The Sediment Regime of the Severn Estuary
Literature Review

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Contents

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1. Introduction

The Severn Estuary is located between the south west of England and south east of Wales and extends from Haw Bridge to the North of Gloucester to a line between Lavernock Point and Brean Down (ABPmer and Atkins, 2010) (Figure 1). The Severn Estuary is hypertidal (10 to 12m) with the second largest tidal range in the world (ABPmer and Atkins, 2010; Severn Estuary Partnership, 2011). The estuary is characterised by high turbidity and high velocity currents (Manning *et al*, 2010).

The estuary's physical attributes have created a unique environment that has been recognised internationally, with the estuary being designated as a Ramsar site for wetlands (Joint Nature Conservation Committee, 2008). The habitats formed from the Severn estuary's physical attributes support a range of species including migratory birds, leading to a designation of a Special Area of Conservation under the European Union's Habitat Directive (Natural England and the Countryside Council for Wales, 2009).

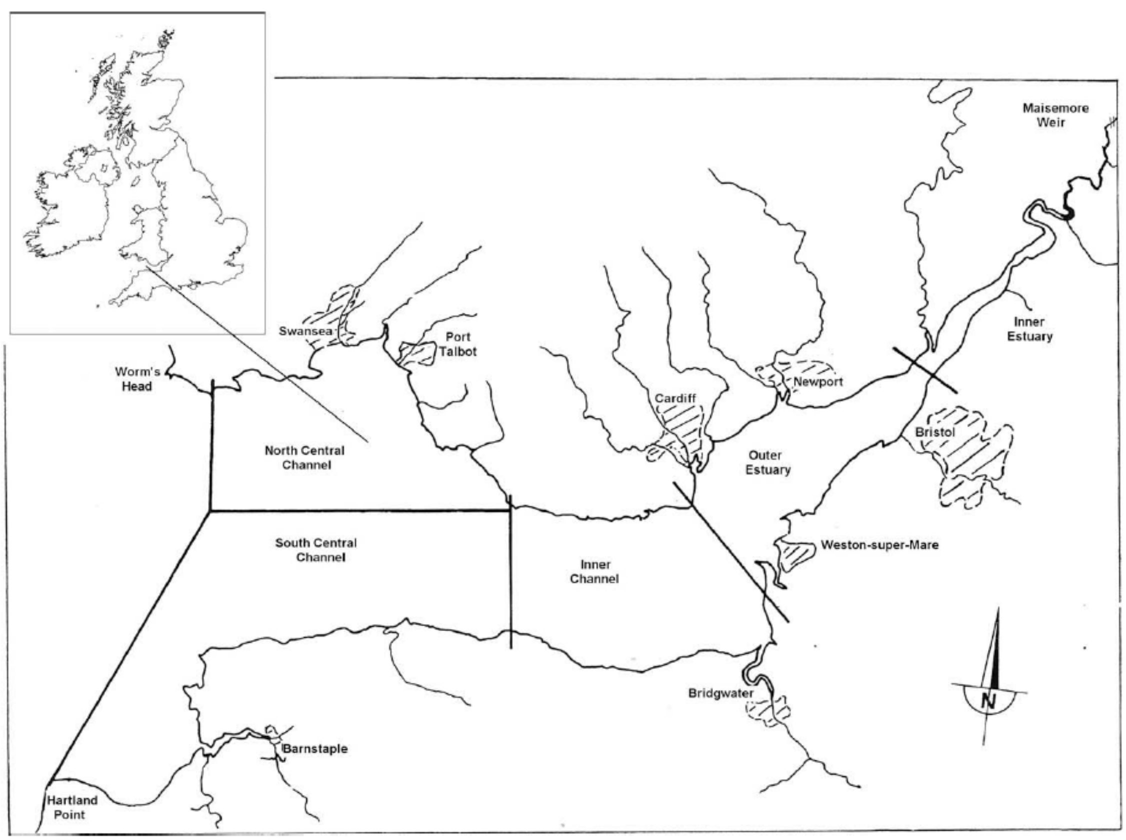

Figure 1. The Severn Estuary location and surrounding areas (Langston et al, 2010).

1.1 Aim

The aim of this report is to provide an overview of the sediment regime of the Severn Estuary, including identifying the sources, movement and sinks for fine and coarse sediment. The sediment processes in the estuary that are less well understood are indicated, and recommendations for further research for the estuary's sediment regime are proposed.

2. Hydrodynamics

The hydrodynamics of the Severn estuary is affected by its morphological form as well as its geographic location (ABPmer and Atkins, 2010). While the Bristol Channel is governed by both tidal currents and Atlantic swell waves (mainly produced from the prevailing south-westerly winds), the Severn estuary's north east-south west orientation partially protects it from most incoming waves, causing it to be tidally-dominated (Severn Estuary Partnership, 2011).

The large tidal range of the estuary leads to very strong currents throughout the main body of the estuary, while the funnel-shape of the estuary channel and shallow water friction effects causes tidal asymmetry with the flood tide dominating over the ebb tide, although the duration of the ebb tide is longer (ABPmer and Atkins, 2010; Bird, 2008; Uncles, 2010). These tides interact with freshwater flowing into the estuary from its tributaries, with the flood tide moving more saline water and sediment up the rivers (ABPmer and Atkins, 2010).

3. Sediment Sources and Sinks

The Severn Estuary is a mixed sediment system containing a wide range of particle sizes, from gravel (2-64mm) and sand (0.125-2mm) to silt and clay (<0.125mm) (Manning *et al*, 2010; Smith, 2014). The movement and sorting of this sediment is mainly controlled by the sediment's properties and the estuary's physical processes, with the principal drivers being the strength and distribution of the currents (Manning *et al*, 2010; Parsons Brinckerhoff Ltd, 2010b; Uncles, 2010). Although both sand and fine material are transported around the estuary in combination, fine sediment exhibits cohesive properties while sand is non-cohesive which causes the different sized grains to be sorted and distributed around the estuary separately (APBmer and Atkins, 2010; Atkins, 2012; Morris, 2006). For the purposes of this review, the movement of cobbles (>64mm) around the estuary will not be discussed.

3.1 Sand

The main source of sand originates from deposits in the Celtic Sea produced by glacial rivers during the last ice age (Severn Estuary Partnership, 2011). The sand is transported up the estuary on strong tidal currents (Figure 3) (Otto, 1998; Parsons Brinckerhoff, 2010b). Since the flood tides dominate around the north side of the estuary, the sand gets moved up the this side of the estuary before settling on defined sand banks in the middle of the lower estuary (Morris, 2006; Otto, 1998). Ebb tides are strongest in the central axis of the estuary, which is where sand is moved downstream (Harris and Collins, 1991). In the estuary areas that contain strong currents, sand is moved and not deposited, causing the estuary bed to be composed of compacted sand and gravel (Otto, 1998) (Figure 2).

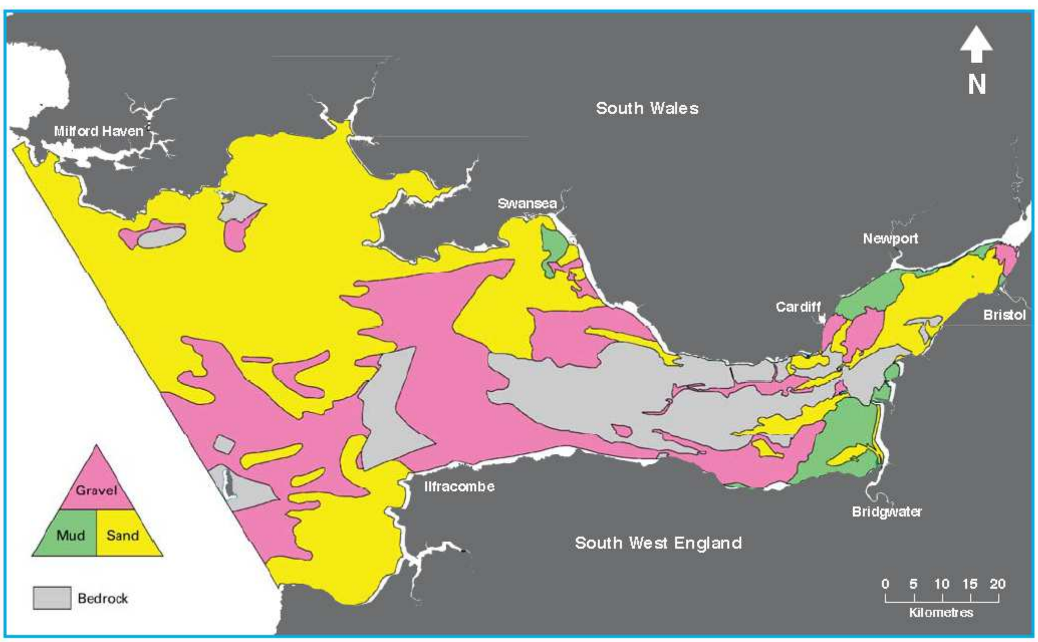

Figure 2. A simplified BGS map showing the distribution of sediment on the bed of the Severn Estuary and Bristol Channel (Mackie et al, 2006).

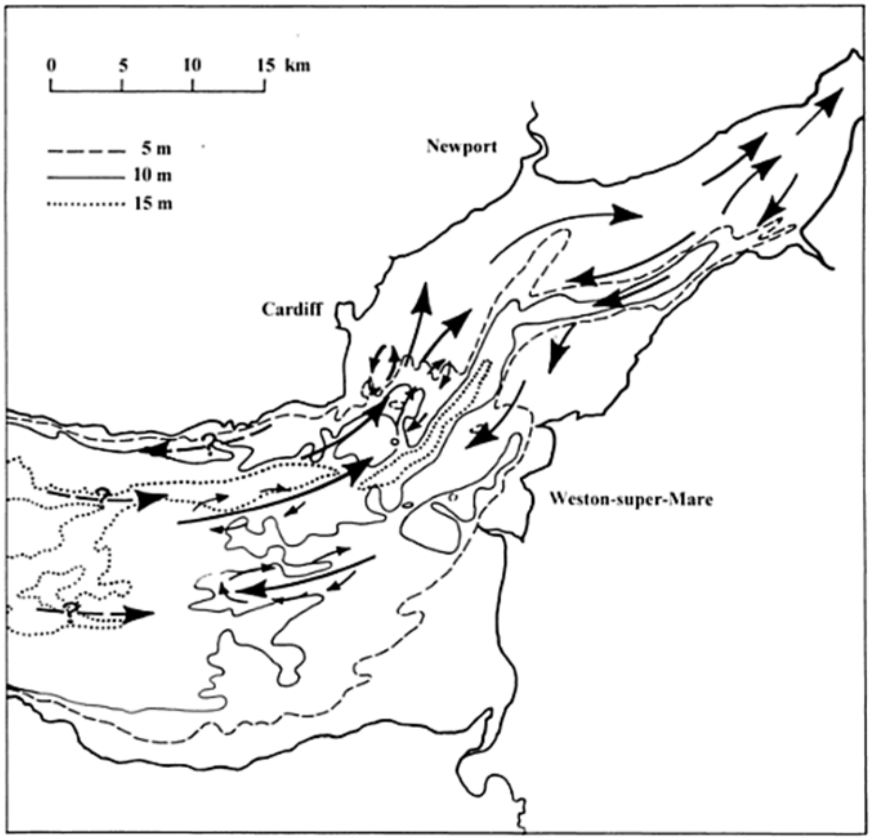

Figure 3. Sand transport pathways for the Inner Bristol Channel and Outer Severn Estuary (Otto, 1998).

3.2 Fine Sediment

3.2.1 Sources

Fine sediment is defined as all sediment that has a particle size that is smaller than 63 microns sand and includes silt and clay particles which are influenced by electrochemical and biological cohesion. The main source of this sediment is from fluvial tributaries with the main contributors coming from the Rivers Severn and Wye (Table 1) (ABPmer and Atkins, 2010; Allen, 1991; Parsons Brinckerhoff Ltd, 2010a; Parsons Brinckerhoff Ltd, 2010b). However, there is very little fine sediment that enters the estuary from the Celtic Sea (Allen, 1991).

Within the estuary, fine sediment is eroded and/or mobilised from the cliffs, saltmarshes, mudflats, and subtidal flats which provide further sources of fine sediment (table 2) (ABPmer and Atkins, 2010; Atkins, 2009; McLaren *et al*, 1993; Parsons Brinckerhoff Ltd, 2010b). The main long-term fine sediment source location within the estuary is Bridgwater Bay (Parker and Kirby, 1982).

Table 1. A summary of the known sediment inputs from the tributaries of the Severn Estuary (ABPmer and Atkins, 2010). Note the rivers Taff and Ely have no sediment input into the estuary due to being impounded by Cardiff Bay.

River	Sediment input (Tonnes/year)
River Severn	262,883
River Wye	347,227
River Avon	53,060
River Usk	41,733
River Ely	0
River Taff	0
River Ebbw	Unknown
River Parrett	Unknown
River Rhymney	Unknown

3.2.2 Sediment Distribution in the Severn Estuary

Fine sediment is transported by both wind-driven waves and tidal currents (Morris, 2006). The concentration of fine sediment in suspension is affected by the semi-diurnal tide and spring-neap cycles. Spring tides have higher current velocities which mobilise fine sediment from the estuarine bed, while neap tides have lower current velocities that cannot maintain this sediment in suspension, causing it to settle back onto the estuary bed (Kirby, 2010). Although this prevents most of the mud from permanently accumulating (ABPmer and Atkins, 2010), mud deposits that are formed during 'slack water' around the neap tide have a longer time to consolidate. This may prevent the mud from being remobilised by the next spring tide, causing it to form an immobile layer on the estuary bed (Manning *et al*, 2010).

The suspended sediment concentrations are higher around the eastern, English side of the estuary than the western Welsh side, with a steep gradient change in concentration occurring in the middle of the estuary creating a suspended sediment front (Figure 4) (ABPmer and Atkins, 2010). This is caused by the orientation of the Shoots channel, which transfers highly turbid water onto the English coast, and the large source/sink at Bridgwater Bay (Kirby, 2010).

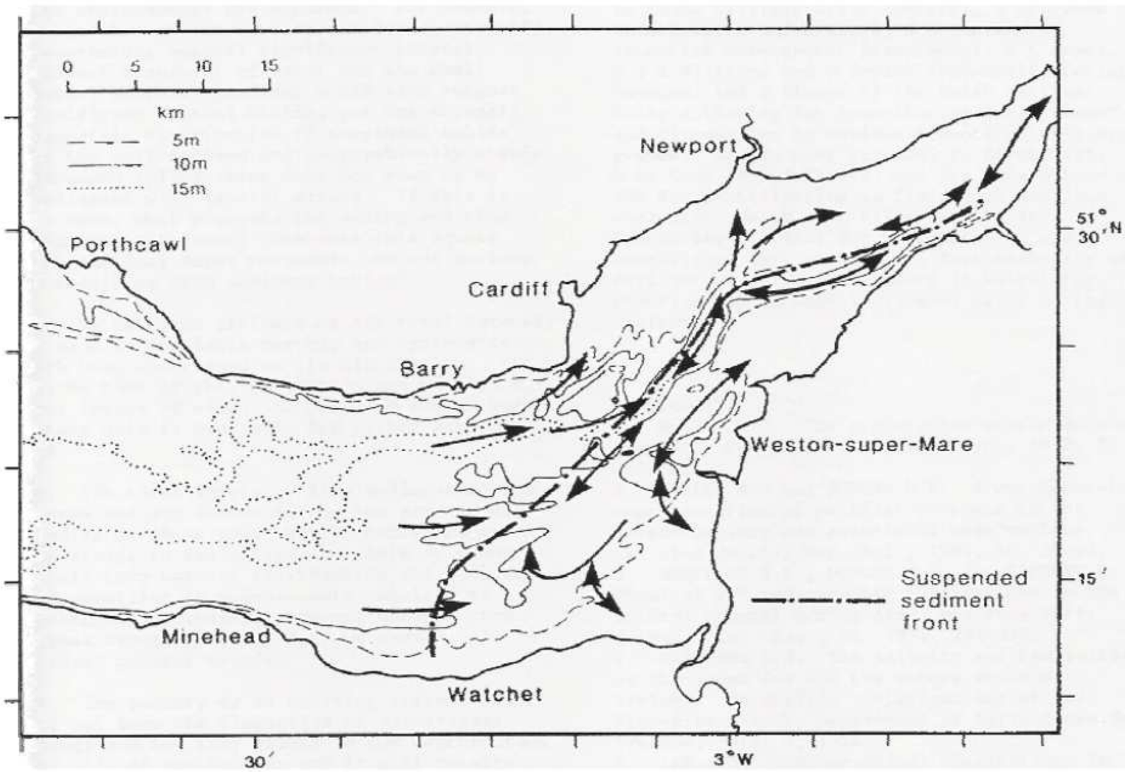

Figure 4. Fine sediment movement around the Severn Estuary (ABPmer and Atkins, 2010).

The total amount of suspended sediment in the estuary is at capacity for the estuary (ABPmer and Atkins, 2010) and is greater than the amount entering it annually from fluvial sources (Manning *et al*, 2010). The high amount of suspended sediment in the estuary is maintained by tidal asymmetry preventing the sediment from being exported to the Celtic Sea (Parsons Brinckerhoff Ltd, 2010b). Additionally, this concentration is also maintained by the lack of a primary pathway for sediment to reach a natural sink caused by historic land reclamation (ABPmer and Atkins, 2010).

Seasonal changes throughout the year also affect fine sediment in the estuary. Suspended sediment concentrations are lower during the summer months due to less sediment being discharged from tributaries, higher water temperatures and a reduction in wind (Allen and Duffy, 1998). Wave energy is less in the summer due to calmer conditions, enabling fine sediment to be deposited before being eroded during the winter storms (Parsons Brinckerhoff Ltd, 2010b). However, there is little seasonal change on suspended sediment concentrations near to the Celtic sea (ABPmer and Atkins, 2010).

Other factors that affect the transport of sediment around the estuary include microphytobenthos biofilms formed on sediment in the estuary increasing the stability of settled sediment in a process called biostabilisation (Underwood, 2010). Dredging around the ports also affects the local sediment budgets, although this sediment is not lost out of the estuary system since it is redistributed to a licensed spoil ground (ABPmer and Atkins, 2010).

In the future, it is predicted that climate change will affect the sediment processes that occur in the Severn Estuary. While there remains a high level of uncertainty around the specific effects of climate change on the sediment regime, it is expected that the sediment carrying capacity of the Severn Estuary could increase. Sediment transport within the estuary is expected to reduce, while an increase in sea-levels could increase sediment accretion (IMCORE Project, 2011; Robins *et al*, 2016; SECCRAG, 2009).

3.2.3 Sinks

Fine sediments are primarily deposited on intertidal mud flats, subtidal mudflats and salt marshes that are positioned away from areas of high energy currents (table 2) (ABPmer and Atkins, 2010; Morris, 2006). Intertidal mud flats and the Deeps (deep channel) act as sinks during neap tides but will revert to a sediment source during spring tides or high energy conditions brought about by local wind-generated waves (Morris, 2006; Parsons Brinckerhoff Ltd, 2010b). The main sediment sink locations for fine sediment are Newport Deep and Bridgwater Bay. Sediment sinks also occur around the estuary's tributaries, including the River Avon and the River Usk (ABPmer and Atkins, 2010).

Table 2. A summary of the Severn Estuary sediment budget (adapted from ABPmer and Atkins, 2010).

Status	Element	Sediment load (Mtonnes/year)	Total (Mtonnes/year)
Sources	Rivers	1.0	4.16 – 5.4
	Cliff	0.06 – 1.3	
	Saltmarsh	0.1	
	Mudflat	2.5	
	Subtidal flat	0.5	
Transfers	Water body suspended sediment	9.0 – 30.0	31.5
	Anthropogenic intervention	1.5	
Sink	Saltmarsh	0.06	1.06 – 2.06
	Mudflat	1.0 – 2.0	

4. Lower Avon Sediment Regime

The amount of suspended sediment contained in the Avon is linked to fluvial flow and meteorological change (Parsons Brinckerhoff Ltd, 2010a). Accretion occurs at the entrance to the Lower Avon from the Severn estuary at a rate of 0.1m in height per month. This is due to the presence of sand within the fluid mud causing dewatering and limiting the muds fluidity (The Bristol Port Company, 2008). The entrance to the Lower Avon acts as a sink, with its width reducing from 0.8Km to 0.17Km forming a mud belt positioned around the mouth of the Avon (Atkins, 2010; English Nature, 1997). To ensure that ships can access the ports, dredging is used to remove 1.5 to 2 million m^3/year of mud from the Portbury and Avonmouth dock entrances (The Bristol Port Company, 2008).

5. Gaps in the literature

Within the available literature, there were a lack of studies documenting the sediment interactions occurring between the river tributaries and the Severn Estuary, particularly for the rivers Parrett, Ebbw and Rhymney. There is also little information about how climate change will specifically affect the sedimentation processes within the Severn Estuary. This is partly due to the large number of potential changes that could occur due to climate change, leaving a high level of uncertainty (Robins *et al*, 2016).

6. Recommendations

A conceptual model of the sediment regime of the Severn Estuary should be developed. This can be used on different zones/habitats in the estuary to assess the areas where there is a lack of knowledge of sediment transport processes. These areas can subsequently be investigated further to enable a more complete picture of the sediment regime of the Severn Estuary to be established.

Another area for further research is to assess the impact of climate change on the Severn Estuary. Since climate change affects a large number of variables, the potential risks that it could have on the sediment regime of the Severn Estuary should be assessed to determine the most suitable variables to focus future studies on. Further research should also focus on improving the understanding of sediment interactions between the Severn Estuary and its tributaries, especially the rivers Parrett, Ebbw and Rhymney.

7. Acknowledgements

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