2002 Bathymetry

7.8.23 As a result of this extreme event there are areas of erosion adjacent to the cofferdams (see Figure 7.56. This erosion is greater near the northern cofferdam with maximum changes of erosion up to 1.79m and deposition of 1.2m. However, these extreme changes in morphology are limited to the immediate area around the cofferdam. The southern cofferdam has a maximum of 0.5m of erosion and 0.75m of deposition local to the cofferdams.

<u>Figure 7.56 - Morphological changes (m) during an extreme event for construction option – Aligned jetty method over a 15 day period</u>



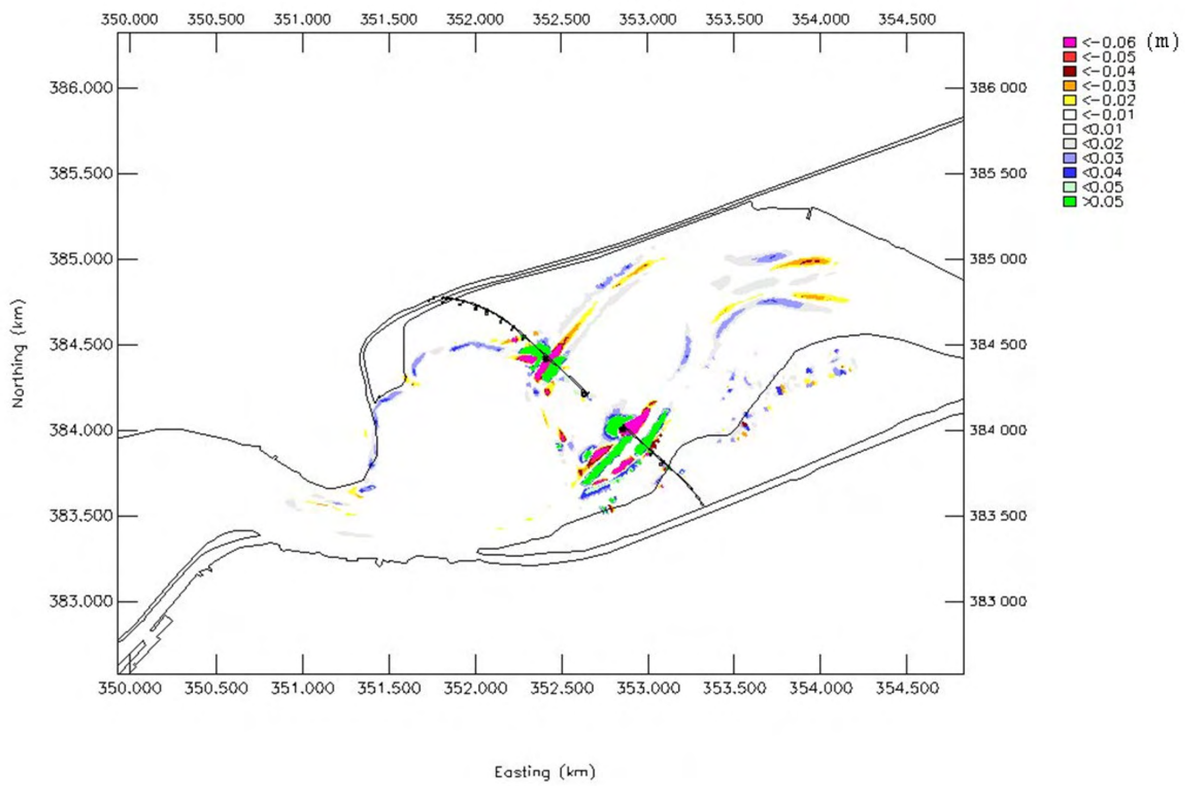
7.8.24 More widespread erosion is predicted within the Study Area extending intermittently downstream to, but no further than, Runcorn Gap. Upstream of the New Bridge some erosion (around 0.01m) is predicted along the margins of the main flood and ebb channels.

7.8.25 The model simulation shows that the changes in bed elevation are large relative to those predicted to occur in the normal spring- neap event. However such extreme events are rare and only last a short time. The change is also not significantly greater than that resulting from an extreme event without the presence of the jetty, altering 10% of the study area when compared with the baseline extreme event.

Morphological Model Outputs: Extreme Events with 2005 Bathymetry

7.8.26 Figure 7.57 shows the changes predicted by the model for an extreme event based on the 2005 Bathymetry. The results indicate an increase in bed elevation of 0.6m adjacent to the northern channel cofferdam. A maximum reduction in bed elevation is also predicted adjacent to the upstream face of the north channel cofferdam. The extent of the predicted areas of erosion is generally limited to the north and south cofferdams. Some accretion (0.1m±0.05m) is predicted along the margins of the main channel upstream of the New Bridge.

Figure 7.57 - Morphological changes (m) during an extreme event for construction option – Aligned jetty method over a 15 day period using 2005 bathymetry



Summary of Results for Construction Phase

7.8.27 Overall the Estuary shows a similar morphological response when modelled using the 2005 Bathymetry compared with the modelling completed using the 2002 Bathymetry.

7.8.28 Table 7.12 summarises the maximum morphological change as a result of each of the events modelled for the construction phase.

Table 7.12 - Summary of maximum morphological change (erosion and deposition) and extent of change over the Study Area as a result of the different construction methods when compared with the equivalent baseline event

Design Option	Duration modelled	Maximum erosion adjacent to the piers	Maximum deposition adjacent to the piers	Extent of plan area which changes within the Study Area
Aligned jetty[1]	12 months	1.38m	0.33m	4% change
Aligned jetty extreme event[1]	15 days	1.79m	0.90m	10% change
Aligned jetty[2]	15 days	1.38m	0.60m	9.2% change

Design Option	Duration modelled	Maximum erosion adjacent to the piers	Maximum deposition adjacent to the piers	Extent of plan area which changes within the Study Area
Aligned jetty extreme event[2]	15 days	1.20m	0.65m	10.7% change
[1] 2002 Bathymetry [2] 2005 Bathymetry				

7.8.29 The construction phase jetty option was modelled as having change over only 4% of the Study Area during a spring neap cycle. The maximum erosion is 1.38m adjacent to the piers, which corresponds to the erosion for the 2005 Bathymetry. However when the 2005 Bathymetry is used a larger extent of change is recorded (9.2%) together with over 0.25m additional accretion. The extreme events were both modelled as changing a similar proportion of the Study Area (around 10%).

7.8.30 All the construction phase scenarios modelled gave rise to small change compared to the percentages of the Study Area changed by the extreme event run for the two bathymetries as a baseline (37.7% and 40.5%). It should be noted that the two comparisons carried out are independent of each other so that the percentage of area changed cannot be summed to give a total area of change. For example for the 2002 bathymetry when the extreme event was compared with the results from the spring-neap cycle 40.5% of the area had changed level. When the effect of an extreme event was compared with and without the aligned jetty 10%of the area had changed of which some overlapped with areas changed by the baseline extreme event and some areas were different.

7.8.31 There is a marked change (albeit small) in activity within the Runcorn Gap (as shown in Figures 7.56 and 7.57) which is present during the construction phase. Sensitivity testing of the model suggests that this is the result of the jetty piers blocking some of the flow through the North Channel.

7.8.32 Table 7.13 summarises the changes in water level modelled for the different scenarios considered during the construction phase.

Table 7.13 - Water level summary table for aligned jetty construction option (from ABPmer Report 1180, Appendix 7.1)

Scenario	Position	Low Water		Peak Flood		High Water		Peak Ebb	
		max (m)	min (m)	max (m)	min (m)	max (m)	min (m)	max (m)	min (m)
Spring – Neap Cycle 2005 Bathymetry	Towers	-	-	0.07	-0.04	0.03	-0.02	0.01	-
	Channels	-	-	0.03	-0.03	0.01	-	-	-
	Intertidal	-	-	0.08	-0.05	0.05	-	0.04	-0.08
Extreme fluvial and surge event – 1:200 return period (2005 Bathymetry)	Towers	0.02	-	0.06	-0.08	0.02	-	0.03	-
	Channels	-	-	0.04	-	-	-	-	-
	Intertidal	-	-	0.01	-	-	-	-	-

7.8.33 All the changes in water level are small with the maximum change modelled being ±0.08m. As this occurs locally to the piers and during the peak flood, it will not give rise to an increase in flood risk.

Results of Computational Modelling for Operation Phase

7.8.34 For the proposed arrangement of piers and towers for the New Bridge, the hydrodynamic model was run for a spring-neap cycle and for high fluvial flows with a tidal surge event. As described in paragraph 7.6.15 structures are modelled using a change in roughness for the appropriate 3m x 3m cells. Results were derived to indicate impacts on water levels, near-surface and near-bed speeds and bed shear stress. The morphological model was then run to predict the likely long-term (one year period) changes in morphology with particular regard to patterns of erosion and deposition and their location. In this scenario the only modelling undertaken for the 2005 Bathymetry was morphological as full hydrological modelling of the 2005 Bathymetry has been undertaken within the remit of the construction phase using the worst case scenario.

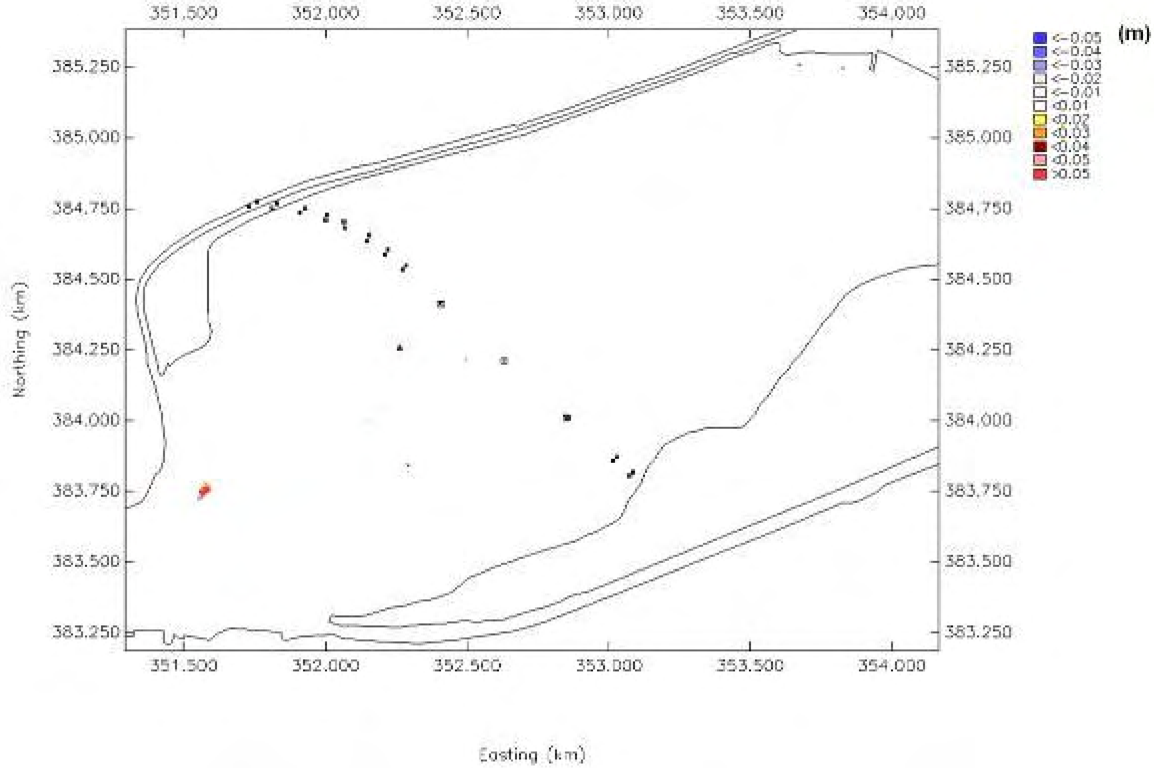
7.8.35 The modelling of the operation phase is described in detail in Appendix 7.4.

Hydrodynamic Model Outputs: Spring-Neap Cycle with 2002 Bathymetry

7.8.36 Changes in water levels for the New Bridge in operation are minimal. At low water there is no discernible change in levels as all New Bridge towers are outside of the low water channels for this chosen bathymetry (Figure 7.58). The changes at high water are negligible and those calculated for peak ebb on a spring tide are also minimal (Figure 7.59).

Figure 7.58 - Differences in water level (m) between the New Bridge and the baseline case for low water (A) and peak flood (B) on a spring tide

A.



B.

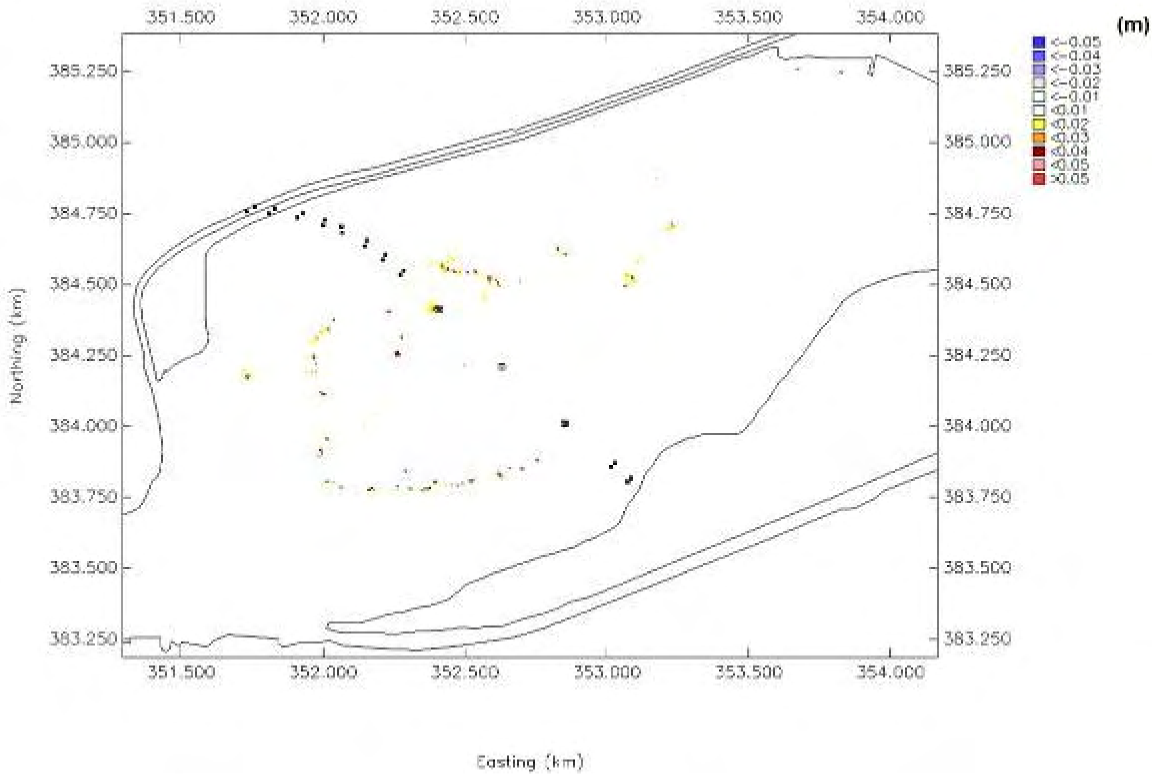
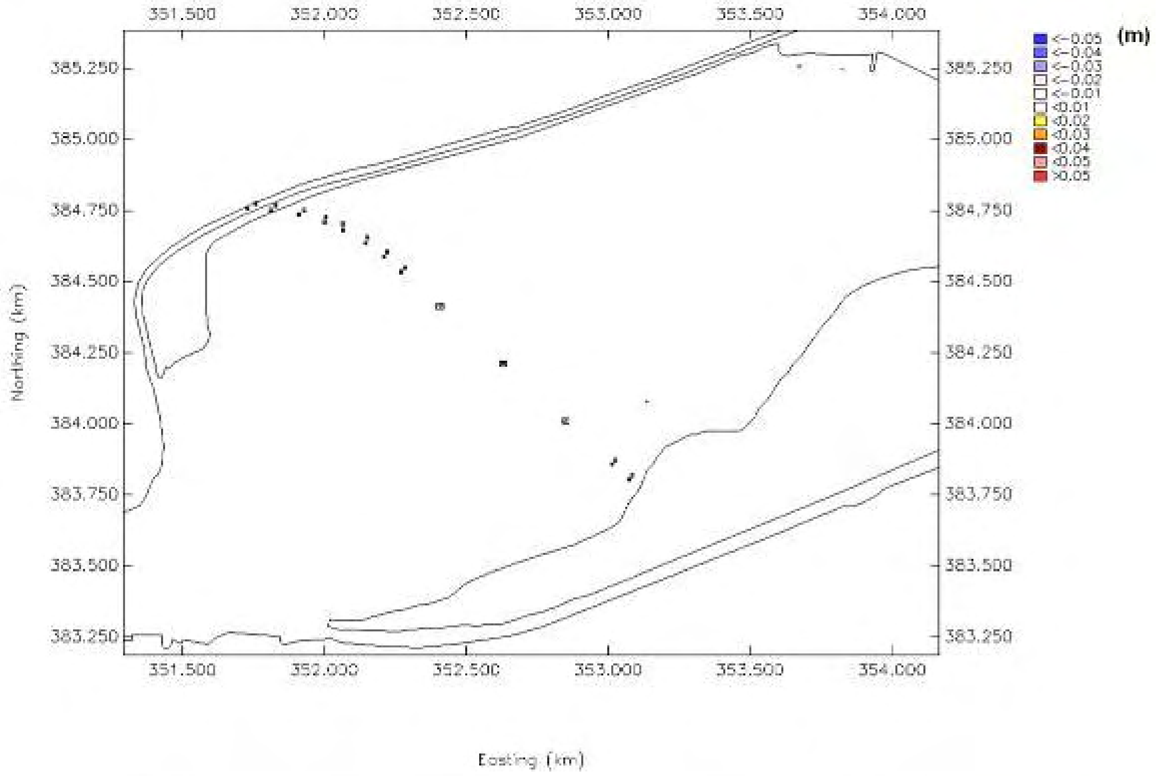
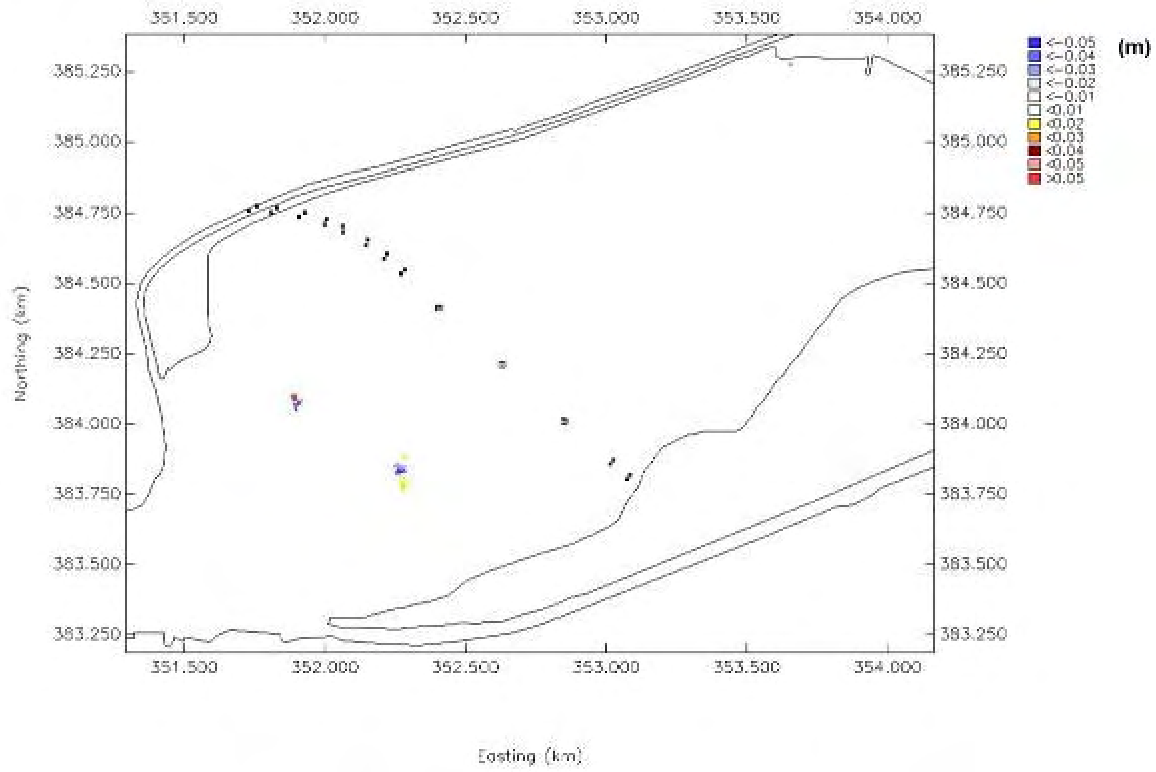


Figure 7.59 - Differences in water level (m) between the New Bridge and the baseline case for high water (A) and peak ebb (B) on a spring tide

A.



B.



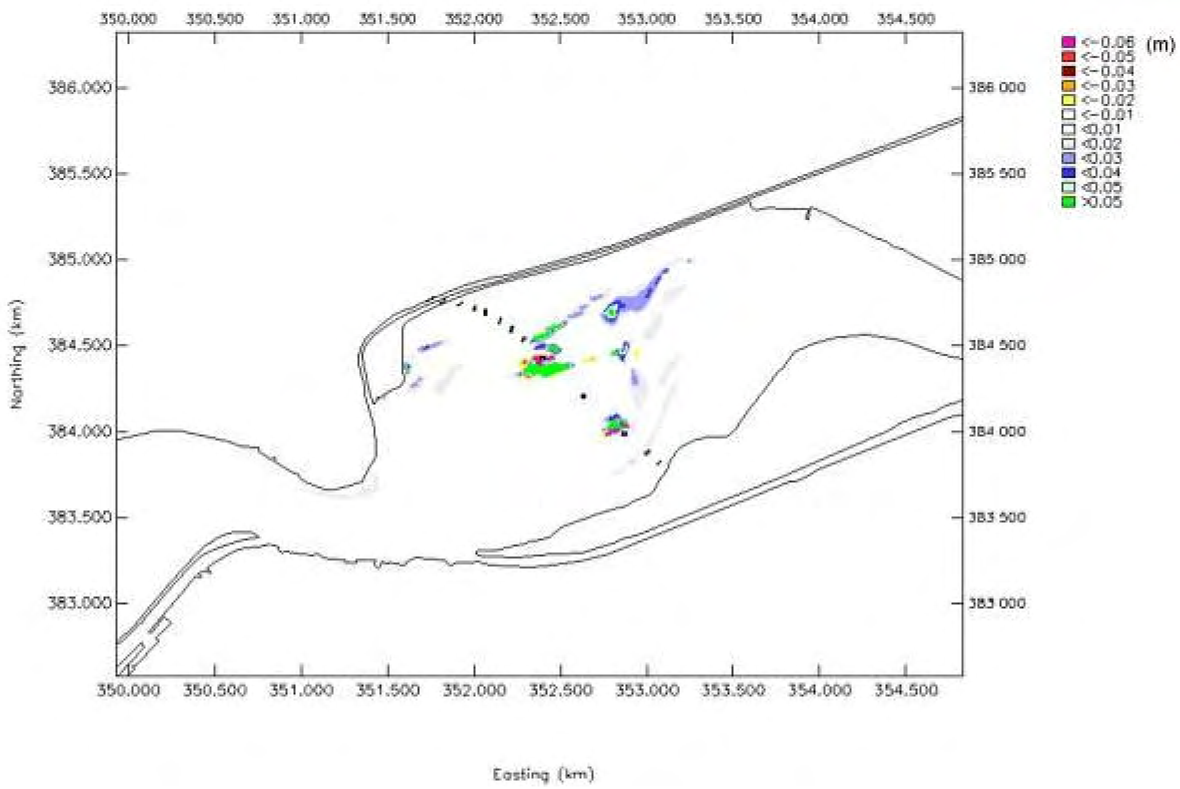
7.8.37 The changes in speeds are local to the tower locations. At low water there is no discernible change in speeds as all the New Bridge towers are outside of the low water channels. In addition, the positioning of the central tower ensures that this only impacts on the system at high water, resulting in changes of speeds around all towers in this time period.

7.8.38 Patterns and extents of changes in bed shear stress mirror the changes in speeds predicted in the model, and changes are confined to the immediate locality of the towers. As seen previously, at low water there is no discernible change in bed shear stress as all the New Bridge towers are outside of the low water channels.

Morphological Model Outputs: Spring-Neap Cycle with 2002 Bathymetry

7.8.39 The main areas of change are focused on the areas local to the towers and on the interface between the low water channels (as detailed in Figure 7.60).

Figure 7.60 - Morphological changes (m) for the New Bridge during operation phase over a 12 month period



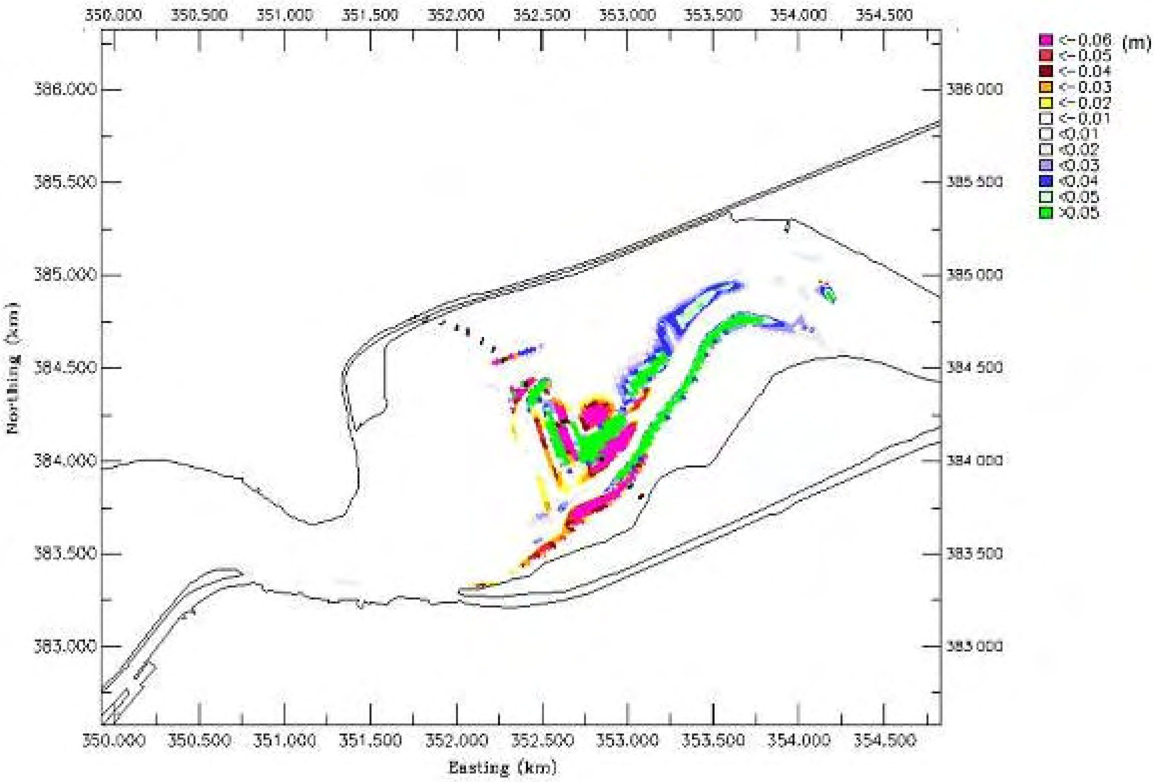
7.8.40 Away from the New Bridge structures morphological changes as a result of the Project are less than ±0.05m. Thus any change will not have an impact on the SJB or the Manchester Ship Canal training wall. The modelling does not show any changes downstream of the Runcorn Gap that could affect the SPA.

7.8.41 The maximum change local to the bridge tower adjacent to the north channel are erosion of 1.38m and deposition of 0.29m. Adjacent to the tower situated close to the south channel the maximum deposition is 0.28m and the maximum erosion is 0.68m. It is important to note that the predicted increases in speeds and bed shear stress adjacent to the central tower have, in the long term, no detrimental effect on the area and very little erosion has been predicted in that area. This is likely to be a result of the relatively short duration of the predicted large changes in bed shear stress and speed that only occur on the spring tide. However, it shall be noted that the assessment of scour immediately adjacent to structures is not well modelled. Estimates for this impact are given in Section 7.11. There are no predicted changes in the interface between the low water channels and the intertidal areas.

Morphological Model Outputs: Spring-Neap Cycle with 2005 Bathymetry

7.8.42 As expected, the variation in bed topography has resulted in a variation in predicted channel change for this scenario (Figure 7.61). The greatest extent of change is upstream of the New Bridge, with accretion predicted to occur along the intertidal shoreline and banks. Downstream of the New Bridge there is some erosion along the intertidal area adjacent to the south bank (typically less than 0.06m).

Figure 7.61 - Morphological changes (m) for the New Bridge for operation phase



7.8.43 Within the south channel the greatest changes occur local to the bridge tower with maximum erosion and deposition of -1.54m and 0.65m respectively. Changes within the north channel are limited to the location of the New Bridge structure.

7.8.44 In general the channel configuration results in a slight increase in bed elevation downstream of the New Bridge crossing. This increase is localised to the margins of the north channel. The results indicate that no change occurred in bed elevation downstream of the immediate area of the New Bridge crossing and so there will be no impact on the existing structures within the Study Area, downstream of the New Bridge or on the SPA.

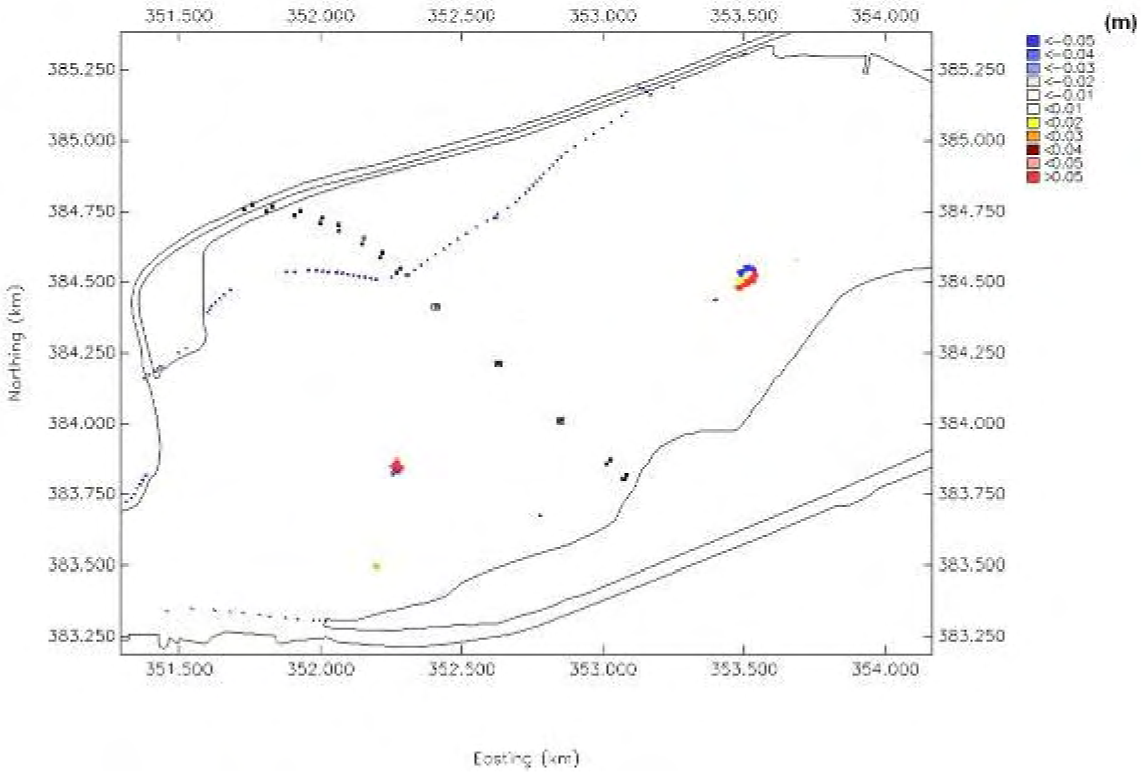
Hydrodynamic Model Outputs: Extreme Events with 2002 Bathymetry

7.8.45 The New Bridge in the operation phase has been modelled for the Extreme Events of the 1 in 200 year return period fluvial event combined with a 1 in 200 year return period tidal surge event.

7.8.46 Change in water levels for the Project during the Extreme Event is minimal. Any changes in water levels during low water and peak flood and ebb are likely to be a result of phase changes (see paragraph 1.6.49). At high water there is a decrease in water levels (typically less than 0.02m). However there is no indication that the structure causes any significant blockage across the Estuary (Figures 7.62 and 7.63).

Figure 7.62 - Differences in water level (m) between the New Bridge and the baseline case for low water (A) and peak flood (B) on a combined 1:200 surge and 1:200 fluvial event

A.



B.

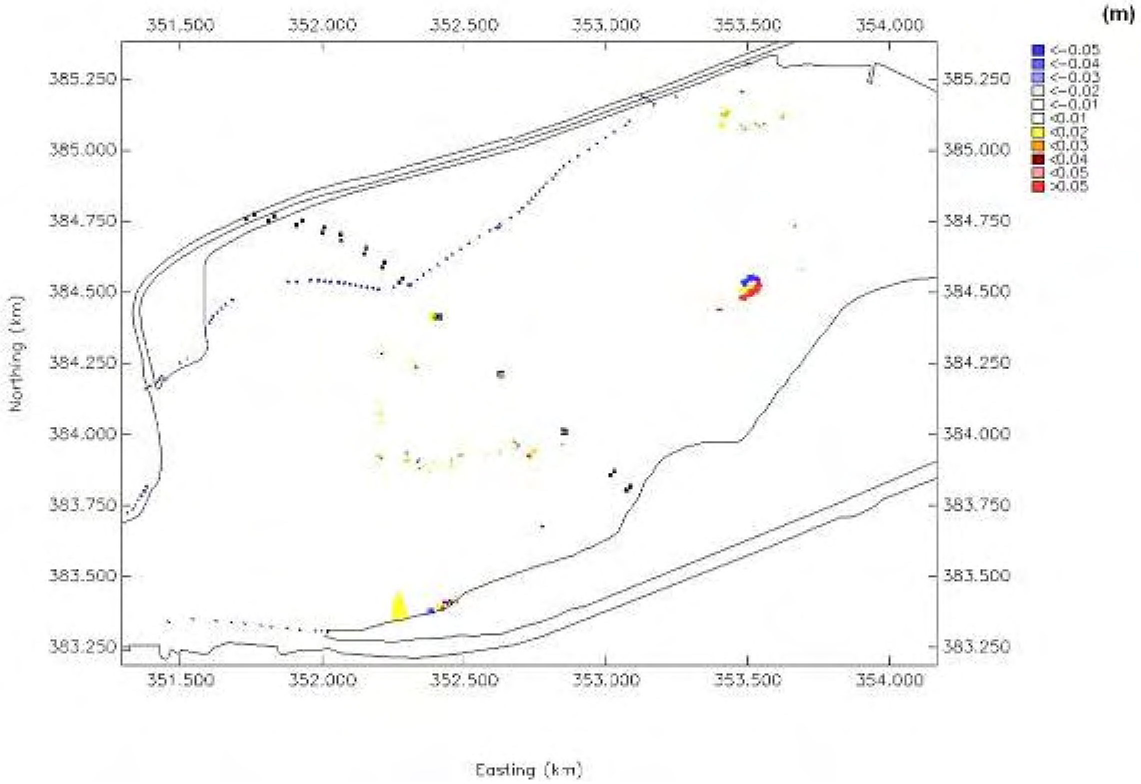
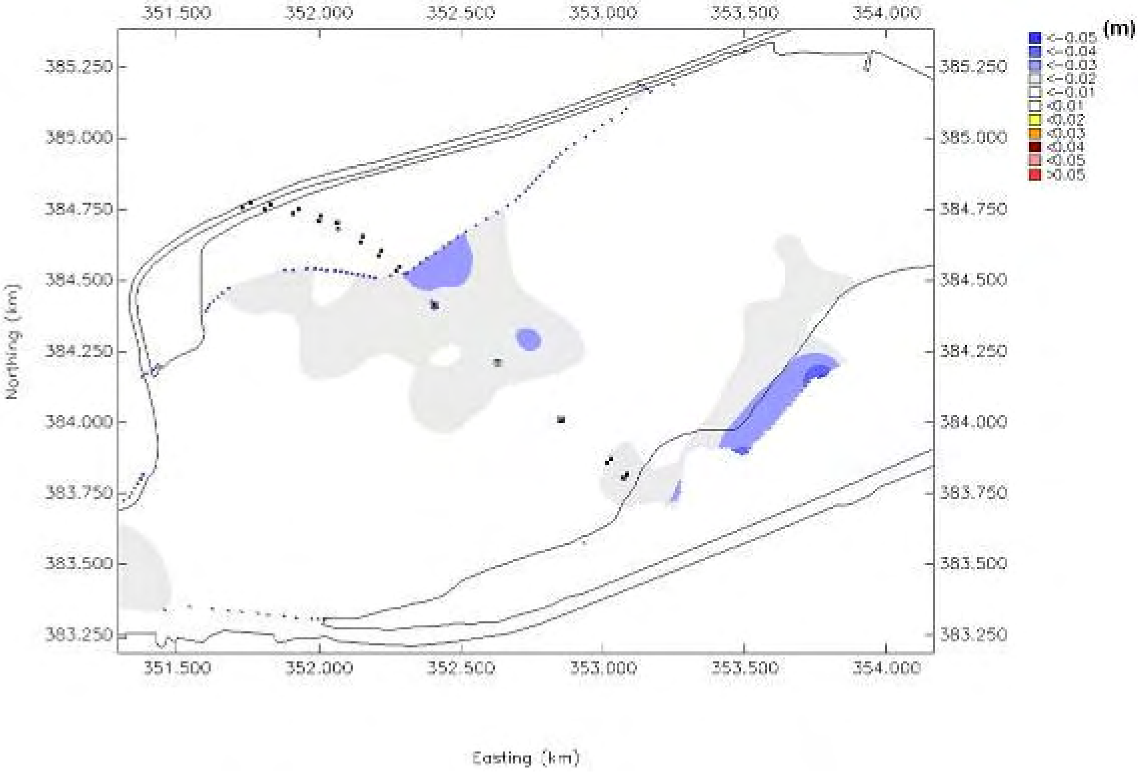
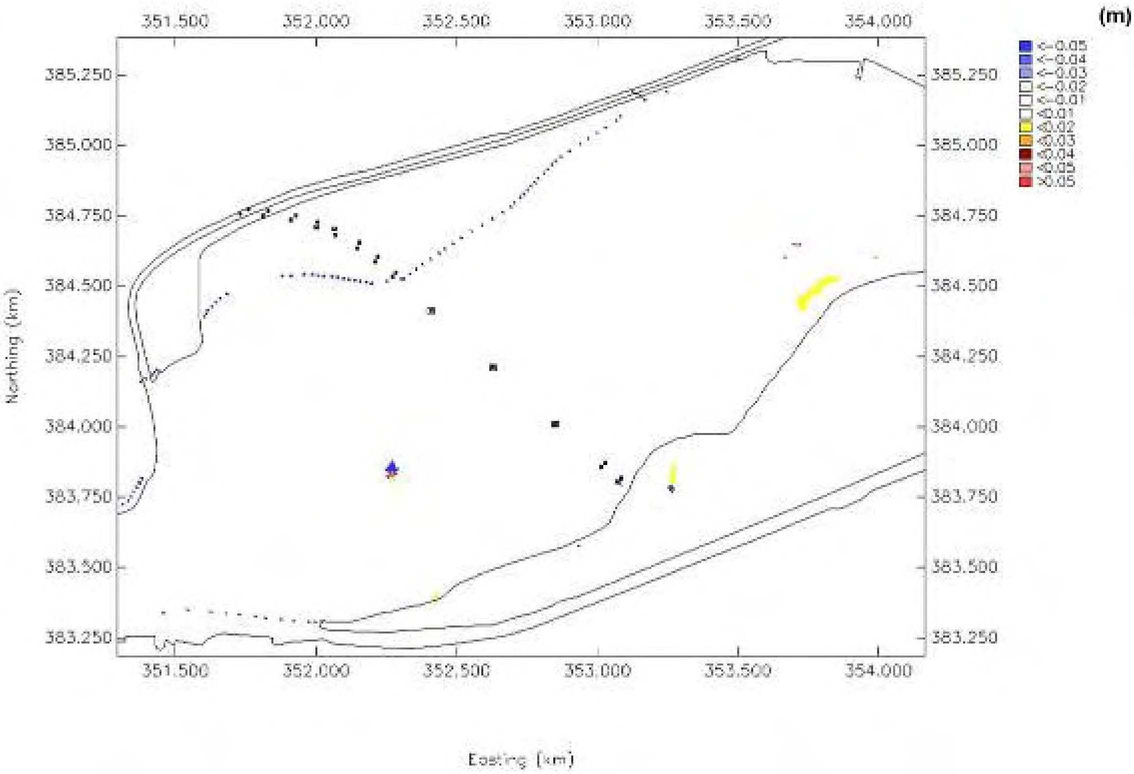


Figure 7.63 - Differences in water level (m) between the New Bridge and the baseline case for high water (A) and peak ebb (B) on a combined 1:200 surge and 1:200 fluvial event

A.



B.

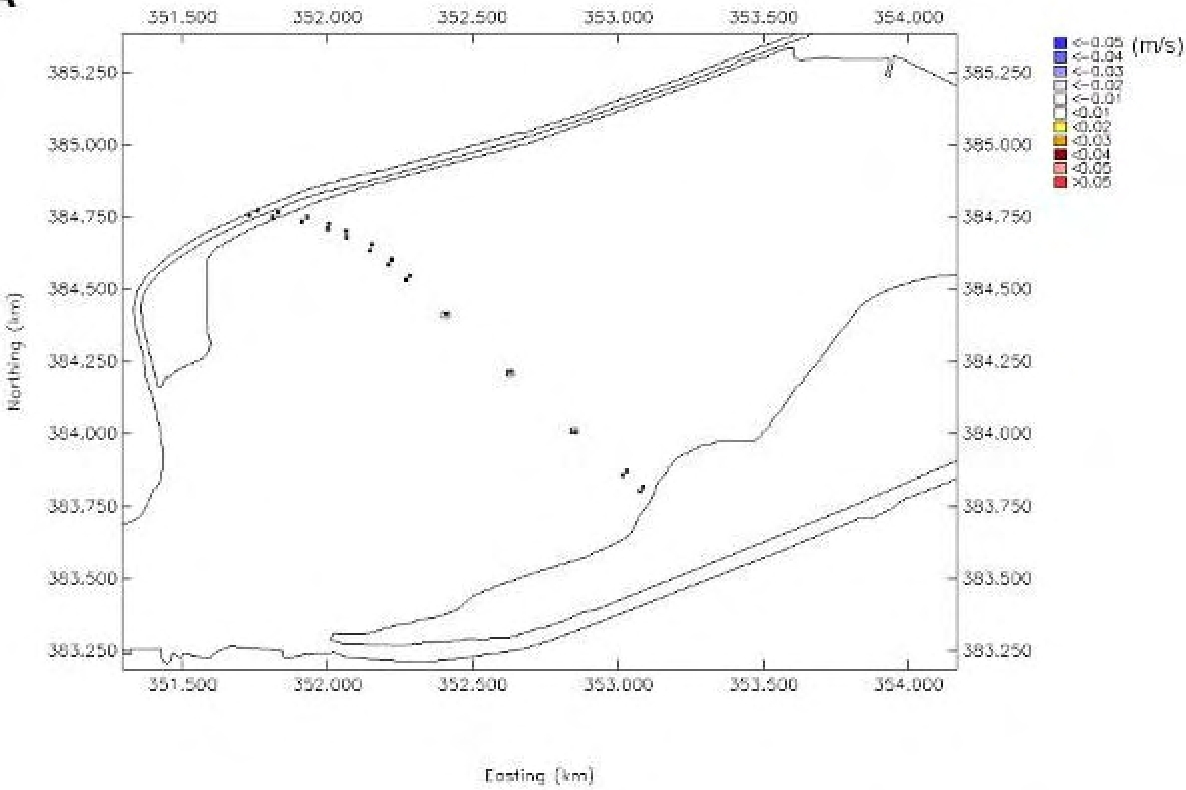


7.8.47 As the flooding tide moves onto the intertidal areas differences can be manifested along the edge of the tidal wave (±0.05m in Figure 7.62). These differences do not provide a real indication of absolute change as they are an artefact of phase differences in the propagation of the front of the tidal wave and represent a positional change in water level.

7.8.48 Changes in near surface and near bed speeds are generally limited to the area around the New Bridge towers, with the exception of high water. Figures 7.64 and 7.65 illustrate this for near surface speed. At high water, Figure 7.65 clearly shows that the spatial extent of the changes in speed is greater than under standard spring neap conditions.

Figure 7.64 - Differences in near surface speed (m/s) between the New Bridge and the baseline case for low water (A) and peak flood (B) on a spring tide

A



B

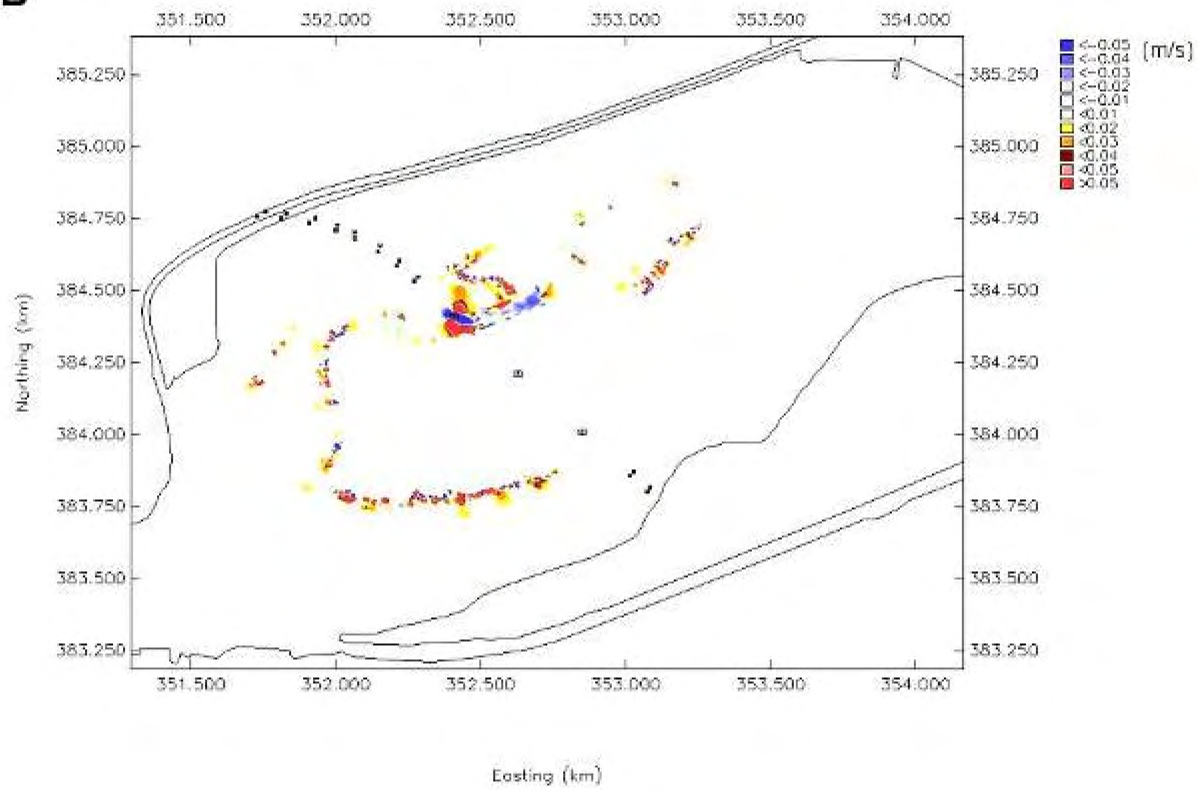
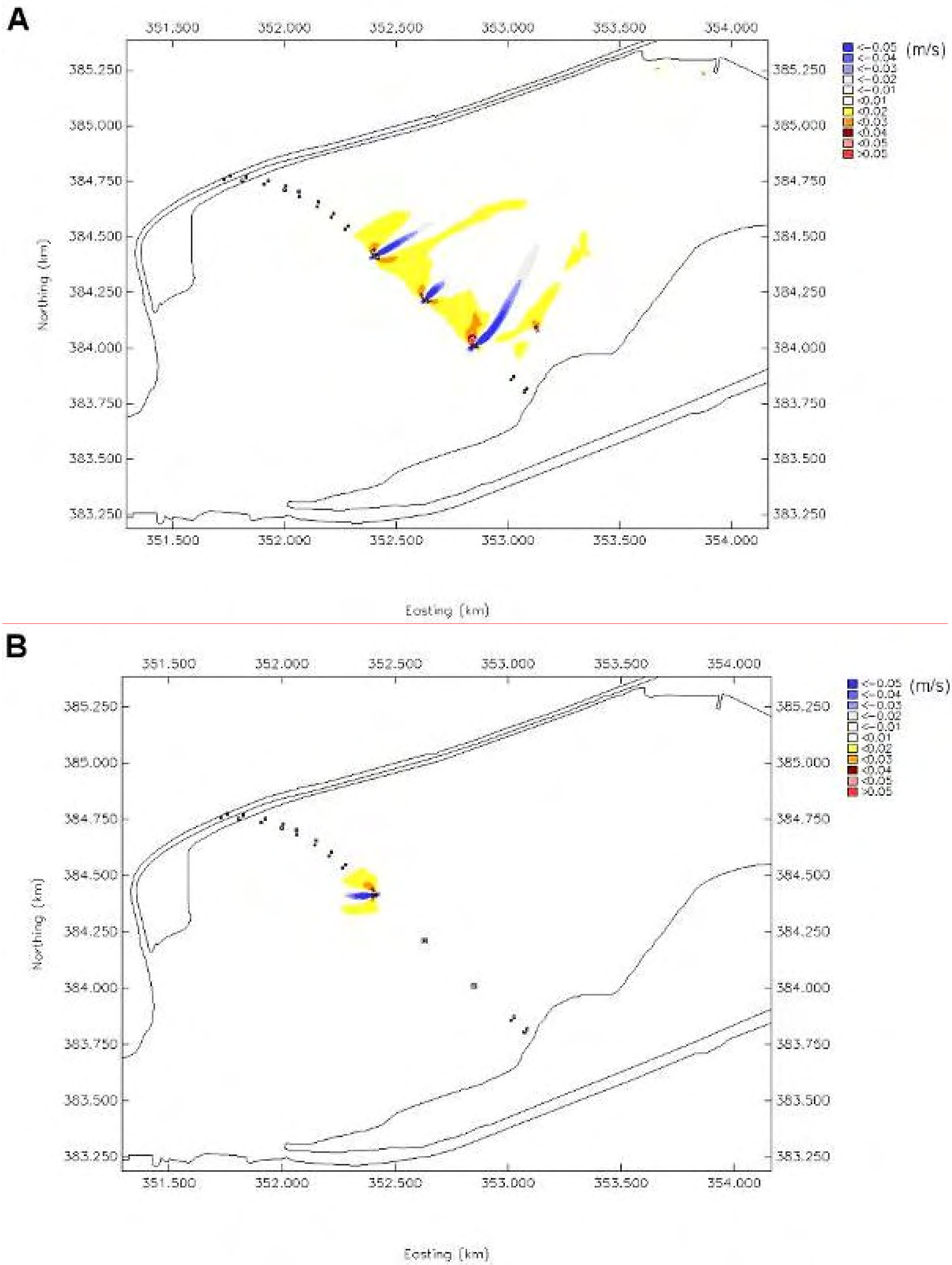


Figure 7.65 - Differences in near surface speed (m/s) between the New Bridge and baseline case for high water (A) and peak ebb (B) on a spring tide



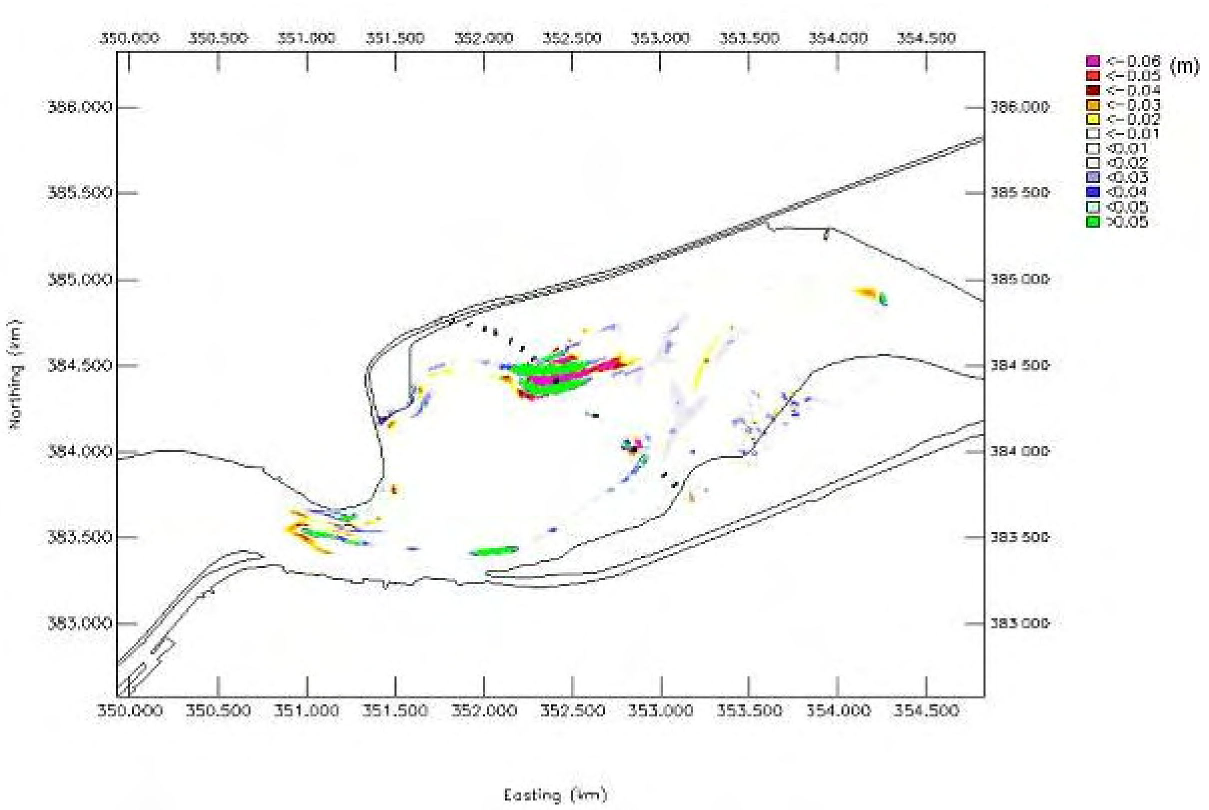
7.8.49 Patterns and extents of changes in bed shear stress mirror the changes in speeds predicted in the model, and changes are confined to the immediate locality of the towers. At most states of the tide, changes in bed shear stress are confined to the locality of the New Bridge towers.

Again, at high water the spatial extent of the changes is greater with lower magnitudes of change.

Morphological Model Outputs: Extreme Events with 2002 Bathymetry

7.8.50 The main areas of change are focused on the areas local to the towers and on the interface between the low water channels (as detailed in Figure 7.66). There is an area of erosion with a maximum change in elevation of around 0.05m in front and behind the north and south tower. The north tower shows the greatest extent of erosion extending approximately 500m either side of the tower. The maximum erosion (around 1.8m change in elevation) is predicted to occur adjacent to the north tower, whilst the largest predicted increase in bed elevation of 1.2m occurs either side of the north tower.

Figure 7.66 - Morphological changes (m) for operational phase for an extreme event after a 15 day period

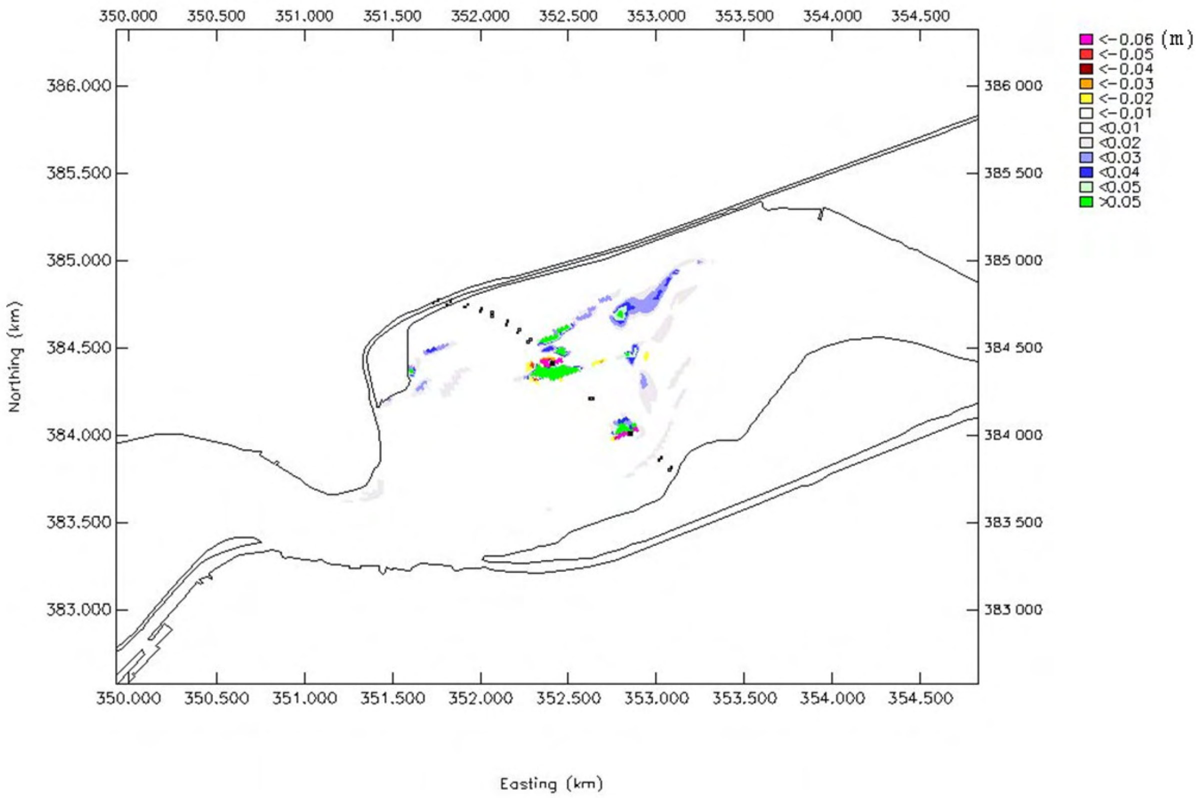


7.8.51 Some changes are seen upstream and downstream of the New Bridge crossing, however, these changes are less than 0.5m and only occur within isolated sections of the Study Area. There is no expected change around the Manchester Ship Canal Training Wall or the SPA. Although there are changes predicted in the Runcorn Gap these are mainly deposition which will not have an impact on the structure of the SJB or the adjacent railway bridge.

System recovery and longer-term morphological change

7.8.52 A morphological assessment was undertaken in order to determine what the response of the system would be to the combined effects of the construction and operation. This was achieved by running the model with the aligned jetty for an extreme event. At the end of this period the temporary structures (cofferdams, piles, jetties and causeway) were removed and the resulting bathymetry was used as the base model for a further spring-neap cycle model run. The results of this were scaled to represent one year. Figure 7.67 shows the results of this model output, which are comparable to the results of a standard spring-neap model run for the operation phase. This suggests that the key impact on the system is the presence of the temporary structures within the system and the initial presence of the permanent structure, once the temporary structures are removed and the final structure in place, the rate of additional change within the system rapidly reduces as the system returns to its natural levels of chaos.

Figure 7.67 - System Recovery



7.8.53 By repeating the morphological model run for a second year (based on the 'new' one year bathymetry as a result of operation) it is shown that the system has returned to its natural chaotic state and that there is little induced change two years after commencement of operation.

Summary of Results for Operation Phase

7.8.54 The modelling carried out shows that there will be minimal differences in water level as a result of the New Bridge. These changes in water level are all localised changes which are not expected to have any impact on flood risk.

7.8.55 Table 7.14 summarises the maximum morphological change as a result of the operation arrangements for different events.

Table 7.14 - Summary of maximum morphological change (erosion and deposition) and extent of change over the Study Area as a result of the different events

Event modelled	Duration modelled	Max erosion adjacent to the piers	Max deposition adjacent to the piers	Extent of change over the Study Area
Operation Phase: spring - neap cycle[1]	12 months	1.38m	0.29m	4.1%
Operation Phase: extreme event (fluvial and tidal)[1]	15 days	1.80m	1.20m	9.0%
Operation Phase: Spring-neap cycle[2]	12 months	1.54m	0.65m	9.8%
[1] 2002 Bathymetry [2] 2005 Bathymetry				

7.8.56 The results show changes within localised areas that are not likely to have an impact on the bridges in the Runcorn Gap, the Manchester Ship Canal Training Wall or the SPA. Although there is a small amount of change predicted to the edge of the saltmarsh, this is less than the change predicted following an extreme event in the baseline case (40.5% and 37.7% for the two different bathymetries). It should be noted that the two comparisons carried out are independent of each other so that the percentage of area changed cannot be summed to give a total area of change. For example for the 2002 bathymetry when the extreme event was compared with the results from the spring-neap cycle 40.5% of the area had changed level. When the effect of an extreme event was compared with and without the New Bridge 9% of the area had changed of which some overlapped with areas changed by the baseline extreme event and some areas were different.

7.8.57 Table 7.15 provides a summary of water levels modelled in the different scenarios for the operation phase. All the changes in level are localised. The maximum changes are not occurring at high water when the maximum increase in level is 0.01m. Thus the results indicate that there will not be an increase in flood risk.

Table 7.15 - Water level summary for operation phase (from Appendix 7.4)

		Low Water		Peak Flood		High Water		Peak Ebb	
		max	min	max	min	max	min	max	min
2005 Bathymetry	Towers	0.08	-	0.02	-0.07	0.01	-0.02	0.08	-0.07
	Channels	-	-	-	-0.03	-	-	-	-
	Intertidal	0.14	-0.09	0.12	-0.10	-	-0.02	0.08	0.06
Extreme Events (2005 Bathymetry)	Towers	0.01	-	0.02	-	-	-0.03	0.01	-
	Channels	-	-	-	-	-	-0.02	-	-
	Intertidal	0.03	-	0.01	-0.02	-	-0.05	0.02	-

7.9 Computational Modelling: Flat Bed Morphological Modelling results

7.9.1 As part of the assessment, a flat bed model study was undertaken by ABP Marine Environmental Research Ltd in December 2005. This was to simulate the development of the morphology from a flat starting surface within the Upper Estuary. This was to explore the ability of the morphological model to develop an uneven bed morphology from a flat bed condition that would be similar in terms of channel form and movement to that which has been observed in the Study Area. If this was successful then the model could be used to investigate the potential impacts from the New Bridge towers in relation to channel migration and the possibility of 'fixity' of the channels at tower locations.

7.9.2 The flat bed modelling report can be found in Appendix 7.7. All model runs used a flat bathymetric surface to start with, and model runs were undertaken with and without the New Bridge towers in place. Figure 7.68 shows the initial bathymetry at the start of this modelling work and Figure 7.69 gives an example of the modelling results.

Figure 7.68 - Initial Bathymetry (2002 Bathymetry)

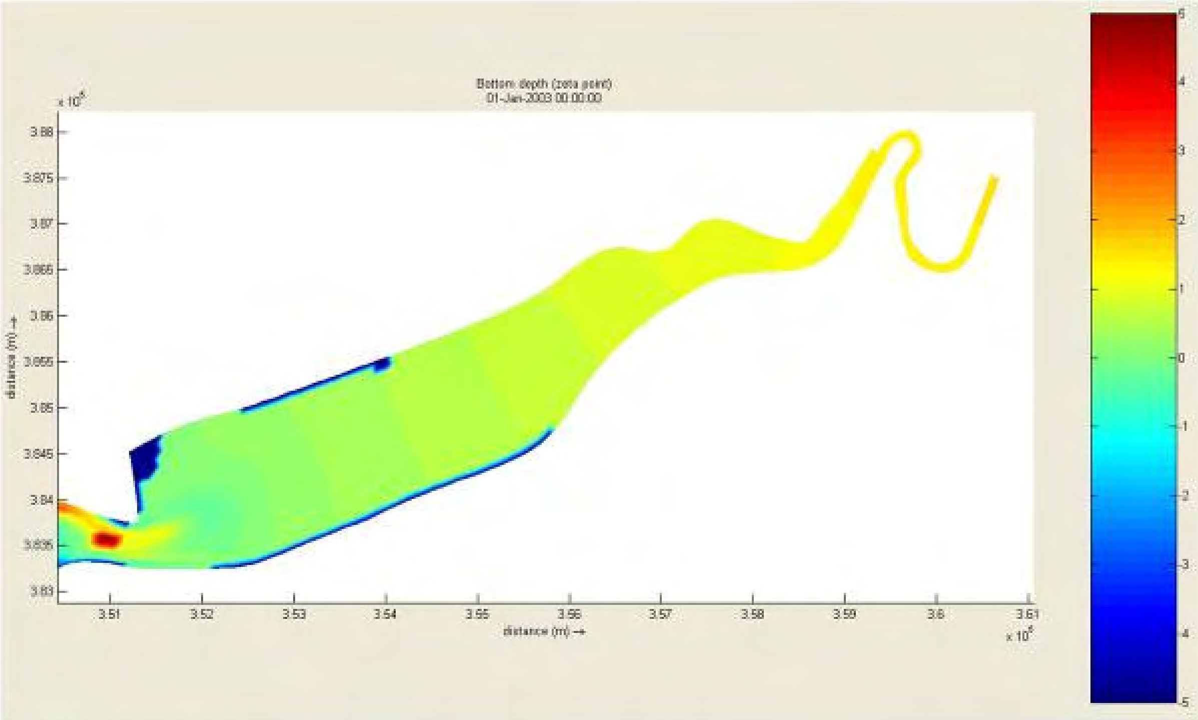
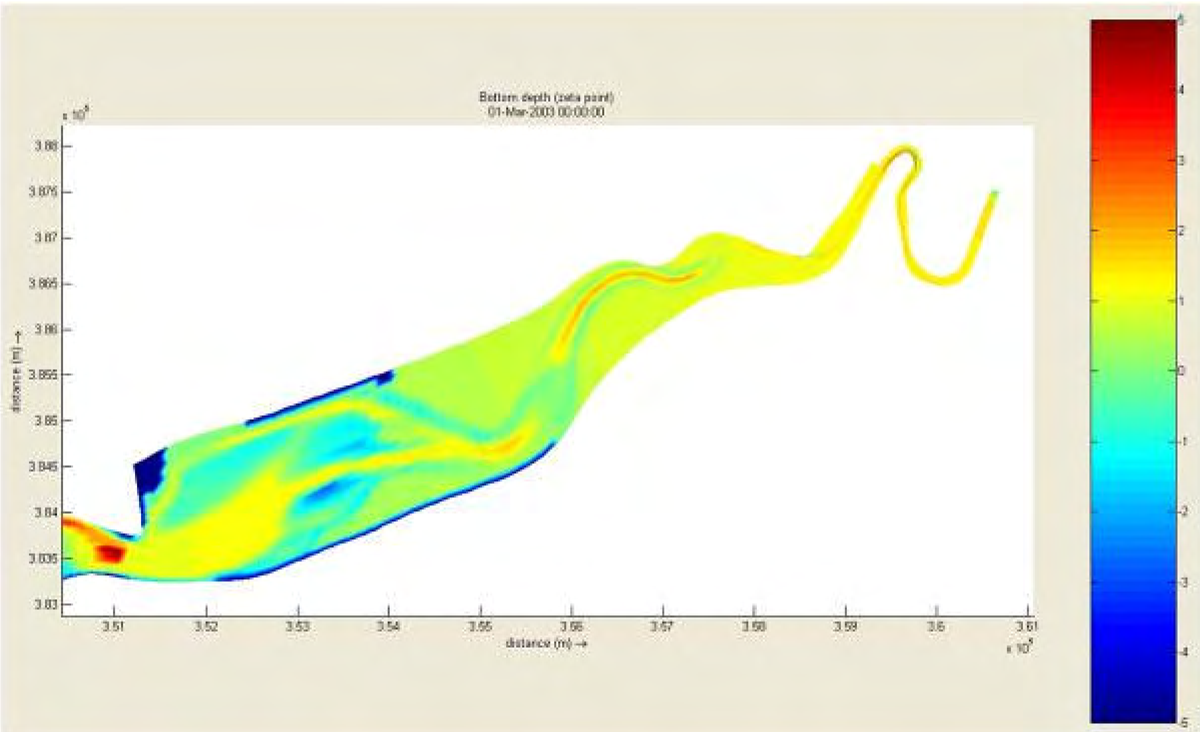


Figure 7.69 - Bathymetric change after 2 months for 300 µm sediment, using a real tidal time – series driver and a constant mean annual fluvial flow



7.9.3 The modelling confirmed the visual observations described elsewhere in this Chapter: in the absence of the New Bridge, the ebb tide interacted with the fixed edges of the Estuary to determine channel location.

7.9.4 A comparison of the model runs with and without the New Bridge towers showed that they had a variable impact on modelled channel morphology, depending on how they were simulated within the model. If a solid 80m x 80m cell was used, the New Bridge towers had a discernible impact. These towers are, however, 8 x 8 times the size of those planned – and are therefore 64 times larger in area. Such a relatively coarse modelling grid was used to allow longer time-scale simulations to be undertaken within a reasonable time span. Therefore, a simulation that contained a bridge tower of its actual size was not possible, and for the cells in which the towers are proposed, an extra roughness value was added. This increase in roughness causes no discernible difference in channel morphology. The actual impact of the towers is likely to be closer to the roughness simulation, rather than the solid cell simulation. Regardless of how the towers were modelled, there was no discernable impact on channel migration and no evidence of channels 'attaching' to the tower locations.

7.9.5 In summary, similar changes and channel formations occurred with and without the tower structures in place. No evidence supports the hypothesis that a channel once formed would become attached to the New Bridge piers from this flat bed modelling.

7.10 Physical Modelling of the Estuary

7.10.1 The mobility of the bed of the Estuary in the Study Area is one of its significant characteristics and it is necessary to assess whether the New Bridge will have a permanent impact on the behaviour of this mobile bed. In particular, loss of mobility of the two main channels, referred to earlier in this Chapter, or the permanent attachment of either of the channels to the New Bridge towers would be a significant change. If the channels were to become fixed to the edges of the saltmarshes, this may increase the rate of erosion of these features.

7.10.2 In order to further explore the flat bed computational model prediction of development of the morphology of the estuary, a small-scale physical model of the Study Area was created in the Pat Kemp Laboratory at the University College, London. This model is shown in Plate 7.1.

7.10.3 It is important to recognise that this physical model is 'fixed' in a number of ways and is thus not intended to fully represent the complex estuarine processes active in the Upper Mersey Estuary. For example the saltmarsh edge was fixed by the shape cut into the waterproof foam and therefore dynamic changes to this edge could not be observed. The limitations of the model therefore need to be recognised. However, it did provide another means by which the development and migration of channels in the mobile sand bed of the model could be observed and that the observations could be done both with and without the presence of the New Bridge towers. The model could also be used to observe the effects of a structure like a bridge tower on the formation of a channel, on how the structure influenced the general movement of channels in the Study Area, and the potential for a series of such structures to effect overall changes in morphology and possible 'attachment' of a channel to the line of such structures.

7.10.4 The model included a central basin simulating the Estuary, an inlet at the seaward end (aligned similar to Runcorn gap), and an outlet at the inland end. The permanent outlines of the river were cut in white waterproof foam (not absorbent) and stuck in the bottom of the central basin. A bed of sand, 50mm deep was placed in the space between the foam boundaries. The simulation of asymmetric tides was controlled by a computer system such that a tide would take approximately 45 seconds and would follow the spring-neap cycle. A constant input was used to represent the fluvial flow. A set volume of water could be added to the upstream end of the model to simulate a major fluvial event. When this was done changes were observed in the bed. However these changes were always transitory.

Plate 7.1 - Mini model of the Estuary

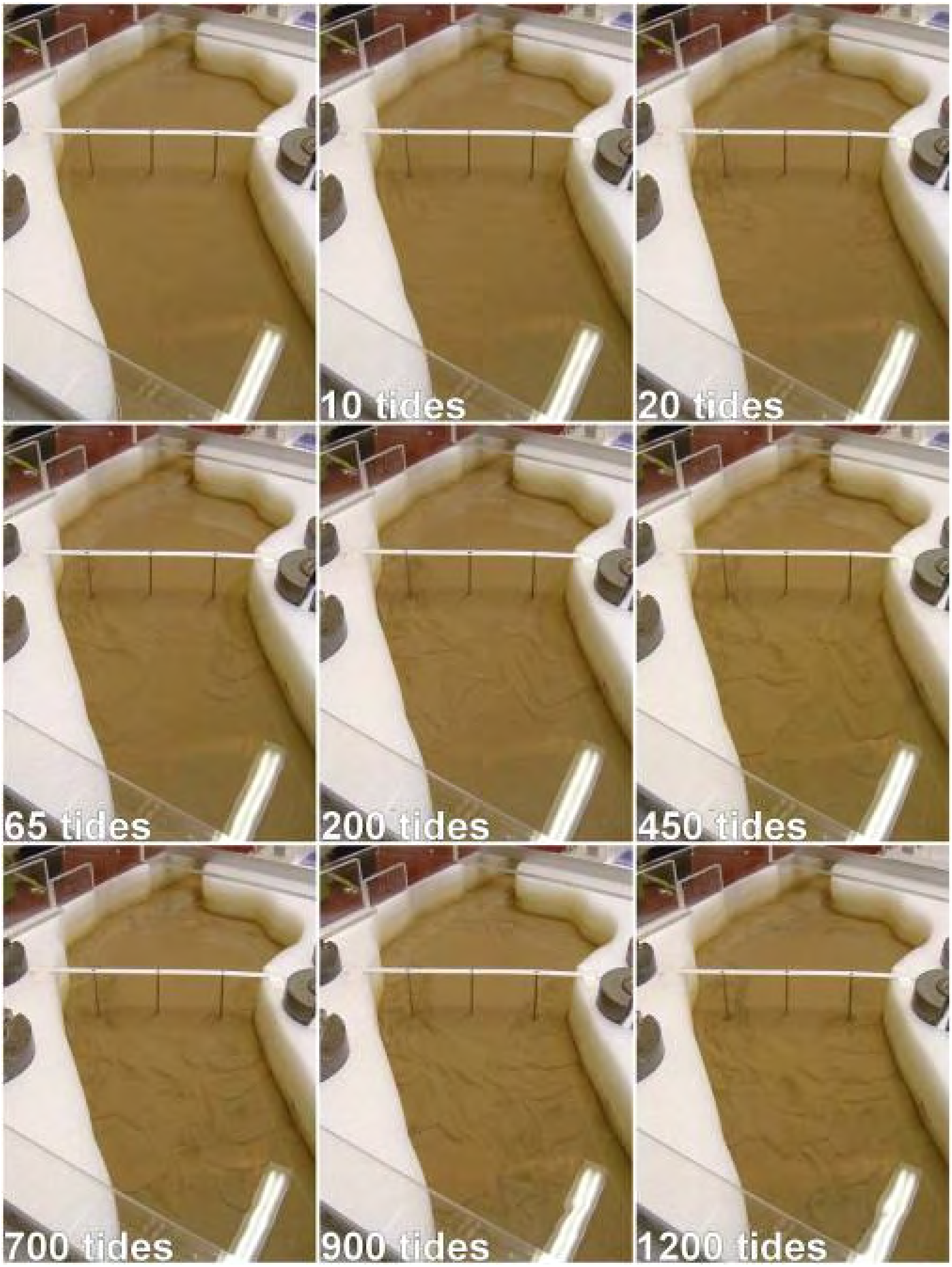
7.10.5 Initial modelling used a flat bed of sand. When the model was run channels started to form at either end of the model, as would be expected, but were slow to link up across the central sand bar. Thus it was felt that an alternative approach should be adopted to allow as much information as possible to be obtained from the modelling.

7.10.6 For the second simulation, main and secondary channels, similar to those that exist in the Estuary, were modelled. The bed at both the inlet and the outlet was seen to become highly dynamic in contour and alignment. However the changes in the central area were far slower.

7.10.7 Finally, sand was added manually to create a central sandbank similar to the actual sandbank in the Study Area such that this would flood (cover) on simulated spring tides. The model was run for approximately 4000 tidal cycles (44 hours) to investigate the longer-term behaviour of the system. Photographs were taken every 20 minutes from the same position on a tripod to create a series of time-lapse images. Processes were seen operating, such as the forming, shaping and growth of small channels, which may play a significant part in the migration of existing channels and the formation of new ones across the sand bank.

7.10.8 Three small cylinders, 5mm in diameter, were placed at the approximate location of the New Bridge towers to investigate the possible effects of introducing these New Bridge towers into the Estuary. The central tower was installed on the sand bank, with the two others in the main and secondary channels. The model was run again for approximately 4000 tidal cycles and Plate 7.2 displays a sequence of the time lapse photographs. Scour holes quickly formed around the bases of the cylinders in the channels. However, careful study of the time lapse photographs showed no inclination of the channels to “fix” the modelled towers. Further evidence to this effect was found by placing additional cylinders directly into the small banks and channels in the tidal flow in the model. None of these had an impact, although it was seen that one small sandbank decayed when a cylinder was placed in it.

Plate 7.2 - Sequence of pictures showing the evolution of channels with the bridge piers



7.10.9 Whilst it is important to recognise the limitations of this model in terms of the physical processes involved in the Estuary, it is interesting that the mini-tidal model was capable of reproducing certain important aspects of natural channel evolution in the tidal estuary. This has demonstrated no evidence for channel attachment; rather it has shown that channel migration continues uninterrupted past the model bridge towers.

7.10.10 The site of the New Bridge appears in the model, in terms of sediment dynamics, to be relatively inactive in comparison to regions upstream and downstream. The introduction of the model bridge towers had no significant impact on the natural behaviour of the bed features in the model, and there was no evidence of channel attachment to the towers.

7.11 Computational Modelling: Tidal Residual Modelling

7.11.1 Modelling of Tidal Residuals was undertaken by ABP Marine Environmental Research Limited in December 2005 in order to assess the potential impact of the bridge towers on channel alignment and the potential for channel attachment to the tower structures. The Residual modelling report can be found in Appendix 7.7. The residual represents the force acting to change the flow direction and thus indicates the potential for movement in channel positions and alignments through changes in sediment paths.

7.11.2 In the first stage flow residuals were considered without sediment transport effects. The results show that the residuals are small in magnitude and directional differences are small and limited to the area immediately surrounding the New Bridge tower. Consequently the New Bridge arrangement has limited impact since the towers are separated sufficiently to act on the flow regime independent of each other.

7.11.3 The modelling used an elongated and a circular tower cross section. The field of influence was significantly larger for the elongated structure suggesting that a circular or near circular cross section for the towers is to be preferred.

7.11.4 In the second stage, sediment was included and used to assess scour, channel alignment and sediment transport mechanisms. Scour depth around the tower was estimated using an established formula and its plan shape defined using estimated angles of response from bed materials. The model comparison was therefore between the baseline and a bridge in place with each tower surrounded by a scour zone. During model runs the scour holes infilled suggesting the original estimated was too severe and that these processes are secondary to other estuarine processes operating.

7.11.5 The third scenario tested whether a channel along the alignment of three towers of the New Bridge would cause a permanent change in the morphology. Whilst a channel at such an alignment would be considered a transient phenomenon, historic data and low water channel movement suggest that a channel could form at such a location although the frequency of this is very low. The results from a spring neap tidal cycle, chosen as it represents the cycle with the greatest magnitude, shows accretion and erosion around both the north and south towers but the channel is infilling across the centre of the Estuary and isolating the central tower from the channel. This suggests that the preferred state for the Estuary is the predominance of channel alignments to the north and south. There is no evidence to support the hypothesis that the channel would become attached to the New Bridge piers.

7.11.6 In summary, the residual modelling indicated that the New Bridge arrangement had only very minor localised impacts on flow and that these were minimised with the circular tower cross section. Scour around the towers appears to operate secondary to other processes in the Estuary. No evidence was provided that channels would attach to the New Bridge structure; to the contrary, in agreement with visual observations described elsewhere in this Chapter, a preference for channel alignments to the north and south was found.

7.12 Scour Assessment

7.12.1 Three methods were used to assess the potential for scouring to occur during the construction and operation of the New Bridge. These were:

a. Initial review of equations and worse case scenario estimation based on the construction phase since this is when the largest structures will be in place in the Estuary;
b. Detailed hydrodynamic modelling of the Project; and
c. Physical small scale modelling of scour.

7.12.2 Formulae for the estimation of scour were considered and used to calculate the scour depth for the aligned jetty construction option. The three towers would be constructed within 30m cofferdams. Scour on these structures was estimated using two formulae: Breusers et al., 1977 and Rance (Ref. 33). The approach of Rance (Ref. 33) provides an assessment of the scour depth around large structures. Using this, the maximum scour depth is estimated as 1.92m for both the flood and ebb tidal period. Breusers (Ref. 34) equation was developed using measurements of scour depths in tidal estuaries. Using this formula produced an estimate of a scour depth of 4.2m for the flood and 3.2 m for the ebb. See Appendix 7.1 for further details. The detailed hydrodynamic modelling took account of the fact that in tidal estuaries, scour will take place in two directions due to the ebbing and flooding of the tide. The local scour around New Bridge piers is largely dependant on their geometry and, generally, will occur quite rapidly. The impact of interest is the maximum scour that will develop once an equilibrium condition is achieved.

7.12.3 The detailed hydrodynamic modelling performed by ABPmer (Appendix 7.3) estimated scour around the New Bridge towers. The model revealed that the largest changes across the Study Area were generally limited to the immediate area around the New Bridge piers. For the baseline scenario used in the study of four bridge towers at a slightly different alignment to the chosen alignment, the depth of the scour hole from the hydrodynamic model would be expected to vary between approximately 3m to 4.5m, although the equation used is recognised as overestimating scour depth. The scenario of the three towers and alignment proposed had the least impact. The greatest depth would be when the scour hole reaches equilibrium, however due to the direction of flow, and therefore scour processes, changing with the tide this will never be reached: the material excavated by scour in one tide will be deposited back in the hole when the cycle reverses. The width of the scour hole can be approximated to 3-4 times the width of the structure, therefore for the tower structures the width of the scour hole will be between 30m and 40m. The scour analysis undertaken was based on recognised empirical relationships, but remained simplistic in its approach, based upon a calculated time series of depths and speeds found at the New Bridge crossing location. It assumes flow is aligned to the tower.

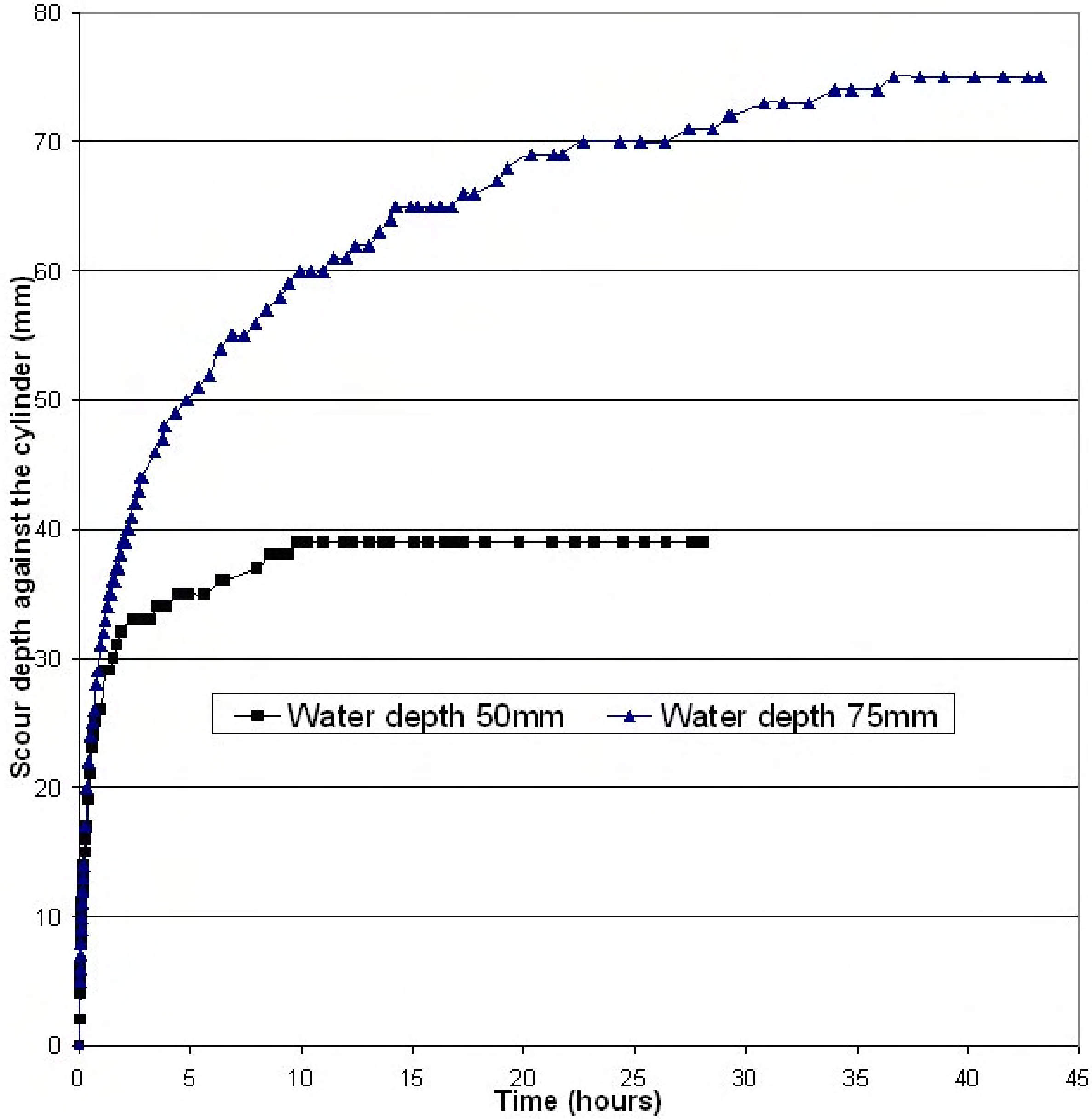
7.12.4 Tests to investigate scour around a cylinder in relatively shallow water were carried out in the wave current flume in the Pat Kemp Laboratory at the University College, London. These tests are described in full in a report from UCL, 2007 (Appendix 7.8). The aim of the tests was to determine which of eighteen different equations to estimate scour, previously identified from a study of the literature, most accurately describe scour in the Upper Mersey. The Upper Mersey, the proposed location of the New Bridge, has tidal conditions with a greater flood velocity than ebb velocity which could lead to an asymmetrical scour hole.

7.12.5 A flume was used to simulate scour around a bridge tower in the Estuary (see Plate 7.3). The flume was set up to minimise turbulence and to enable photographic images to be taken. Direct measurements were taken of scouring in the 4m long sand bed, test area of the flume. A vertical Perspex cylinder, 15cm diameter, was installed at the centre of this space to represent the bridge tower. In order to mimic the conditions of flow in the Estuary, scaling of the model was done in accordance with the laws of fluid dynamics.

Plate 7.3 - Model cylinder in flume showing scoured bed

7.12.6 Ten experiments were run, each to a maximum of 34 hours duration, using different hydrodynamic scenarios of water depth and velocity. Initially four tests were carried out to determine the capability of the flume to produce velocities and water depths relevant to the Mersey. In two of these experiments the velocity was greater than and equal to the critical velocity (critical velocity is the flow at which material is moved from the bed). In such live-bed conditions, the scour depth increased quickly and reached the bottom of the sand bed before reaching equilibrium. In the other two initial tests approximately half the critical velocity was used but this was not strong enough to initiate local scour. From these experiments it was concluded to adopt a range of velocities greater than half of the critical velocity but less than the critical velocity for further tests. The aim of the remaining six experiments was to determine which of the equations for estimating scour previously identified most accurately described scour in the model. The model was used to validate the equations, by comparing model scenario results with those calculated for the eighteen equations identified. Figure 7.70 shows an example of these results.

Figure 7.70 - Comparison of scour depth evolution for different water depths (constant velocity 17.4 cm/sec)



7.12.7 Results from the tests with current direction reversed (i.e. simulating tides) supported the theory that scour is reduced under certain tidal conditions. However, the effects of turbulence, waves and extreme storm events will largely counter this effect and it is recommended not to make any reduction to account for tidal reversal in the Estuary. The values that best fitted the results from the physical modelling were those using the formulae from May (Ref. 35) and May & Escameira (Ref. 36). Predictions using May, Ackers & Kirby (Ref. 37) and Breusers, Nicollet & Shen (Ref. 36) were also close to results. All these formulae take into account the water depth and velocity. Any of these four approaches should provide a conservative prediction for equilibrium scour depth in the Estuary.

7.12.8 The scour depth to tower diameter ratio derived from the experiments ranged from 0.26-0.513 at equilibrium under different flow conditions. i.e. for a tower diameter of 10m a scour depth of approximately 2.5-5m is predicted. The upper limit is similar to the result from the scour estimates of the above equations. Recognising the asymmetry of the tides in the Study Area, it is recommended that no adjustment is made for infilling of scour on the ebb tide. The scour depth for design is therefore of the order of 4.5-5m.

7.13 Wave action

7.13.1 In order to assess the potential impact of wave action on the New Bridge, an estimate of wave height has been made. The method used was that described by Yarde et al (Ref. 38) (see Appendix 7.5, Wave Height Calculation).

7.13.2 The following data was used:

a. Topographic survey dated February 2005;
b. Admiralty Chart 3478, Edition No 3, 17 May 2001;
c. Wind data from the Meteorological Office for the period March 2005 to March 2007; and
d. Windspeed data from BS 6399-2: (1997), 'Code of Practice for Wind Loads'.

7.13.3 The waves offshore in Liverpool Bay are generally wind generated. Previous work has shown that the hourly mean wind speed for 75% of the time is 3m/s (Ref. 4). During winter months, significant wave heights of 5m have been observed (Ref. 5). The prevailing wind direction is from the west, but the Estuary is also open to winds from the north-westerly sector.

7.13.4 The narrow entrance to the River limits the propagation of waves into the Estuary. Although it is important to note that waves are not only limited by the narrow entrance, but by the bathymetry as the tidal range ensures that the drying banks induce wave-breaking and thus limiting the height of waves entering the Estuary. Locally generated waves within the Estuary may influence sediment transport in intertidal areas. However, such waves are fetch limited and are unlikely to exceed 2m in height. Given this and the distance from the Bay, it is considered that the swell waves from the outer sea in Liverpool Bay will not affect the Study Area.

7.13.5 Locally generated waves within the Study Area are limited by the available fetch. Analysis of three different fetch lengths is presented in Appendix 7.5. The conclusion of this work is that the normal range of wave heights within the Study Area for winds of Force 2 – Force 4 is 0.1 to 0.2m. For extreme weather conditions, wave heights may grow to 0.9m within the Study Area. Bed friction and the interaction between waves and tidal currents have been excluded from the analysis. Excluding bed friction results in a more conservative estimate of wave height.

7.13.6 The propagation of waves is limited because much of the area dries out for long periods of the tidal cycle. The shallow depth in channels will induce wave breaking and this will impact on channel morphology. However, compared with the scour depths predicted for the New Bridge towers, it is likely that wave action would only have transitory impact and no significant impact in relation to the extent of morphological change local to these structures.

7.14 Management and Monitoring requirements

Temporary Structures

7.14.1 The most significant hydrodynamic impacts are predicted to occur during the construction phase as a result of the additional installations in the Estuary. The temporary jetty piers are narrow and use relatively small diameter piles to minimise effects on hydrodynamics. The 30m diameter cofferdams needed for the construction of the towers have been sized to enable the construction of the permanent pile cap (of about 24m diameter) for each tower.

7.14.2 All temporary structures will be removed upon completion of the New Bridge. This includes the cofferdams, the aligned jetty and the stone causeway across the saltmarshes. This will ensure that these impacts are limited and the Estuary is predicted to recover quickly from their presence. The dynamic nature and tidal flows of the Estuary mean that voids left by removal of structures will naturally infill and consequently no additional works will be needed. Natural infilling is the most desirable option as it minimises further disturbance to the environment and ensures no additional foreign material is added to the Estuary.

Permanent Structures

7.14.3 The modelling showed that least impact from scour occurred around a cylindrical tower. The modelling used an elongated and a circular tower cross section for comparison. The field of influence was significantly less for circular or near circular cross section towers and thus this cross section is proposed for the design.

7.14.4 The cap depth for the three towers will be below the estimated scour depth. Were the caps above this level a much wider structure would be subject to scour creating much larger scour holes. This design will ensure that the impact of scour is kept to a minimum and localised to the tower positions.

Monitoring Requirements and Programme

7.14.5 It is considered important to maintain the morphological monitoring programme throughout the construction period and the first five years of the operation period of the Project. A detailed baseline of the characteristic or expected morphological forms and processes has been developed with which to compare potential future changes observed with regard to the morphology of the low water channels. The baseline level of change can be compared with ongoing change recorded by the monthly aerial photographs of the Study Area. As now, if any significant changes are observed in the aerial photographs these should be supported by topographical survey and subsequent analysis.

Spatial Scale

7.14.6 The Upper Mersey Estuary displays areas of differing frequencies of significant morphological change that require different levels of monitoring. The areas that are affected by, and will themselves affect, the New Bridge, require further monitoring.

7.14.7 Over the course of two years, the section of estuary at Norton Marsh (S1) has been recorded as being relatively stable. Historic records show changes over decades, and it is recommended that monitoring of this area is undertaken by aerial photography on an annual basis.

7.14.8 A high level of morphological activity occurs around Hempstones Point and along the northern and southern banks. Given that morphological activity originating at Hempstones Point has a tendency to be transferred downstream towards the region in which the Project is proposed to traverse, it is important that the areas of the Estuary within S2 and S3 continue to be monitored by monthly aerial photography.

7.14.9 The section of the Estuary within S4, downstream of the SJB, appears to be relatively stable. Annual monitoring should be adequate. Morphological monitoring of this area will be required during construction and for the first five years post construction of the Project.

Timescales

7.14.10 During the monitoring period an annual aerial survey (as part of the ongoing monitoring of areas S2 and S3) should be undertaken over S1 and S4, in order to document major changes.

7.14.11 Monthly aerial photograph surveys of S2, S3 and the panhandle upstream of S2 are required in order to ensure that the patterns and processes observed during the course of this two year study period are typical.

7.14.12 If any changes are observed in any of the aerial surveys the change will be compared with baseline data. Where it is considered necessary, to enhance the information available, further topographical survey will be carried out. The change will then be compared with the baseline change. Where excessive change is observed this will be discussed with the relevant authorities prior to any action required being identified.

7.15 Discussion of results of the assessment with reference to key predicted impacts

7.15.1 The effects of the New Bridge on the hydrodynamics and morphology of the Estuary have been assessed using historic evidence of channel movements, careful monitoring of short-term movements using aerial photography, and both computational and physical modelling.

7.15.2 The potential for the New Bridge to interfere with changes to hydrodynamic conditions occurring as a result of climate change was considered. Best practice, PPS 25 (Ref. 30) is to allow for a rise in sea level and increased rainfall. Due to the nature of the Estuary and New Bridge towers it is thought that the New Bridge will have a similar impact for the same depth of water, irrespective of what level this is relative to the New Bridge tower below deck soffit level. In the eventuality that water should become deeper it is believed this would have no more effects than those demonstrated for the 1:200 year surge and fluvial event.

7.15.3 The results in terms of the predicted impacts are summarised below:

a. Impacts on flood defence;

   i. The increases in water level at high water predicted by the model are all minimal and no increase in flood risk is anticipated based upon the modelling.

b. Impacts on intertidal areas and saltmarshes;

   i. There is some erosion and deposition predicted on the interface of saltmarshes at a number of locations. These are relatively minor and it is unlikely that this will result in any additional change in the location of the saltmarsh edge other than that which would occur naturally;
   ii. The changes in the saltmarsh as a result of the single event in 2007 exceeded any changes that are predicted as a result of the New Bridge construction or operation. The current monitoring has also shown a typical erosion rate or retreat of the saltmarsh edge of 2.05m per year on the southern saltmarsh. This suggests that the impact of the New Bridge in comparison to natural change is insignificant.

c. Changes to estuary morphology due to bridge construction and naturally occurring events;

   i. The hydrodynamic and morphological modelling provides some indication of the patterns of change that may occur as a result of the construction and operation of the New Bridge. These are less than the modelled impacts caused by an extreme event on the existing condition without the New Bridge. The changes are also small compared with a normal event with less than 10% of the study area changing during a spring-neap cycle;
   ii. The area underneath the New Bridge towers contains channels and sand bars that change position and morphology over days, weeks and years. The pattern of channel change is partially predictable where lateral channel migration occurs, a process that is capable of reworking hundreds of square metres of sediment within hours and days; and such an energetic system is unlikely to be interrupted permanently by relatively small diameter bridge towers.
   iii. The morphological assessment indicates that the northern and southern bridge towers are likely to be located within or partially within channels on a relatively frequent basis. However, the central tower is unlikely to be within a channel except on rare occasions. There is little evidence that a channel would form in a north-west to south east direction along the New Bridge alignment and thus little likelihood of a channel forming to encompass all three towers.

d. Assessment of the potential for channels to 'attach' (remain permanently located) next to structures within the Estuary and thus change the chaotic character of sediment movement within the Study Area;

   i. In the short-term there is no evidence of change that is permanent within the limitations of the model;
   ii. The modelling of the tidal flow residuals suggests that the bridge towers are hydrodynamically independent of each other and that there is no evidence to suggest a tendency for channels to attach to the structures;
   iii. The physical modelling of the Estuary also provided no evidence of the channels tending to attach to piers placed within the bed;
   iv. There is no evidence of this phenomenon occurring with circular structures as proposed for the New Bridge towers, particularly where their diameter is small relative to the width of the Estuary.

e. Assessments of the potential impacts on the SPA site downstream of Runcorn;

   i. There is some change in the morphology of the Runcorn Gap for the construction phase. However, the modelling shows that these impacts only last for the duration of the construction phase and recover within 12 months after the cofferdams are removed;
   ii. The changes in the Estuary as a result of the extreme event exceed any changes that are predicted as a result of the New Bridge construction or operation.

f. Assessment of the potential impact on existing structures, in particular the Manchester Ship Canal;

   i. The New Bridge and construction method does not cause any significant erosion adjacent to the training walls of the Manchester Ship Canal or any other structures within the Estuary;
   ii. The changes in the Estuary as a result of the modelled extreme events without the bridge exceed any changes that are predicted as a result of the New Bridge construction or operation. Thus natural events are of greater significance than the New Bridge. The extent of natural change normally experienced is discussed in Sections 7.4 and 7.5.

g. Estimates of scouring around proposed structures;

   i. The range of maximum erosion depths predicted are from 0.75m to 1.8m for the operation phase and 1.38m to 1.79m for the construction phase. However, the physical processes of scour are not fully modelled and thus results of the physical models are more relevant.
   ii. The physical assessment of scour (Section 7.11) estimated the range of maximum scour depths to be from 2.5m to 5.0m, for the three towers of about 10m diameter in the Estuary. Whilst some infill would be expected to occur as flow direction changes with the tide, due to the asymmetry of tides it is recommended that no adjustment is made for this infilling.
   iii. The scour depth for the design is therefore 4.5 - 5.0m. The New Bridge will be constructed with the top of the pile caps set at this distance below the bottom of the channels to allow for this effect.

7.16 Conclusions

7.16.1 The existing hydrodynamic and morphological regime has been investigated and a baseline identified. Regular morphological monitoring has been carried out and these records assist in understanding the nature of changes that occur within this dynamic estuary.

7.16.2 A variety of different methods have been used to identify predicted changes for the construction and operation of the New Bridge.

7.16.3 The results showed that the impact of the New Bridge was not significant compared with the naturally occurring rate of change within the Study Area. The evidence gathered as a result of the range of modelling and investigations carried out suggests that there is no impact on the dynamics of the Estuary.

7.16.4 The results of the investigations for Long-term and Short-term change are as follows:

Long term

7.16.5 All datasets conclude that the main channel splits into two just north of Hempstones Point and then converges just upstream of the Runcorn Gap. One channel runs along the north bank (here referred to as the north channel) and one along the south bank (the south channel). This channel arrangement has meant that there have been two areas of mudflats, one to the south of Cuerdley Marsh and one in the centre of the Estuary near to the Runcorn Gap, although the exact positions have varied.

7.16.6 The aerial photographs suggest that there are small changes in the physical location of the seaward edges of the marsh with an overall trend of saltmarsh loss through erosion and reclamation. The current direct measurements of the saltmarsh edge indicate that saltmarsh loss is continuing at Astmoor but that the edge at Widnes Warth is relatively stable.

7.16.7 The results from the accumulation of the aerial photographs, bathymetric surveys and EMPHASYS data show that the low water channel system is very dynamic.

7.16.8 By comparing the positions which the channels have occupied at different times in the past, the frequency of a channel occupying a particular location can be estimated for this dataset. This frequency analysis confirms that there is a low chance of a channel coinciding with the proposed position of the central bridge tower. Although the north and south towers are more likely to coincide with a channel location, the modelling has shown no evidence that this will give rise to a significant effect on channel location.

Short term

7.16.9 A dataset of the results of analyses of oblique aerial photographs and a limited set of topographic surveys have enabled short term change in the Study Area to be established for the period since 2005. Generally, the results of this work show:

a. The short term patterns of change tend to mimic those observed over the longer term;
b. There is some evidence that a sequence of several strong spring tides can induce significant channel movement although this is by no means a reliable trigger for change;
c. The volume of the Study Area is showing a small but measurable decline in volume indicating that estuary filling is continuing in this part of the Estuary;
d. A stability plot has been produced of the likelihood of channels being at specific locations within the Study Area; and
e. This is similar to the plots produced from the analysis of long-term data sets. Although the mechanism and development of new channels is observed in more detail by the short-term assessment, the net result in relation to channel position relates closely to the long-term results.

Modelling

7.16.10 A wide range of bed shear stresses apply within the Estuary. Modelling has been used to consider how these change, both in magnitude and location, between low water, high water, peak flood and peak ebb. Given how much greater these values are than the threshold values for the mobilisation of bed material, the figures explain why the Study Area has a chaotic and highly mobile morphology.

7.16.11 The impacts of the extreme events on the morphology of the Study Area without the New Bridge in place can be substantial in terms of changes in morphology and the depth of erosion or deposition predicted.

Operational

7.16.12 The modelling carried out shows that there will be minimal differences in water level as a result of the New Bridge. These are all localised changes which are not expected to have any impact on flood risk.

7.16.13 Table 7.16 summarises the maximum morphological change as a result of the operation arrangements for different events. This compares with the baseline results for an extreme event which show changes to around 40% of the Study Area. As before, it should be noted that the two comparisons carried out are independent of each other so that the percentage of area changed cannot be summed to give a total area of change.

Table 7.16 - Summary of maximum morphological change (erosion and deposition) and extent of change over the Study Area as a result of the different events

Event modelled	Duration modelled	Max erosion adjacent to the piers	Max deposition adjacent to the piers	Extent of plan area which changes within the Study Area
Operation Phase: spring - neap cycle[1]	12 months	1.38m	0.29m	4.1% change
Operation Phase: Spring-neap cycle[2]	12 months	1.54m	0.65m	9.8% change
Operation Phase: extreme event[1]	15 days	1.8m	1.2m	9% change
[1] 2002 Bathymetry [2] 2005 Bathymetry				

7.16.14 The results show changes within localised areas that are not likely to have an impact on the bridges at Runcorn Gap, the Manchester Ship Canal Training Wall or the SPA. Although there is a small amount of change predicted to the edge of the saltmarsh this is significantly less than the change predicted following a natural extreme event impacting on in the baseline case.

Construction

7.16.15 The modelling carried out shows that there will be minimal differences in water level as a result of the New Bridge. These are all localised changes which are not expected to have any impact on flood risk.

7.16.16 Table 7.17 summarises the maximum morphological change as a result of the construction arrangements for different events and compares that with the baseline results for an extreme event.

Table 7.17 - Summary of maximum morphological change (erosion and deposition) and extent of change over the Study Area as a result of the different events

Design Option	Duration modelled	Maximum erosion adjacent to the piers	Maximum deposition adjacent to the piers	Extent of plan area which changes within the Study Area
Aligned jetty[1]	12 months	1.38m	0.33m	4.0% change
Aligned jetty extreme event[1]	15 days	1.79m	0.90m	10.0% change
Aligned jetty[2]	15 days	1.38m	0.60m	9.2% change
Aligned jetty extreme event[2]	15 days	1.20m	0.65m	10.7% change
[1] 2002 Bathymetry [2] 2005 Bathymetry				

7.16.17 Whilst these changes are larger than those for the operation phase, they are still small in comparison to those changes that may occur naturally, for example the baseline extreme event showing changes occurring over 40% of the Study Area. In addition to this these effects are only temporary as all temporary structures will be removed once construction is complete.

Observations from the Modelling

7.16.18 There is no significant erosion identified as a result of the construction or operation of the New Bridge around either the Manchester Ship Canal Training Wall, the SJB or the Railway Bridge. Models indicate that there will be scour around New Bridge piers, but that this is a minor local effect. The SJB is founded on the sandstone rock and as such any erosion will not affect the New Bridge stability.

7.16.19 The increase in water levels at high water is minimal and there will be no significant increase in flood risk.

7.16.20 Changes in the limits of intertidal habitat and saltmarsh have been recorded and a rate of change calculated on a day to day basis. No changes are expected as a result of the New Bridge's construction that exceed the changes recorded during the morphological monitoring. There is a very small amount of change which may be caused to the edge of the saltmarsh near the New Bridge.

7.16.21 Changes to estuary morphology as a result of the New Bridge construction are less than those occurring in extreme events. There is no evidence to show that channels will 'attach' (remain permanently located next) to a bridge tower and thus change the chaotic character of sediment movement within the Study Area.

7.16.22 There is no evidence that there will be impacts on the SPA site downstream of Runcorn. There is not expected to be any change to the SSSI in excess of natural change

7.16.23 There is no evidence that there will be impacts on existing structures, in particular the Manchester Ship Canal, the SJB or the Railway Bridge.

7.16.24 The results of the investigations show that the natural changes and fluctuations within the system are in excess of the possible impacts of building a bridge. During construction, changes are expected to occur that exceed those present during the operation phase, but the modelling carried out suggests that the Estuary has good capacity to recover following construction. A period of two years is suggested for the system to return to its natural chaotic state.

7.16.25 There is no substantial impact on the hydrodynamic and morphological regime. As there is no substantial impact there is no proposed mitigation. It is however recommended that monitoring is continued during the construction phase and the first five years of the operation phase to provide further understanding of the estuarine system.

7.17 References

Ref. 1 Harvey, A.M., 1985. *The river systems of North-west England*, p.122-142 in Johnson, R.H. (ed) The geomorphology of North-west England., Manchester University Press, Manchester and Dover, New Hampshire.

Ref. 2 Brown, E.H., 1979. The Shape of Britain. *Transactions of the Institute of British Geographers, New Series*, 4, p.449-462.

Ref. 3 Johnson, R.H., 1969. A reconnaissance survey of some river terraces in part of the Mersey and Weaver Catchment., Memorandum. *Proceedings of the Manchester Literary and Philisophical Society*, 112, p.1-35.

Ref. 4 JNCC, 1996. *Coasts and seas of the United Kingdom: Region 13- Northern Irish Sea: Colwyn Bay to Stranraer, including The Isle of Man* Joint Nature Conservation Committee.

Ref. 5 ABPmer, 2001. Futurecoast West Coast Process Review. Start point to River Eden. Report No. R.917. pp. 26-27.

Ref. 6 Pye, K. & Van der Wal, D., 2000a. *Historical trends analysis (HTA) as a tool for long-term morphological predictions in estuaries.* EMPHASYS Consortium Paper 14. Modelling estuary morphology and process. Final Report, p.92-94. EMPHASYS.

Ref. 7 Thomas C., 2000. 1-D modelling of the hydrodynamic response to historical morphological change in the Mersey Estuary. EMPHASYS Consortium Paper 9. Modelling estuary morphology and process. Final Report. EMPHASYS. p.55-61.

Ref. 8 Pye, K. Blott, S. & Van der Wal, D., 2002. *Morphological Change as a result of Training Banks in the Mersey Estuary*, Northwest England, Internal Research Report CS4, Royal Holloway, University of London.

Ref. 9 Prandle, D., & Lane, A., 2000. *Modelling tide and marine sediments in the Mersey with 1-D, 2-D and 3-D models – A critique of their respective capabilities and limitations*. EMPHASYS Consortium Paper 6. Modelling Estuary Morphology and Process. Final Report, p.27-33. EMPHASYS.

Ref. 10 Thomas, C., 1999. *Analysis of bathymetric surveys of the Mersey Estuary*. HR Wallingford Report IT 469. HR Wallingford, UK.

Ref. 11 Centre for Ecology and Hydrology. 1999. National River Flow Archive.

Ref. 12 ABPmer, 2001. An investigation of the gross properties of UK estuaries. Report No. R.900.

Ref. 13 Van der Wal, D. & Pye, K., 2000. *Long-term morphological change in the Mersey Estuary, northwest England*. Surface Processes and Modern Environments Research Group, Royal Holloway, University of London, Internal Research Report CS5.

Ref. 14 O'Conner, B.A., 1987. Short and long term changes in estuary capacity. *Journal of the geographical society*, 144 p.187-195.

Ref. 15 Price, W.A. & Kendrick, M.P., 1963. Field and model investigations into the reasons for siltation in the Mersey Estuary. *Proceedings of the Institute of Civil Engineers*. April, p. 473-517.

Ref. 16 Heaps, N.S., 1972. Estimation of density currents in the Liverpool Bay area of the Irish Sea. *Geophysical Journal of the Royal Astronomical Society*, 30, p.415-432.

Ref. 17 McDowell, D.M. & O'Conner, B.A., 1977. Hydraulic behaviour of estuaries. London: McMillan Press Ltd.

Ref. 18 Prandle, D., 2000. *Database for EMPHASYS project – Mersey Estuary.* EMPHASYS Consortium Paper 3. Modelling estuary morphology and processes. EMPHASYS.

Ref. 19 Environment Agency, Light Detection and Ranging (LIDAR) data.

Ref. 20 EMPHASYS consortium, 2000. EMPHASYS database.

Ref. 21 Geosense personal communication.

Ref. 22 Lane, A., 2004. Bathymetric evolution of the Mersey Estuary, UK, 1906-1997: causes and effects, *Estuarine, Coastal and Shelf Science*, 59, p.249-263.

Ref. 23 Hooke, J.M., 1997. *Styles of channel change* in Thorne, C.R., Hey, R.D., Newson, M.D. Applied fluvial geomorphology for river engineering and management. John Wiley New York.

Ref. 24 Kendrick, M.P. & Stevenson, T., 1985. *Changes in the tidal capacity of the Mersey. Report on studies made in 1984-5*. HR Wallingford Report SR43, HR Wallingford, UK

Ref. 25 Personal communication., 2007. To Andrew Russell (Environmental Scientist for Gifford) at meeting with Halton Environment Round Table held on 23rd January 2007. Halton, England.

Ref. 26 Roelvink, J.A. Coastal morphodynamic evolution techniques. *Coastal Engineering*, 53, p. 277-287.

Ref. 27 ABPmer., 2001. Futurecoast – Macro review of coastal processes around England and Wale. Report No. R.920.

Ref. 28 Environment Agency., 1998. Extreme sea levels for section 105 surveys. Final Report. Produced by Jeremy Benn Associates.

Ref. 29 Pethick, J., 2001. Coastal management and sea level rise. *Cantena*, 42, p.307-322.

Ref. 30 Department of communities and Local Government., 2006. Planning Policy Statement 25: Development and Flood Risk.

Ref. 31 Bartlett, J.M., 1998. *Quality Control Manual for Computational Estuarine Modelling,* Environment Agency, R & D Technical Report W113

Ref. 32 Wallingford, HR., 1983. *Changes in Tidal Capacity of the Mersey; Report on studies made in 1982-3.* H.R. Wallingford Report. EX1280, HR Wallingford UK.

Ref. 33 Rance, P.J., 1980. The potential for scour around large objects. In *Scour prevention techniques around offshore structures,* Proceedings of a one day seminar, 16 December 1980, Society for Underwater Technology. London. p. 41-53.

Ref. 34 Breusers, H.N.C., 1966. Conformity and time scale in two-dimensional local scour.

Proceedings of the Symposium on Model and Prototype Conformity, Hydraulics Research Laboratory, Poona, India. p. 1-8.

Ref. 35 May, R.W.P. 1998. Wide pier equation. in Jones, J.S. & Sheppard, D.M., 2000. *Scour at wide bridge piers*. ASCE, US Department of Transportation, Federal Highway Administration, Turner-Fairbank Highway Research Center.

Ref. 36 May, R.W.P. & Escarameia, M., 2002, Local scour around structures in tidal flows. *Proceedings of the First International Conference on Scour Foundations*, Texas A&M University, p.320-331.

Ref. 37 May, R.W.P., Ackers, J.C. & Kirby, A.M., 2002, Manual on scour at bridges and other hydraulic structures. *Construction Industry Research and Information Association*.

Ref. 38 Yarde, D. et al. 1996. Prediction of Waves on Inland Waters. In McConnell, K. & HR Wallingford, *Revetment Systems Against Wave Attack – A Design Manual*, Section 3. Thomas Telford.

Map 1 Ordnance Survey Explorer 266. 2000. Wirral & Chester/Caer.

Map 2 Ordnance Survey Explorer 275. 2000. Liverpool, St Helens, Widnes & Runcorn.

Chart 1 Admiralty Chart 2001. Manchester Ship Canal and Upper River Mersey. Chart no.3478.

Chart 2 Admiralty Chart 2001. Port of Liverpool. Chart no. 3490.

Chart 3 Upper Mersey Navigation Commission (UMNC) charts July 1871 – March 1973.

Chart 4 Bathymetric surveys five yearly intervals 1963-1977.

Chart 5 Bathymetric survey 1997 with assistance of HR Wallingford.

The following documents have been consulted to provide supporting information in the preparation of this assessment, but are not directly referenced:

Breusers, H.N.C., Nicollet, G. and Shen, H.W., 1977. Local scour around cylindrical piers. *Journal of Hydraulics Research*., IAHR, 15(3), 211-252.

Bridge, J.S.. 2003. Rivers and Floodplains. UK, Blackwell.

British Standard., 1997. *British Standard 6399-2, Code of practice for wind loads*, wind speed data. British Standards Institution.

Cashin, J.A., 1949. Engineering Works for the Improvement of the Estuary of the Mersey, *Maritime and Waterways,* Paper No.13. p.296-359.

DEFRA, 2006a. Shoreline Management Plan Guidance: Appendix 7.5: Open Coast SMP Boundaries. Department for Environment, Food and Rural Affairs.

DEFRA, 2006b. Shoreline Management Plan Guidance: Appendix 7.6: Integration of Estuaries. Department for Environment, Food and Rural Affairs.

Hay, A.E. Burling, R.W. & Murray, J.W., 1982. Remote acoustic detection of a turbidity current surge. *Science*, 217, 833-5. cited in Leeder, M., 1999. *Sedimentology and sedimentary basins: from turbulence to tectonics*. Oxford: Methuen.

Horton, B.P., Innes, J.B., Plater, A.J., Tooley, M.J., & Wright, M.R., 1999. *Post-glacial evolution and relative sea-level changes in Hartlepool and the Tees Estuary, England*, p.65-67 in Bridgland, D.R., Horton, B.P., & Innes, J.B. (eds) Later Quaternary of Northeast England, Field Guide, Quaternary Research Association, University of Durham.

James, C.S., 1985. Sediment transfer to overbank sections. *Journal of Hydraulic Research*, 23, p.435-52.

Knight, D.W. & Shiono, K. 1996, River channel and floodplain hydraulics, in *Floodplain Processes*, (Eds Anderson, Walling & Bates), Chapter 5, J Wiley, pp 139-181.

Knighton, A.D., 1994. Fluvial forms and processes. Hodder Arnold.

Leopold, L.B. & Wolman, M.G., 1957. River channel patterns – braided, meandering and straight. *US Geological Survey Professional Paper*, 282-B.

Masselink, M. & Hughes, M. 2003. *An introduction to coastal processes and geomorphology*. Arnold: London.

Pizzuto, J.E., 1987. Sediment diffusion during overbank flows. *Sedimentology*, 34, p.301-17.

Pye, K. & Van der Wal, D., 2000b. *Expert Geomorphological Assessment (EGA) as a tool for long-term morphological prediction in estuaries*. EMPHASYS Consortium Paper 15. Modelling estuary morphology and process. Final Report. p.97-101. EMPHASYS.

Richards, K.S., 1982. *Rivers: form and process*. London: Methuen.

Robinson, A.H.W., 1960. Ebb-flood channel systems in sandy bays and estuaries. *Geography*, 45, p.183-199.

Van Veen, J., 2001. Ebb and Flood Channel Systems in the Netherlands Tidal Waters, Reprint of the original Dutch text with English translations and annotations, originally published in 1950. *Journal of the Royal Dutch Geographical Society*, 67, p.303-325.