F Integration of estuaries

CONTENTS

F.1 Introduction

Under a fully comprehensive approach towards the management of flooding and erosion risks in England and Wales, all areas of open coast, estuarine, tidal inlet, tidal river and riverine frontage should, ultimately, be considered in a strategic manner[1]. However, with many of the first generation SMPs focusing primarily on open coasts, and with the more recent initiative of Catchment Flood Management Plans (CFMPs) focusing primarily on riverine frontages, there is a need for further consideration of where estuaries sit within Defra's strategic approach to flood and coastal management. The aim of this Appendix is to assist users in determining whether, and how, estuarine shores should be included in the Shoreline Management Plan (SMP) process. (Note, given the linkages with CFMPs it is possible that boundaries may already exist for some estuaries, and as such it is recommended that Coastal Groups consult with their Defra Regional Engineer before proceeding with determining estuarine limits.)

The need to consider such issues exists because of increased awareness, over the past decade, within the flood and coastal management industry of physical processes, and resulting interactions between different components of the natural system (see Annex F1 for further details).

A number of approaches exist for classifying estuarine type, and various empirical and theoretical relationships exist to determine particular estuarine 'regimes', parameters or processes (Annex F1). However, in the context of whether or not an estuary should be included in the SMP process, the critical process issue is whether there are important interactions in existence between the estuary and open coast (Box F1).

In developing guidance to enable determination of whether, and how, estuarine shores should be included in the SMP process, focus has primarily been on the application of information contained within the *Futurecoast* estuaries database, and the resulting plots and tables derived from these data, as described and presented in Annex F2.

The guidance adopts a staged approach that involves three key questions:

- ***Should*** the estuary be included in the SMP process?
- If so, ***how*** should the estuary be included?
- ***How far upstream*** should the estuary be included?

Box F1 Potential interactions between estuaries and the open coast

- The open coast can provide sediment to the estuary or its mouth through processes of shoreline erosion from a near or remote 'updrift' source and subsequent longshore transport of sediment to the estuary. The volume of sediment erosion or transport

1 Consideration should be to an appropriate level of detail commensurate with the degree of risk.

(and hence input to the estuary) can vary according to different management practices along the open coast. For example, seawalls can reduce or stop the erosion of soft cliffs and as a consequence reduce the volume of sediment reaching the estuary. It is important to note that an estuary can be an important sink for both cohesive and non-cohesive marine sediment transported from the coast. (see Estuary Guidance Table 3)

- The flow of water through an estuary mouth can partially or fully block the longshore transport of coastal sediments across the mouth of the estuary, enabling sediment to accrete in spits. Periods of particularly high river spate can push sediment drifting along the shoreline further offshore as a plume from the estuary mouth. Such sediment may then be lost from the littoral system rather than returning to the shoreline. (EGT 2)
- In many estuaries, the transport of sediments across the estuary mouth is achieved through a more complex transport pathway. Sediment can pass into the estuary where it is temporarily stored within flood tide deltas before being transported back out of the estuary to reach the 'downdrift' shoreline of the open coast. (EGT 3)
- Changes to the tidal prism (volume of water that enters and leaves an estuary on a tide) of an estuary, caused for example by a significant change in management practice (reclamation would reduce, and re-alignment would increase, the tidal prism of the estuary), can alter tidal asymmetry and/or flow velocities of the estuary. This could potentially lead to changes in existing erosion/deposition patterns and/or to changes in present net tendencies for sediment to either enter or leave an estuary (e.g. if the tide becomes more ebb-dominated due to the management intervention, then estuarine sediments may be more likely to be transported out of the estuary to the open coast). (EGT 4)
- Ebb tidal deltas form at the mouths of many estuaries and their associated sand bars provide important natural coastal defence features to both the estuary mouth and the adjacent open coasts. The size of the delta depends on the tidal prism of the estuary and consequently the degree of natural protection can change as the prism changes through differing estuary management techniques. (EGT 3)
- Predictive models used in the EMPHASYS programme indicate that sea level rise will result in the progressive landward migration ('roll-over') of the entire morphological form in many estuaries. This process is achieved through erosion of the outer estuary (often located within the Schedule IV boundary) and deposition of eroded sediments towards the head of the estuary (often beyond the Schedule IV boundary). In order to fully incorporate such interactions, the entire estuary needs to be considered as a whole, not just a short length at, or close to, the estuary mouth.

F.2 Should the Estuary be Included in the SMP Process?

To some extent, all estuaries will interact physically with the open coast. This interaction is expressed in terms of both the influence of the estuary on the coast, and the influence of the coast on the estuary. However, the **type and scale of physical interaction** will differ from estuary to estuary.

For example, in general terms the physical influence of an estuary on the coast may range from:

- Limited – e.g. a very small discharge of flow into a wide coastal embayment; to
- Extensive - e.g. a major supply of sediment to the coastal system, with significant delta formations at the estuary mouth offering protection to the adjacent open coast shoreline over several kilometres either side of the estuary mouth.

Similarly the physical influence of the coast on an estuary may range from:

- Limited – e.g. virtually zero alongshore littoral transport on a rocky coast that is intersected with deep fjords or ria type estuaries that may be exhibiting limited infilling with marine sediment; to
- Extensive – e.g. high longshore sediment transport leading periodically to the closure of an estuary mouth and/or a high degree of estuarine infilling with marine sediment.

The examples above demonstrate that changes in one system can lead to changes in the other system. For example, coastal defences constructed along the open coast (e.g. seawalls and groynes) can result in the cessation or reduction of sediment supply to an estuary. Alternatively, beach replenishment along the open coast may increase the supply of sediment to spits or estuarine deltas. Conversely, reclamation or re-alignment of existing estuarine defences within an estuary can affect the hydrodynamics and therefore estuarine-open coast interactions. In addition to these anthropogenically-induced changes, natural changes can also occur which alter the degree of influence between the two environments. For example, natural breaching of spits at estuary mouths during extreme storm events will allow greater wave penetration into the outer estuary, or increased supply of sediment to the estuary mouth due to updrift erosion may result in diversion of the estuary mouth along the coast.

These factors underline the importance of including, in appropriate circumstances, both coastal and estuarine systems within Shoreline Management Plans because these documents can, through the recommendation of preferred shoreline management policies, potentially bring about significant changes in physical aspects of each system.

Gaining an understanding of the type and scale of physical interactions between the estuarine and coastal systems assists in determining which estuaries should be included in the SMP process, with those having significant interactions being included and those exhibiting insignificant interactions not being included. However, as well as physical process interactions, the decision of whether or not to include an estuary in the SMP also needs to consider management aspects, such as the presence of interlinked flood risk areas, the number and complexity of management issues, or the continuity of important habitat features.

Those estuaries identified as not having sufficiently significant physical interactions or management issues to warrant their inclusion within the SMP are most likely to be small in size, typically narrow and fluvially-dominated, or located along hard rock coasts characterised by little available littoral sediment. However, these estuaries (or tidal rivers) potentially could still be incorporated in the strategic flood and coastal management approach through appropriate 'downstream' placement of the relevant CFMP boundary.

The question of whether or not an estuary should be included in the SMP process can be addressed by considering:

- The type and scale of physical interactions[2], and their significance; and
- Management issues, and their significance.

F.3 How Should the Estuary be Included in the SMP Process?

If it is identified that a particular estuary should be included in the SMP process due to physical process reasons, management reasons, or both, then a decision needs to be made about the best way of incorporating the estuary.

The two practical options for including an estuary within the SMP process are:

- The estuary could be included within the relevant open coast SMP; or
- The estuary could have its own estuary SMP (eSMP).

F.4 How Far Upstream Should the Estuary be Included in the SMP Process?

The physical extent to which an estuary should be included in the SMP process is difficult to define precisely. Theoretically, shoreline management policies should be considered for estuarine shores up to the tidal limit because any change in shoreline management policy (e.g. new options of 'managed re-alignment' or 'advance the line') can change the margins and inter-tidal areas of the estuary. This in turn will change the tidal prism of the estuary, with potential for changes in flow velocities and tidal asymmetry that could affect not only the remainder of the estuary, but also its interface with the coast.

However, for two practical reasons it is not always possible to consider shoreline management policies up to the limit of tidal influence of an estuary within an SMP:

In heavily modified estuaries or in long, narrow tidal rivers, the limit of tidal influence may be

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2 Whilst it is recognised that biological and chemical interactions also take place, the SMP is a document primarily produced for flood and coastal management purposes and consequently its focus is on physical process. The importance of other interactions can be recognised, where relevant, within the guidance framework by considering 'management issues'.

many tens of kilometres inland (e.g. Rivers Nene and Great Ouse in the Wash). For example, the tidal limit of the River Thames is at Teddington and it is not necessarily appropriate to consider such a geographical extent in one SMP.

It is inappropriate to insist that shoreline management policies are considered within an estuary where there is little opportunity for significant changes in management practice, since physical interactions with the open coast will largely remain unaffected by maintaining the ‘status quo’. This scenario could apply to heavily urbanised estuaries, or to fjard or ria type estuaries where the topography, rather than flood defences, is the principal control on the extent of tidal inundation and the volume of water contained within an estuary.

As an alternative, it is possible to consider estuary processes as fully as possible, select shoreline management policies as fully as practicable to some upstream limit, and to then assume no change in shoreline management policy beyond this limit. Box F2 identifies key criteria that could be applied to determine the upstream estuarine limit of a SMP.

Box F2 Criteria to determine upstream estuarine limits

The following criteria can all potentially be applied, with various degrees of difficulty, to determine the location of the upstream estuarine limit of consideration within SMPs:

- Approximate limit of tidal influence (preferred theoretical option);
- Approximate limit of wave influence (although this would be difficult to define and may vary over time with climate change);
- Approximate limit of non-cohesive sediment exchange, as indicated by a marked change in sedimentary deposits from sands and/or gravels close to the estuary mouth to cohesive sediments;
- Limit of continuity of habitats, development (existing or proposed), risk zones, or flood reservoirs between the open coast and estuary;
- Limit of the existing CFMP boundaries;
- Limit as defined by the existing Schedule IV boundary.

F.5 Estuary Guidance Tables

In developing guidance on the inclusion of estuaries, it was not considered appropriate to define either a fully prescriptive approach or ‘inclusion criteria’ with *absolute* values. For example, whilst it theoretically would have been possible to state that estuaries in excess of a certain physical size, or with a tidal range exceeding a certain value, should be included in an SMP, this approach has not been followed due to one major disadvantage. There are so many processes that operate within an estuary, many in combination with other processes both in the estuary and at the mouth or along the adjacent coast, that it would be impossible to accurately prescribe the threshold values of inclusion criteria for a particular parameter, or combination of parameters, that would universally be applicable.

Instead, an approach has been developed that enables the user to consider a range of parameters or issues in a *relative* manner and guides them towards a decision about inclusion, or otherwise, of a particular estuary, based upon identification of whether an identified aspect is ‘significant’, ‘marginal’, or ‘insignificant’.

This approach has been facilitated through the development of a series of Estuary Guidance Tables (EGTs) that draw, where required, upon information contained within the *Futurecoast* estuaries database and other reference sources. The inter-relationship between these EGTs is outlined in EGT1, which provides the overall decision-support framework. It is intended that the tables guide the user through a series of thought processes rather than a series of physical operations or calculations.

In applying the EGTs, there are some key points to note:

- Determination of the three key parameters is intended to be *qualitative.* It is not necessary, or correct, to attempt to quantify parameters based upon the data provided.
- The *Futurecoast* estuaries database should be applied with some caution since trial application has revealed areas where data are incorrect, missing, or inconsistent. Consequently, there is a need to enhance the parameters listed in this database (presented in Appendix F2) with additional information derived from the *Futurecoast* ‘estuaries assessment’ report (not reproduced here) which supplements the database in Futurecoast. This contains useful information (e.g. management issues) and provides a qualitative context for appreciating the complexity of issues and/or validity of information presented elsewhere within the *Futurecoast* estuaries database.
- Local knowledge of specific processes or management issues undoubtedly assists the user in applying the EGTs to particular estuaries. Indeed, knowledge of the estuary, together with an appreciation of the rational of the EGTs should be sufficient to undertake the assessment. (The benefits of this approach are exemplified through example application to Chichester Harbour (see Annex F3), where the spit ratio and the *Futurecoast* ‘estuaries assessment’ report do not take into account the fact that East Head spit has recurved around a hinge point into the harbour mouth, but this fact is known from local knowledge of the estuary.)
- The EGTs are useful in enabling a decision to be made about whether an estuary should be included in the SMP process, but identification of *how* it should be included (i.e. within the open coast SMP or in its own eSMP) is essentially made using a pragmatic decision on what is the ‘most appropriate’ approach. This starts with the premise that the estuary should be included within the open coast SMP unless this would be logistically difficult to achieve, for example due to its

physical size or complexity of management issues. The advantage of this approach is that economies of effort and consistency of approach can be achieved between the estuary and coastal systems through their consideration as a continuum, rather than by considering them as separate entities.

- It is not possible to precisely define the limit of inclusion of the estuary from the EGTs without more detailed knowledge of the processes and management issues specific to that estuary. This finding is in keeping with previous research into the definition of estuarine limits. It is suggested that this information needs to be fed into a local knowledge-based decision, rather than solely determined through the application of generic national guidance.
- A pragmatic approach must be taken to the application of the EGTs. The output from the tables, particularly EGT 5, should be taken only as guidance and not an absolute decision. The sensitivity of the decision at EGT 5 to changes in outputs from EGTs 2, 3 and 4 should be reviewed.

Estuary Guidance Table 1 General Decision-Support Framework

The purpose of this Table is to provide the overall context within which decisions will be made concerning the inclusion, or otherwise, of estuaries within the SMP process. EGT1 is supported by further tables EGT2-EGT7.

<table>
<tr><th>Key Question</th><th>Key Issues for Consideration</th><th>Indicators</th><th>Reference Tables</th></tr>
<tr><td rowspan="2">Should the estuary be included in the SMP process?</td><td>Type, scale and significance* of physical** interactions</td><td>▪ Physical size parameters of the estuary
▪ Physical process parameters of the estuary, and degree of sediment supply from river(s) and sediment exchange with the open coast
▪ Presence/absence of morphological features within estuary and/or at estuary mouth
▪ Physical constraints within estuary and/or along adjacent coast (e.g. defences and/or geological controls)
▪ Potential for large-scale changes in alignment of defences within estuary and/or along open coast</td><td rowspan="2">EGT2-5</td></tr>
<tr><td>Nature and complexity of management issues</td><td>▪ Presence/absence of control structures at the estuary mouth and/or within the estuary and/or along the open coast
▪ Common sources of risk between the estuary and open coast (e.g. tidal flooding, wave erosion)
▪ Continuity, location and/or scale of receptors at risk close to the estuary /coast interface (e.g. life, development, nature conservation, natural heritage, existing land and water uses)
▪ Limits of other ‘strategic’ flood and coastal management initiatives (e.g. CFMPs and/or CHaMPs)</td></tr>
<tr><td rowspan="2">How should the estuary be included?</td><td>SMP</td><td rowspan="2">▪ Physical size (logistics)
▪ Complexity of management issues</td><td rowspan="2">EGT6</td></tr>
<tr><td>eSMP</td></tr>
<tr><td rowspan="2">How far upstream should the estuary be included?</td><td>Consideration of estuarine processes</td><td>▪ Balance in fluvial, tidal and coastal processes throughout estuary and extent of interactions (physical and logistical)
▪ Presence of natural or man-made constraints and assessment of cross-sectional morphological form</td><td rowspan="2">EGT7</td></tr>
<tr><td>Selection of shoreline management policy</td><td>▪ Presence/absence of morphological features and their interconnectivity between different environments
▪ Location, extent and type of management issues</td></tr>
<tr><td colspan="4">*‘Significant’ interaction need not necessarily only be confined to ‘large’, but could relate to other factors key to the development of either the coast or estuary (i.e. complexity of interactions). Assessment of ‘significance’, therefore, needs to take account of the scale of the interaction relative to other factors (e.g. resistance of geology, availability of sediment).
**Physical interactions principally relate to water and sediment exchanges between the estuary and open coast. Chemical and biological interactions and water quality issues may be incorporated, if appropriate, in consideration of ‘management issues’.</td></tr>
</table>

Estuary Guidance Table 2 Significance of Water Exchange

This table assists the user in determining the significance of water exchange between the estuary and the open coast in order to inform the decision about whether or not an estuary should be included in the SMP process.

1. Make an informed assessment about the overall **scale** of water exchange between the estuary and the open coast by considering the following estuary parameters from the *Futurecoast* estuaries database and judging whether they fall into the range ‘insignificant to low’, ‘moderate’ or ‘high to extensive’:
    - Total area
    - Inter-tidal area
    - Channel length
    - Mouth area
    - Mouth width
    - Tidal range
    - Mean freshwater flow
2. Supplement the above information with local or specific knowledge about the following estuary parameters:
    - Tidal prism
    - Tidal velocities
3. Use the above understanding to make an informed assessment of the **significance** of the water exchange between the estuary and the open coast. This may be assisted by consideration of the following factors, although there may some anomalies, usually large estuaries or inlets, where the ratios do not apply:
    - Ratio of total area to channel length (large = wide embayment more likely to be subject to wave processes, small = longer, narrower estuary more likely to be dominated by tidal processes)
    - Ratio of tidal range to mean freshwater flow (large = tidal processes dominate, small = river process dominate)
    - Ratio of mouth area to mouth width (large = large average mouth depth and hence large water exchange, small = small average mouth depth)
    - Geology of mouth and adjacent coast (hard = relatively erosion resistant even with high flows associated with high water exchange, soft = erodible even with marginal water exchange)

Assess significance of water exchange

Significant | **Marginal** | **Insignificant**

Estuary Guidance Table 3. Significance of Sediment Exchange

This table assists the user in determining the significance of sediment exchange between the estuary and the open coast in order to inform the decision about whether or not an estuary should be included in the SMP process.

1. Make an informed assessment about the overall **scale** of sediment exchange between the estuary and the open coast by considering the following estuary parameters from the *Futurecoast* estuaries database or 'estuaries assessment' report (not presented here) and judging whether they fall into the range 'insignificant to low', 'moderate' or 'high to extensive':

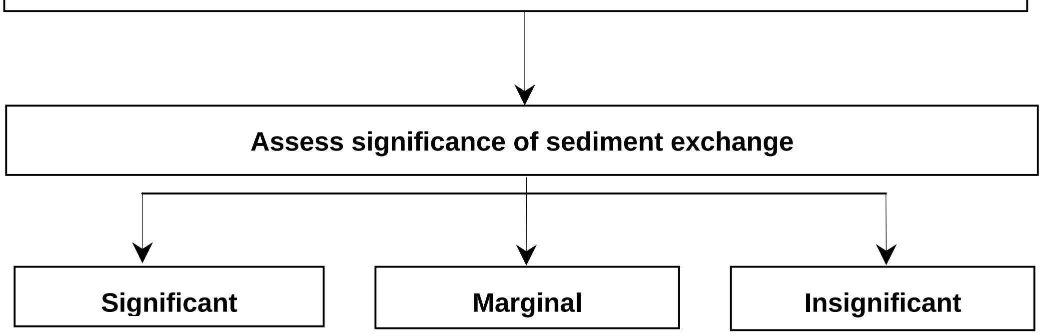
- Tidal asymmetry
- Presence or absence of morphological features such as banks and deltas
- Source or sink relationship with open coast (for both cohesive and non-cohesive sediments) – (see 'estuaries assessment' report)
- Potential for plume generation during river spate (see 'estuaries assessment' report)

2. Supplement the above information with local or specific knowledge about the following issues:

- Catchment area and existing/planned catchment land uses (influences sediment supply from estuary to coast)

3. Use the above understanding to make an informed assessment of the **significance** of the sediment exchange between the estuary and the open coast, taking into consideration the following factors:

- Availability of sediment (both cohesive and non-cohesive) to feed transport potential
- Critical thresholds for erosion, transport and deposition of estuarine and coastal sediments



Estuary Guidance Table 4. Significance of Management Issues

This table assists the user in determining the scale of management issues between the estuary and the open coast in order to inform the decision about whether or not an estuary should be included in the SMP process.

1. Make an informed assessment about the scale of management issues by considering the following factors from the Futurecoast estuaries database:

- Historic reclamation
- Presence / absence of jetties at the mouth

2. Supplement the above understanding with local or specific knowledge about the following issues:

- Scope for large-scale anthropogenic intervention (e.g. barrage construction, development proposals)
- Presence or absence of continuous 'at risk' zones between the estuary and coast (e.g. flood risk zones, designated habitat areas, historic environment)
- Indicative residual life of existing estuarine and coastal defences and scope for widespread changes in shoreline management policy to 'managed realignment', 'hold the line' (with new defences on eroding cliffs) or 'advance the line' (thereby significantly changing existing estuarine tidal prism, or supply of sediment from the coast)
- Consistency of approach with adjacent SMPs and relevant CHaMPs
- Relevance of other management issues which can influence the physical interactions between the estuary and coast (e.g. beach replenishment, weirs and sluices, navigation and aggregate dredging, bridges and causeways, training works)

3. Combine the above information to make an informed assessment of the significance of the management issues.

↓

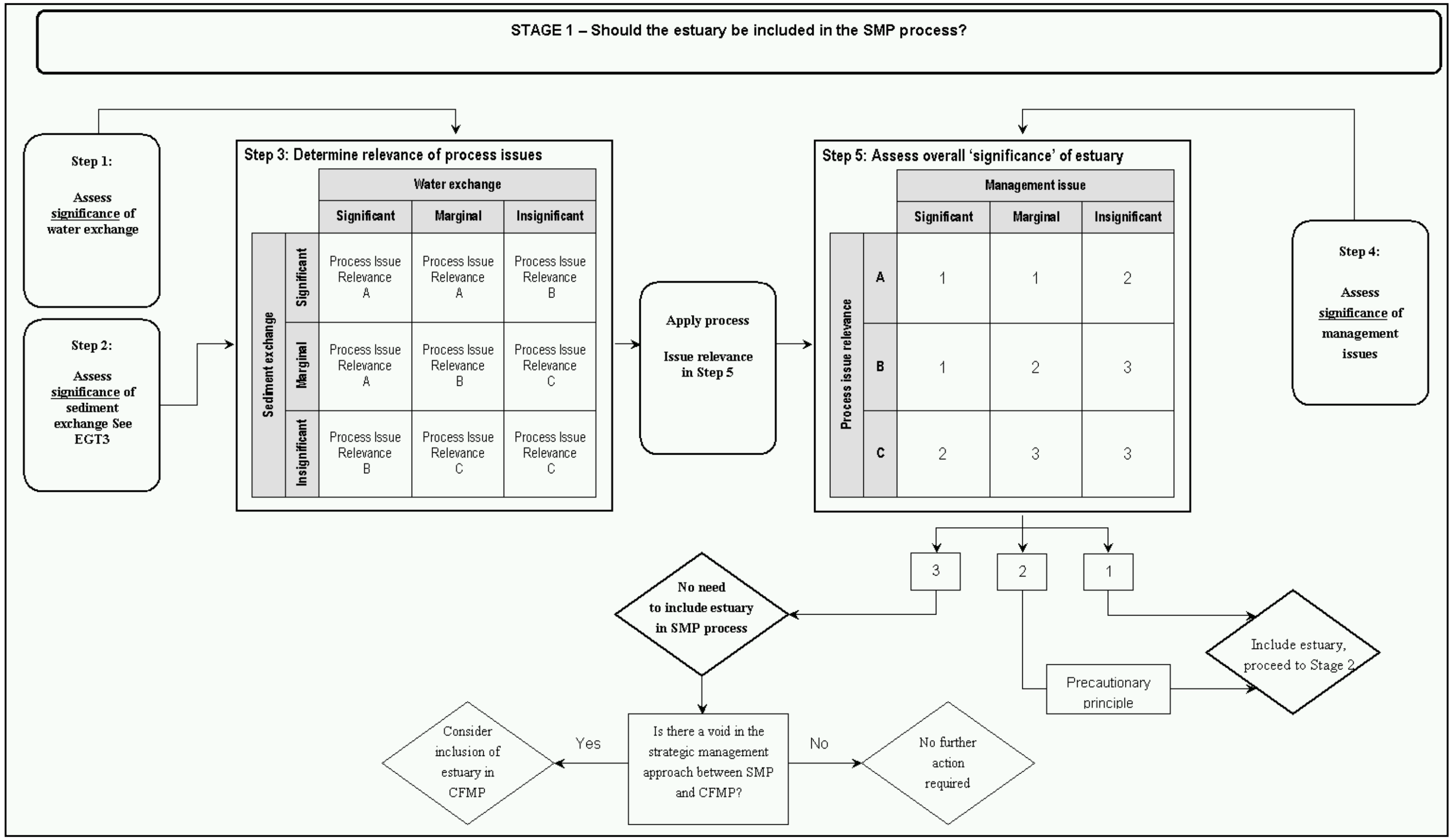
Assess significance of management issues

↓

Significant	**Marginal**	**Insignificant**

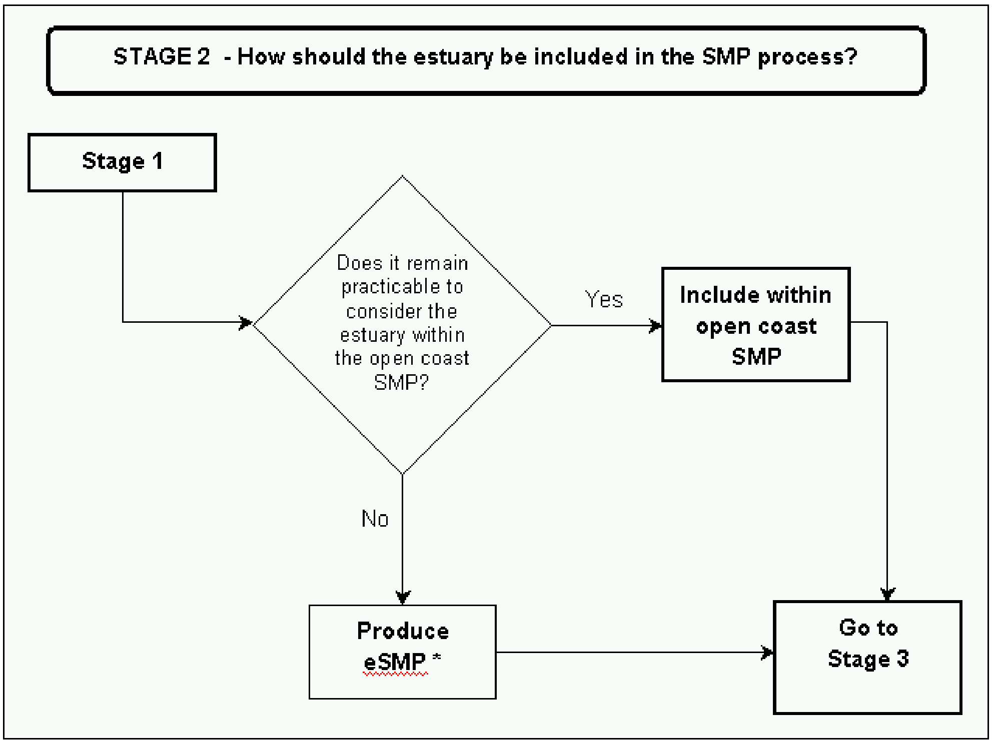
Estuary Guidance Table 5. Assessment of Estuarine Inclusion in SMP Process

The purpose of Estuary Guidance Table 5 is to assist the user in combining findings from EGT2-4 to determine whether or not an estuary should be included in the SMP process. The sensitivity of the decision from this table to changes in the outputs from tables 2, 3 and 4.



Estuary Guidance Table 6. Assessment of Method for Inclusion of Estuaries in SMP Process

This table assists the user in determining how an estuary should be included in the SMP process. It is clearly a qualitative appraisal and should only be undertaken by those familiar with the estuary and its issues.



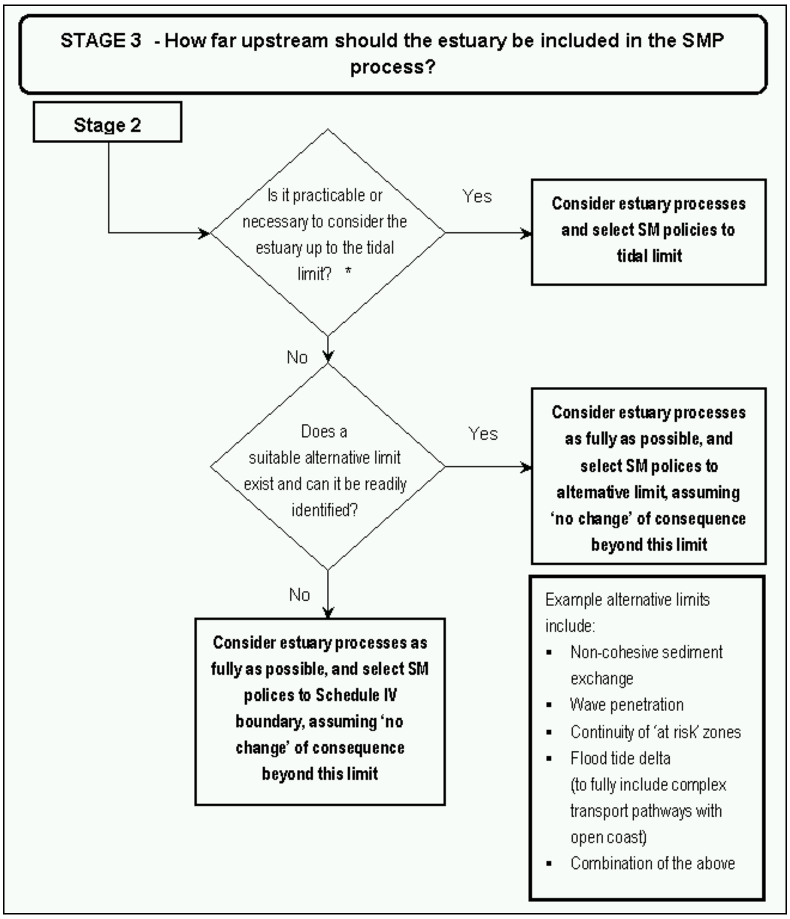
*eSMP must overlap with open coast SMP and those producing each plan must maintain information exchange throughout the plan preparation process

Examples of where it is not practicable to include estuary within open coast SMP are:

- Where the estuary is sufficiently large to necessitate consideration of its process and management policies outside of the open coast SMP.
- Where the estuarine management issues are too complex or diverse to consider within the open coast SMP.

Estuary Guidance Table 7. Assessment of Extent of Estuarine Inclusion in SMP Process

This table assists the user in determining how an estuary should be included in the SMP process.



* It may be necessary to consider an estuary to the tidal limit where there is potential for large-scale change in tidal prism or the estuary is morphologically dynamic (i.e. high natural variability).

F.6 Summary

First generation Shoreline Management Plans exhibited an inconsistent approach to the inclusion of estuaries within the strategic flood and coastal management framework. This led to some estuaries being fully included in the approach (through the development of their own estuary Shoreline Management Plans or through their inclusion in the relevant open coast SMP), some estuaries being partly included (e.g. from the mouth to the limit of the Schedule IV boundary) and many estuaries being excluded. The purpose of this Appendix is to provide guidance that enables the assessment of whether, and how, an estuary should be included in the SMP process.

This guidance enables the scale of water and sediment exchanges between the open coast and estuary, and the scale of management issues to be identified. This approach makes best use of the data and information that has been presented in the *Futurecoast* study, supplemented where appropriate by more detailed estuary-specific knowledge. The guidance provided then enables a decision to be made about whether or not an estuary should be included in the SMP process, based upon the significance of these exchanges and issues. Further guidance is then provided on how the estuary should be included (i.e. through its own eSMP or through inclusion in the relevant open coast SMP) and how far the estuary should be included (i.e. definition of an appropriate limit). The overriding aim of the guidance is to assist the end-user in enabling decisions to made using <u>informed professional judgement</u>, rather than being fully prescriptive guidance.

Given the generic nature of the guidance, it is not considered possible to precisely define the limit of inclusion of the estuary without the availability of more detailed knowledge of the processes and management issues specific to a particular estuary. It is therefore suggested that this information needs to be fed into a local knowledge-based decision of how far an estuary should be included, rather than determined through the application of generic national guidance. The guidance has been applied to a number of trial estuaries to exemplify how it operates (Annex F3).

Annex F1: Review of estuary types, influences and decision-support tools

Estuary Types

A number of previous estuary classification systems have been developed and presented in the scientific literature. These generally have been biased towards one particular aspect (i.e. geomorphology, hydrography, salinity, sedimentology, or ecosystems). A small number of examples of these are summarised in Table F1-1.

Table F1-1 Examples of existing estuary classification schemes

Focus	Author	Date	Description
Geomorphology and physiography	Pritchard	1967	Drowned river valleys (coastal plain estuaries) Lagoon type bar-built estuary Fjord Tectonically-produced
Hydrography	Pritchard	1955	Salt-wedge estuary, highly stratified Partially-mixed estuary, moderately stratified Vertically homogeneous estuary, with lateral salinity gradient Sectionally homogeneous estuary, with longitudinal salinity gradient
Tidal characteristics	Hayes	1975	Micro-tidal (tidal range of 0-2m, sediments of tidal and river deltas) Meso-tidal (tidal range of 2-4m, sediments deposited largely by tidal currents) Macro-tidal (tidal range of >4m, completely tidally-dominated)
Sedimentation	Rusnak	1967	Positive filled (entirely filled with river sediment) Inverse filled (filled by marine sediments by the flood tide) Neutral filled (in equilibrium with no basin volume change)
Ecosystem energetics	Odum & Copeland	1974	Natural stressed systems of wide latitudinal range Natural tropical ecosystems of high diversity Natural temperate ecosystems with seasonal programming Natural Arctic ecosystems with ice stresses Emerging new systems associated with man Migrating sub-systems that organise areas.

As can be seen from this Table, most of these classifications are of limited value to this study since they are either too general or require detailed field measurements (e.g. of salinity profiles). Hume and Herdendorf (1988) developed a more comprehensive classification scheme for estuaries, reflecting their origin and the dominant hydraulic, sedimentological and ecological processes operating. The purpose of this system was to aid recognition of different estuary types, thereby simplifying their description and enabling the transfer of knowledge between estuaries of the same type. The classification scheme led to the grouping of estuaries in New Zealand on a regional basis, using geological and topographic mapping data, complemented by aerial photographs and site visits.

Initially, Hume and Herdendorf (1988) grouped estuaries into five classes based on the primary process that shaped the basin, before it was modified by sedimentary processes associated with the Holocene. These classes are:

- **Fluvial erosion**. These are estuaries where the depositional basin was originally cut by river action, commonly when sea level was lower than present. The landform has since been drowned by a rise in sea level, and modified by sediment deposition of both fluvial and marine origin.
- **Marine erosion**: These are small coastal embayments that have been shaped by a combination of stream erosion, wave attack and sub-aerial weathering. They have small catchments and very little fluvial input.
- **Tectonics**: These are flooded basins of tectonic original, for example fault-defined basins.
- **Volcanics**: These are drowned explosion craters that have been breached by the sea and partially infilled with sediment.
- **Glacial activity**: These are represented by fjords and are elongate, with steep parallel shores.

Within these 5 classes, there was a further sub-division of 16 specific types, based on the geomorphic and oceanographic characteristics of the estuary, as described in Table F1-2.

Table F1-2 Hume and Herdendorf Classification Scheme (after: Humbe and Herdendorf, 1988)

Mode of Basin Origin	Estuary Type	Description
Fluvial erosion	1 – Funnel-shaped	Simple or branched drowned-valley systems with funnel-shaped inlets. No barrier features or deltas at inlets. Low wave energy shores. Little fluvial sediment. Well-mixed.
	2 – Headland enclosed	Inlets constricted by rock headlands, with a deep throat maintained by strong currents. Inside of mouth constriction, the estuary widens significantly.
	3 – Barrier enclosed (double spit)	Drowned river valleys and embayments whose inlet is formed by spit, tombolo, island or beach landforms. These barriers are formed from sediment transported onshore and/or by littoral drift. Tidally-dominated and well mixed. Typically wide inter-tidal areas.
	4 – Barrier enclosed (single spit)	
	5 – Barrier enclosed (tombolo)	
	6 - Barrier enclosed (island)	
	7 - Barrier enclosed (beach)	
	8 – River mouth (straight-banked)	River dominated hydrology and large fluvial input.
Fluvial erosion	9 – River mouth (spit lagoon #1)	
	10 – River mouth (spit lagoon #2)	
	11 – River mouth (deltaic)	
Marine erosion	12 – Coastal embayment	Small coastal embayments that have been shaped by a combination of stream erosion, wave attack and sub-aerial weathering. Small catchments and very little fluvial input.
Marine erosion or Tectonics	13 – Fault-defined embayment	These are flooded basins of tectonic original.
Tectonics	14 – Diastrophic embayment	
Volcanics	15 – Volcanic embayment	Drowned explosion craters that have been breached by the sea and partially infilled with sediment.
Glacial activity	16 – Glacial embayment	Elongate, with steep parallel shores.

A similar classification scheme was used by Dyer during the *Futurecoast* study (Halcrow, 2002). This was a modified version of the system developed by Hume and Herdendorf (1988), extended to incorporate a qualitative assessment of important processes and geomorphological features. It was principally focused on simple dimensional relationships, since there is a general paucity of basic data on water flow and salinity characteristics. Dyer's classification is listed in Table F1-3 and described in more detail in Box F1-1.

Table F1-3 Dyer's *Futurecoast* classification system

<table>
<tr><th>Origin</th><th>Type</th><th>Sub-type</th></tr>
<tr><td rowspan="4">Glaciated valley</td><td rowspan="2">Fjord (1)</td><td>With spits (1a)</td></tr>
<tr><td>No spits (1b)</td></tr>
<tr><td rowspan="2">Fjard (2)</td><td>With spits (2a)</td></tr>
<tr><td>No spits (2b)</td></tr>
<tr><td rowspan="7">Drowned river valley</td><td rowspan="2">Ria (3)</td><td>With spits (3a)</td></tr>
<tr><td>No spits (3b)</td></tr>
<tr><td rowspan="3">Spit-enclosed (4)</td><td>Single spit (4a)</td></tr>
<tr><td>Double spit (4b)</td></tr>
<tr><td>Filled valley (4c)</td></tr>
<tr><td>Funnel-shaped (5)</td><td>-</td></tr>
<tr><td>Embayment (6)</td><td>-</td></tr>
<tr><td rowspan="2">Drowned coastal plain</td><td rowspan="2">Tidal inlet (7)</td><td>Symmetrical (7a)</td></tr>
<tr><td>Asymmetrical (7b)</td></tr>
</table>

Dyer applied this classification system to the ninety-six estuaries around England and Wales during the *Futurecoast* study (Halcrow, 2002). Table F1-4 shows specifically which estuaries fall into which class.

Box F1-1 - Description of Dyer's Different Estuary Types (source: Halcrow, 2002)

Fjords and fjards are present in glaciated areas, the former created in more resistant rock than the latter. Both are likely to have small, but seasonally very variable river flow. Fjords (Type 1) often have mouths that have been overdeepened, and despite a rock sill at their mouths, normally do not have sufficient coastal erosion to provide enough sediment to create spits. Fjards (Type 2), on the other hand, tend to be shallower and more likely to support spits.

Drowned river valleys are defined in periglacial areas, where the original valley was produced by fluvial processes. Rias (Type 3) are present in hard rock. They have steep relief, often with much exposed rock. They have other characteristics of river valleys, with a meandering form, a triangular cross-sectional shape and deep areas on the bends.

Other drowned river valleys occur where the rocks are in general relatively soft. Therefore the relief is subdued, and cliffs are of small vertical extent. Spit enclosed types (Type 4) have distinctive spits restricting their mouths. These tend to limit high tidal velocities to the mouths, and wave action within the estuary is relatively small. At low water salinity in the estuary can be very low. Double spits occur in situations where there are coastal sources of sediment on both sides of the mouth, and the wave climate produces significant littoral drift in both directions, converging at the estuary mouth. Single spits occur when there is one predominant direction of littoral drift. In this case the growth of the spit can be terminated by hard rock outcrops and a small cliff. A feature of spit enclosed estuaries are large flood and ebb deltas. When there has been sufficient sedimentation to fill the estuary, there is no low water channel and the water surface forms a continuation of the river, with the flood current starting well after low water on the adjacent coast.

Funnel shaped estuaries (Type 5) are a distinctive group which may be close to the classical definition of equilibrium form, where the cross-sectional area of the mouth is related to the active tidal volume (tidal prism) of the estuary. They do not possess spits, which implies strong tidal motion and relatively weak sources for littoral drift. One distinctive feature of this type is elongated linear sandbanks within the estuary mouth that are aligned with the current flow direction. However, because of the regular expansion at the mouth, it is difficult to define the mouth as anything other than a zone in which there is interaction with the sea and complicated sediment circulation patterns.

Embayments (Type 6) often form where several rivers converge, with their joint valleys creating a wide mouth area open to large wave and weather effects. They have large inter-tidal areas, and the salinity is high throughout the embayment over high water.

Inlets (Type 7) are produced where the sea level rise has occurred over an extremely low relief coastal plain. These are characterised by narrow mouth areas backed by extensive tidal lagoons, and barrier beaches. They have many similarities to spit enclosed types, except that the backing lagoons are large enough for weather effects to be significant. Symmetrical and asymmetrical types mirror the double and single spit enclosed drowned river valleys. Davis and Hayes (1984) have categorised inlets in terms of the ambient tidal range and wave conditions. This illustrates that there can be a wide temporal range of different relative strengths of the two dominant processes. However, most inlets average mainly tide or wave-dominated mixed energy types. It is assumed here that the former creates symmetrical inlets and the latter, asymmetric. In the symmetric type the inlet channel is directed almost straight out to sea, with spits that are approximately aligned with each other. Sand bypassing is then by migration of shoals, outer channel shifting or deflection of the littoral sand transport (Fitzgerald et al, 2001). These are likely to be tide-dominated mixed energy inlets. The asymmetric inlets have spits that overlap such that the channel is oblique to the coastline. They are characterised by more frequent channel shifts, and are likely to be more wave-dominated. The sand bypassing mechanisms are then by breaching of the spit or ebb tidal delta.

Table F1-4 Dyer's Classification of Estuaries in England and Wales

Fjard		Ria		Spit-enclosed			Funnel	Embayment	Tidal inlet	
2a	**2b**	**3a**	**3b**	**4a**	**4b**	**4c**	**5**	**6**	**7a**	**7b**
Pwllheli	Alaw	Wear	Tweed	Coquet	Aln	Cuckmere	Thames	Wash	Pagham H.	Foryd Bay
		Christchurch	Tyne	Wansbeck	Tees	Wootton	Ribble		Chichester H.	Traeth Melynog
		Aberystwyth	Esk	Blyth	Deben	Newtown	Solway		Langstone H.	
		Dovey	Medina	Humber	Hamford Water	Yar			Portsmouth H.	
		Mawddach	Dart	Yare	Colne	Lymington			Afan	
		Glaslyn	Kingsbridge	Waveney	Rother				Artro	
		Traeth Dulas	Avon	Blyth	Bembridge	Axe				
		Conwy	Erme	Ore/Alde	Poole	Otter				
			Yealm	Harwich	West Bay	Parrett				
			Plymouth	Blackwater	Hayle	Neath				
			Looe	Crouch	Taw-Torridge	Tawe				
			Fowey	Medway	Lougher	Nyfer				
			Falmouth	Swale	Carmarthen	Teifi				
			Helford	Stour/Pegwell	Clwyd					
			Gannel	Ouse	Morecambe					
			Camel	Adur	Duddon					
			Severn	Arun	Esk					
			Milford Haven	So'ton Water						
			Cefni	Beaulieu						
			Mersey	Weymouth						
				Exe						
				Teign						
				Ogmore						
				Dysynni						
				Dee						

Estuary Influences

Although a review of different estuary types is an interesting and necessary task to meet one of the specific objectives of this study, it alone has not provided information relating to the 'influence' of different estuary types on the coast (and *vice versa*). Indeed, there is a general absence of such information from the scientific literature, suggesting that classification of different types is a relatively academic exercise. Hume and Herdendorf (1988) present one of the few examples where a more applied approach has been adopted, suggesting that estuaries of different types exhibited different levels of stability to certain factors, as described in Table F1-5.

Table F1-5 Hume & Herdendorf's characterisation of different estuary types

Factor	Magnitude	Estuary Types
Channel stability	Low	Funnel-shaped estuary Headland enclosed estuary Barrier enclosed estuaries (all types) River mouth estuaries (all types except straight banked) Coastal embayment
	High	River mouth – Straight banked Tectonic Volcanic Glacial activity
Inlet stability	Low	Funnel-shaped estuary Barrier enclosed estuaries (all types) River mouth estuaries (all types except straight banked) Coastal embayment
	High	Headland enclosed estuary River mouth – Straight banked Tectonic Volcanic Glacial activity
Sediment infilling	Moderate	Funnel-shaped estuary Headland enclosed estuary River mouth – spit lagoon Fault-defined embayment Volcanic embayment
	High	Barrier-enclosed estuaries River mouth –Spit lagoon River mouth –Deltaic

As has previously been seen from Box F1-1, the information presented in the *Futurecoast* study relating to Dyer's classification system (Halcrow, 2002) describes the typical characteristics of different estuary types around England and Wales, focusing to a large extent on mode of origin. However, the information available in this classification system does not provide detail on the degree of influence of each estuary type with the open coast, or information to assist with assessments of the extent to which different estuaries should be included in the SMP process.

In addressing the issue of ‘degree of influence’, Dyer suggested that there are two principal interactions that need consideration (Halcrow, 2002):

- Estuaries can be a source of, or a sink for sediment, either contributing river- or estuarine-derived sediment to the coastal sediment budget, or removing coastal sediment and trapping it within the estuary.
- During periods of river spate, the hydraulic forcing of the river flow can act as an effective means of transferring nearshore sediment further offshore, normal to the coastline.

In relation to the above issues, Dyer (Halcrow, 2002) suggested that generally, highly stratified, short and ebb-dominated estuaries are likely to be sources of riverine sediment to the coast. Conversely, partially mixed, longer and flood dominated estuaries are likely to be sinks for coastal sediment. The former are likely to be dominated by river flow, whilst the latter are likely to be dominated by tidal motion. Further general relationships suggested by Dyer are simplified in Figure F1-1.

In addition to the typical influences of estuaries on the open coast described above, it should be remembered that it is the mouth of the estuary and its sub-tidal and inter-tidal morphology that are the key regulators of hydraulic processes within the estuary. Should these factors be altered through either anthropogenic (e.g. reclamation or re-alignment, barrages, etc.) or natural factors (e.g. mouth widening to accommodate sea level rise, ‘squeeze’ of inter-tidal areas against rising ground, etc.) then the estuary processes will alter, possibly also leading to alteration of the influences of the estuary upon the open coast.

Additionally, an estuary, whilst possessing identifiable components and identifiable processes, functions as a complex integral whole which can influence, and can be influenced by, the open coastal processes and management (MAFF, 1998). This means that management intervention along a particular section of open coast can influence the processes within an estuary or at its mouth. Conversely, management intervention within one section of an estuary can potentially not only influence the entire estuary system, but also the adjacent open coast. Some examples of these interactions are described further in Box F1-2.

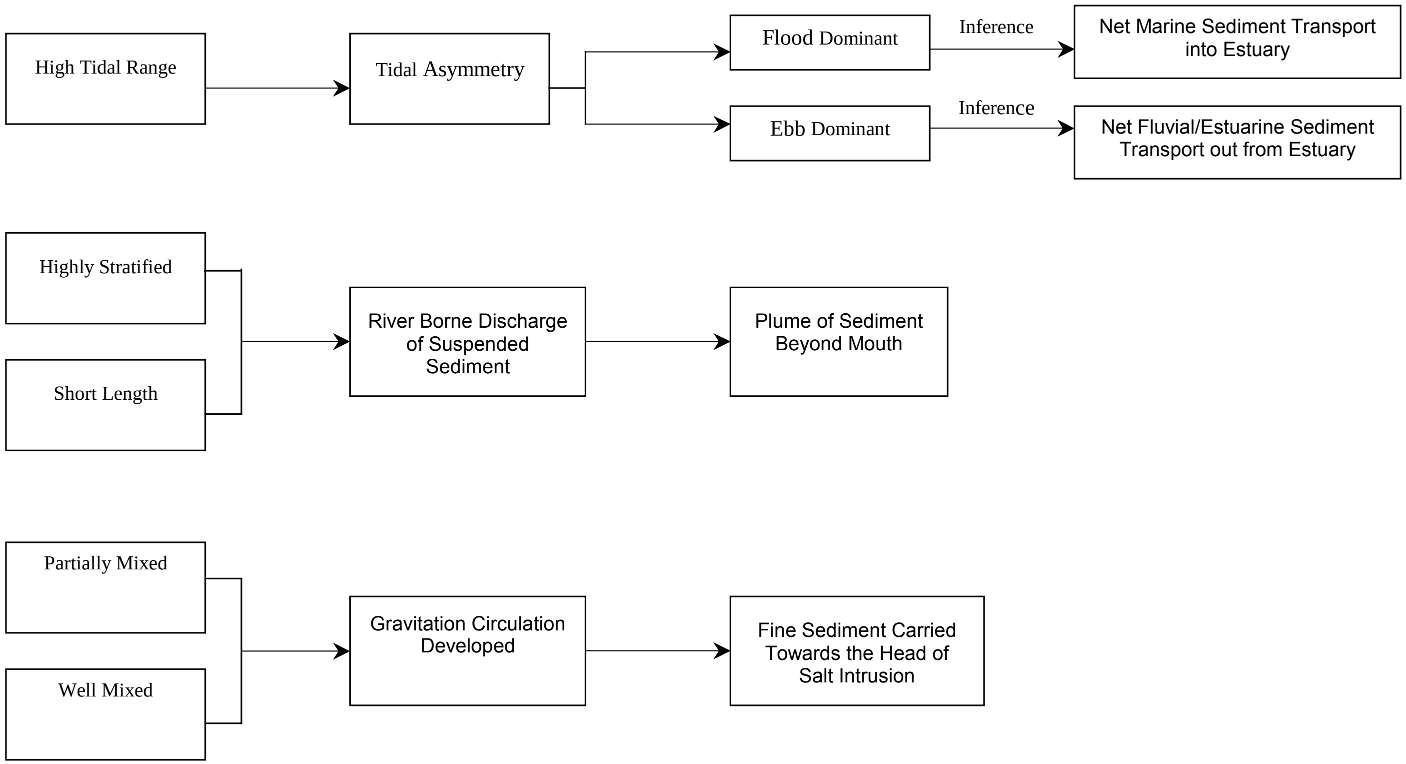


Figure F1-1 Simplified relationships suggested by Dyer (after Halcrow, 2002)

Box F1-2 - Potential interactions between estuaries and the open coast

The open coast can provide sediment to the estuary or its mouth through processes of shoreline erosion from a near or remote ‘updrift’ source and subsequent longshore transport of sediment to the estuary. The volume of sediment erosion or transport (and hence input to the estuary) can vary according to different management practices along the open coast. For example, seawalls can reduce or stop the erosion of soft cliffs and as a consequence reduce the volume of sediment reaching the estuary. It is important to note that an estuary can be an important sink for both cohesive and non-cohesive marine sediment transported from the coast.

The flow of water through an estuary mouth can partially or fully block the longshore transport of coastal sediments across the mouth of the estuary, enabling sediment to accrete in spits. Periods of particularly high river spate can push sediment drifting along the shoreline further offshore as a plume from the estuary mouth. Such sediment may then be lost from the littoral system rather than returning to the shoreline.

In many estuaries, the transport of sediments across the estuary mouth is achieved through a more complex transport pathway. Sediment can pass into the estuary where it is temporarily stored within flood tide deltas before being transported back out of the estuary to reach the ‘downdrift’ shoreline of the open coast.

Changes to the tidal prism of an estuary, caused for example by a significant change in management practice (reclamation would reduce, and re-alignment would increase the tidal prism of the estuary), can alter tidal asymmetry and/or flow velocities of the estuary. This could potentially lead to changes in existing erosion/deposition patterns and/or to changes in present net tendencies for sediment to either enter or leave an estuary (e.g. if the tide becomes more ebb-dominated due to the management intervention, then estuarine sediments may be more likely to be transported out of the estuary to the open coast).

Ebb tidal deltas form at the mouths of many estuaries and their associated sand bars provide important natural coastal defence features to both the estuary mouth and the adjacent open coasts. The size of the delta depends on the tidal prism of the estuary and consequently the degree of natural protection can change as the prism changes through differing estuary management techniques.

Predictive models used in the EMPHASYS programme indicate that sea level rise will result in the progressive landward migration (‘roll-over’) of the entire morphological form in many estuaries. This process is achieved through erosion of the outer estuary (often located within the Schedule IV boundary) and deposition of eroded sediments towards the head of the estuary (often beyond the Schedule IV boundary). In order to fully incorporate such interactions, the entire estuary needs to be considered as a whole, not just a short length at or close to the estuary mouth.

As existing sediment cell and sub-cell boundaries were defined according to non-cohesive sediment transport processes, many estuaries around England and Wales have been used as an existing SMP boundary (e.g. Humber, Wash, Thames, Solway). This means that often some highly important processes and interactions between either bank of the estuary and/or between the estuary and the open coast may not have been dealt with in a consistent and 'strategic' manner in the first generation of SMPs. The next generation will, if appropriate, consider such issues more comprehensively.

Decision-Support Tools

A range of tools exists to assist in identification of the nature and extent of influence between an estuary and the open coast. These are outlined below:

(a) Desk-based

Reviews of scientific and professional literature and analysis of existing field measurements can be undertaken to develop a 'conceptual understanding' of the process and morphological linkages between the open coast and an estuary (and indeed those operating within an estuary). This can involve identifying:

- sediment linkages (e.g. sources from the open coast and within the estuary, stores at the estuary mouth, and sinks within both the inter-tidal and sub-tidal areas of the estuaries); and
- hydrodynamic linkages (e.g. tidal prism, flows and water levels, extent and magnitude of wave influence, etc.).

Such approaches are relatively cost-effective and quick to undertake, but are dependent upon the quality and availability of existing literature sources.

Various empirical and theoretical relationships can be applied to the estuary parameters to determine the present 'condition' of an estuary relative to a theoretical goal, and its role as a source or sink of sediment. These approaches require certain parameters of an estuary to be defined and available, but are useful in identifying the general role that the estuary plays in influencing, or being influenced by, the open coast.

(b) Field-based

Direct measurements can be undertaken to capture information relating to flow velocities, water levels, wave heights, suspended sediment concentrations, sediment transport and erosion/accretion rates. Such information can then be interpreted to assist in identifying the extent of influence (e.g. coastal sediments may be entering the estuary to be deposited on the inter-tidal areas, may be stored in deltas at its mouth, or alternatively may bypass the estuary mouth or be flushed offshore by river spates). The disadvantage of this approach is that the natural system is highly variable and the measurements taken may not be representative of ‘normal’ or ‘extreme’ conditions. Furthermore, gaining a sufficient spatial spread of measurements over an appropriate time period to characterise key interactions would be both difficult and cost-prohibitive. Consequently, field-based studies may be undertaken in specific locations to address issues, data gaps or uncertainties that have been identified following a broader-level desk-based approach.

(c) Numerical Model-based

Numerical modelling of tidal flows, waves, sediment transport pathways and morphological change can be undertaken to characterise the existing regimes and determine the extent to which open coast and estuarine systems interact through water and sediment exchanges. The disadvantages of this approach are the cost, timescale and input data requirements, and the fact that such models can only characterise the short- to medium-term process and morphological changes. The advantages, however, are that once set-up, a numerical model can investigate the relative effects of changes in particular processes or morphological conditions on the entire coastal-estuarine system for particular developments or ‘what-if’ scenarios.

Further detail concerning the applicability, data requirements, advantages and limitations of various approaches to assessing estuary morphology and processes was presented in the reports from Phase I of the MAFF-funded Estuaries Research Programme (sometimes known as EMPHASYS – Estuary Morphology and Processes Holistic Assessment System) (EMPHASYS Consortium, 2000).

Empirical and Theoretical Relationships

Estuaries world-wide appear to exhibit some consistent relationships between several of the properties that reflect their size and shape (Townend *et al*, 2000). A number of tools exist to explore the relationships between various parameters. Many of these tools were used during the EMPHASYS project and are briefly summarised in this section.

O’Brien ratio

The empirical relationship proposed by O’Brien (1931) is between the spring tidal prism (the volume of water that enters and leaves the estuary during a tide) and the cross-sectional area of the entrance at mean tide level. It is an empirically-derived measure of inlet stability and takes the following form:

$$A = C\,\Omega^n$$

Where:

A = cross-sectional area of estuary mouth at mean tide level (m^2);

Ω = tidal prism (m^3);

C and n = empirical coefficients.

The mean tidal prism can be calculated by subtracting the volume of water in the estuary at mean low water from the volume of water at mean high water.

Application of the relationship demonstrates commonalities for a large number of estuaries, and based upon such empirical findings from a ‘group’ of estuaries (e.g. perhaps in different geographical regions, or of different estuarine types) it can be used to determine whether the mouth of any particular estuary or its tidal prism are too small or too large compared to the theoretical value.

A study was undertaken as part of the EMPHASYS project to explore the O’Brien relationships for UK estuaries. A full listing of results is presented in ABP Research Report R.900 (ABP Research, 2000) and a summary is presented below.

When tidal prism data were plotted against cross-sectional area data for UK estuaries alongside corresponding US, New Zealand and Dutch estuary data, it was apparent that a high degree of scatter and a wide range of scales were observed within the UK data. This reflects a diverse range of estuary systems around the UK coast. A weak sub-division of estuary types was observed, enabling two regional groups to be identified, namely: (i) South-West and South-East Coasts; and (ii) West (including Wales) and East Coasts. The O’Brien relationships for these two groups are:

SW and SE $A = 0.051\ P^{0.68} r^2 = 0.75$

W and E $A = 0.003\ P^{0.82} r^2 = 0.78$

Due to the different data sources and data quality used in the assessment, it was recommended that these regression fits be used with great caution.

Further investigation was undertaken to determine whether different O’Brien relationships existed for different estuary types (as classified by Davidson *et al*, 1991). It appeared that a division could be made between different estuaries using the classification in Table F1-6.

From the results, it was concluded that Group 2 of the UK data appears to conform to the type of estuary system that has only limited sedimentary influence at the mouth and it is suggested that these estuaries are in an early stage of Holocene development. The complex estuaries that fall into this category were identified to be either deep and wide near the mouth or long narrow channels with little or no inter-tidal. The key attributes of the coastal plain estuaries included in this group is their sheltered location in the Solent. Group 3 is thought to comprise estuaries that have experienced a degree of in-filling with Holocene sediments. Further assessments undertaken during the study revealed no particular influence of isostatic land movement or tidal range on the relationships that existed.

Table F1-6 Grouping of estuaries based on O'Brien Rule

Group	Type	O'Brien Relationship for UK Estuaries
1	Fjords and fjards	N/A
2	Rias, coastal plain estuaries of the Solent, and selected complex estuaries	$A = 0.0305\ P^{0.747}$
3	All other coastal plain and complex estuaries	$A = 0.0004\ P^{0.911}$
4	Bar-built estuaries	$A = 0.0060\ P^{0.783}$

Dronkers' asymmetry ratio

The relative strengths and durations of the flood and ebb tides within an estuary can cause an asymmetry in the tidal curve which influences the net import or export of sediment. Dronkers derived a ratio (γ) for determining the relative flood or ebb dominance of an estuary (Dronkers, 1998).

$$\gamma = \left(\frac{h+a}{h-a}\right)^2 \cdot \frac{S_{lw}}{S_{hw}}$$

Where:

h = mean hydraulic depth of estuary: $h = a + (v_{lw} / s_{lw})$;

a = tidal amplitude of offshore M_2 tidal constituent;

s_{lw} = low water surface area;

s_{hw} = high water surface area;

v_{lw} = low water volume.

Empirical evidence suggests flood dominance occurs when $\gamma > 1$ and ebb dominance when $\gamma < 1$. If $\gamma = 1$, the tidal propagation is symmetrical.

Dronkers showed that if the high water slack period is more protracted than that at low water, then more sediment will be deposited on the upper mudflats at high water than on the lower mudflats at low water. This produces a net landward movement of sediment within the estuary. Conversely, a longer low water slack will lead to the seaward movement of sediment.

Renger relationships

The Renger relationships (Renger & Partensky, 1974) characterise an estuary in area and volume terms.

Area ratio: $s_{lw} / (s_{hw}^{1.5}) = 2.5 \times 10^{-5}$

Volume ratio: $v_{lw} / (s_{hw}^{2}) = 8 \times 10^{-9}$

If the calculated ratios for a particular estuary exceed the theoretical thresholds for both of these equations, then the system is considered to be flood dominant. Similarly, if the calculated values are less than both of the theoretical thresholds, the system is considered to be ebb dominant.

Slack duration

Tidal curves can be complex, particularly around the time of slack water. As a consequence, the gradient of slack water is not always representative of the slack duration. An alternative approach is therefore required to determine the duration of time when the flow is below a certain threshold, known as v_{slack}. Taking the difference in time between high and low water threshold exceedence values provides a measure for the asymmetry for the movement of fine sediments, with positive values indicating flood dominance and negative values indicating ebb dominance. Commonly, the thresholds used for v_{slack} are related to the thresholds of transport and deposition of the particular sediment type in the estuary.

Tidal excursion

Peak velocities on the flood and ebb tides are often used as a first indicator of the preferred direction of movement of coarse-grained sediments. However, this indicator can only be applied through inference since water movements do not necessarily coincide with sediment movements: the latter also depends on the availability of sediment of suitable size grains. Additionally, this measure takes no account of the duration of such peak velocities. Indeed, it is quite often common for a slightly lower velocity on one stage of the tidal curve to prevail for a much longer period than the slightly higher peak value on the opposing stage. In order to obtain a more representative indicator of the direction of preferential transport of coarser sediment, it is possible to calculate the tidal excursion. This can be achieved by calculating the difference in areas under the curve for the flood and ebb velocities, taking into consideration an appropriate threshold velocity, $v_{threshold}$. A positive value indicates flood dominance, and a negative value indicates ebb dominance.

Numerical Modelling

The above approaches all provide useful information to enable the grouping of a range of estuaries into classes that exhibit similar empirical relationships and assessment of the relative flood or ebb dominance of particular estuaries, and hence determination of their tendency for preferential import or export of sediment. However, in order to provide a more detailed understanding of the spatial extent of estuarine-open coast interactions and influences and how these may vary through time (e.g. tidal cycle) more detailed numerical modelling approaches may be required.

These can be adopted to characterise:

- Tidal levels at different locations in the estuary / along the open coast at various stages of the tidal cycle;
- Corresponding flow velocities (speed and direction) and bed shear stresses to determine the tendency for material transport, deposition or erosion;
- Preferential transport directions of sediments (although different techniques are required for suspended-load and bed-load transport);
- Extent of wave propagation into the estuary and, in wide or long estuaries, the generation of wind-waves within the estuary.

It is unreasonable to expect that such detail will be required to assess the coast-estuary interactions in all estuaries. However, it may be appropriate for those where the scale of interactions is anticipated to be of major significance, or has not previously been quantified.

Annex F2: Analysis of *Futurecoast* database of estuary parameters

In order to determine a means for assessing the potential inclusion of estuaries within the SMP process, it would ideally be beneficial to utilise a nationally consistent database of estuarine parameters. As the *Futurecoast* study has produced such a database, the information contained within it was reviewed in this section as a pre-cursor to developing guidance. Although it has subsequently been found that this information alone is often insufficient to make robust assessments concerning the inclusion, or otherwise, of a particular estuary, and hence additional local knowledge is required, the *Futurecoast* data provides an extremely useful starting point for assessments.

Type and Scale of Interactions

To some extent, all estuaries will have an influence on the open coast and in turn may be influenced by the open coast. However, the scale and type of influence will differ from estuary to estuary. For example, it may range from one extreme of a very small discharge of freshwater flow into a wide coastal embayment, to the other extreme of a major supply of sediment to the coastal system, with significant delta and spit formations at the estuary mouth offering protection to the adjacent shoreline over several kilometres.

Estuary Type

As an initial investigation, each of the estuary types classified by Dyer in the *Futurecoast* study (Halcrow, 2002) was considered as a possible starting point for discrimination of different scales and types of influence. It was envisaged that some types of estuary might be identified as having ‘small’ interactions, others ‘moderate’ and others ‘major’. However, this approach has had only partial success and has revealed that classification of the main type of a particular estuary (e.g. fjard, ria, spit-enclosed, funnel, embayment, tidal inlet) <u>alone</u> is not particularly revealing in terms of determining estuarine interactions with the open coast. For example, the River Humber estuary is classified as a ‘spit-enclosed estuary with a single spit’. It is quite evident that this estuary has a major influence on the open coast in terms of both water and sediment exchanges. The River Arun estuary is also classified as a ‘spit-enclosed estuary with a single spit’, but has a considerably smaller scale of interaction with the open coast. This finding suggests two factors:

- It is more useful in terms of identifying interactions and influences to note the particular sub-type of estuary, rather than main type. This generally reveals whether or not a particular estuary possesses spits and hence leads to the identification of an interaction between the longshore transport processes along the coast and the movement of water into and out of the estuary mouth.

- The scale of interaction depends to a large extent on factors other than estuary type. In particular, the physical size and shape of the estuary (i.e. its morphology), the underlying geology and sediment characteristics, the relative magnitude of the processes that operate, and the scale and nature of management intervention are considered to be the dominant parameters in determining type and scale of influence.

Due to the above findings, it is considered that a staged approach should be adopted to provide a mechanism that will enable the identification of different 'degrees of influence' (i.e. none, low, moderate, high, extensive or insignificant, marginal, significant) between the estuary and the open coast. This staged approach considers physical size, processes and management of the estuary. The investigations draw upon the database of different estuary parameters that was generated during the *Futurecoast* study. It should be noted, however, that where the *Futurecoast* database provided a largely incomplete set of information (e.g. in relation to 'stratification number' or peak velocities), these parameters have been omitted from this investigation.

Physical Size

From the *Futurecoast* database, physical size was represented by the following factors (these have been defined in *Futurecoast* report 'Estuarine Methodology'):

- Total area (ha);
- Inter-tidal area (ha);
- Salt marsh area (ha);
- Shoreline length (km);
- Channel length (km);
- Mouth area (m^2);
- Mouth width (m);
- Valley width (m).

The following relationships were also used:

- Percentage area (ratio of inter-tidal area to total area).

Using information presented in the *Futurecoast* study (Halcrow, 2002), the estuaries were ranked in order of magnitude for each of the above parameters.

Figure F2-1 presents the ranking of estuaries by total area. For those estuaries with a large total area, it is anticipated that there might be a significant degree of influence between the estuary and the open coast, and for those with a small total area, a smaller degree of influence.

From Figure F2-1 it can be seen that the Wash, Humber, Severn, Solway and Morecambe Bay all have ‘extremely large’ total areas, with the Thames, Mersey, Ribble, Dee, Harwich (Stour/Orwell), Medway and Loughar all having ‘large’ total areas. Identifying a distinct boundary between ‘large’ and ‘medium’ estuaries from this figure is difficult, but a ‘medium to large’ grouping of Milford Haven, Blackwater, Duddon, Southampton Water, Plymouth, Poole Harbour, Carmarthen, Swale, Crouch/Roach, Alde/Ore, Chichester Harbour, Hamford Water is evident. This is followed by a ‘medium’ grouping of Falmouth, Tees, Langstone Harbour, Exe, Taw-Torridge, Colne, Portsmouth Harbour, Glaslyn, Yare, Tyne, Deben, Dovey and Alaw. The remaining estuaries can be grouped as ‘small to medium’ (East Anglian Blyth to Kingsbridge), ‘small’ (Helford to Pagham Harbour) and ‘very small’ (Christchurch Harbour to West Bay).

Total estuary area alone, however, is not an accurate indicator of the degree of influence on the open coast. An estuary that has a large total area, but a small tidal range may, theoretically, have less interchange with the coast than a smaller estuary with a significantly larger tidal range. Although tidal range is investigated later, the degree of influence can be inferred from Figure F2-2, showing the ranking of estuaries in terms of the inter-tidal area. The assumption used is that the larger the inter-tidal area, the greater the tidal prism and hence the larger the exchange of water between the estuary and the open coast and hence the greater the degree of influence. Figure F2-2 reveals a similar pattern to Figure F2-1, with estuaries from around England and Wales clearly possessing a very wide range of inter-tidal areas.

Similar rankings have been undertaken for the other physical size parameters and results are presented in Figures F2-3 to F2-9 and Table F2-1. From these results, it is evident that a small number of estuaries are of a sufficient physical size (as defined by large total area, inter-tidal area, shoreline and channel lengths, mouth cross-sectional area and width, valley width) to seemingly have a very significant effect on the open coast. These estuaries are (in no particular order):

- Wash;
- Humber;
- Severn;
- Solway;
- Morecambe Bay;
- Thames;
- Ribble;

- Dee;
- Mersey.

Other estuaries are clearly presently of an insufficient physical size (as defined by large total area, inter-tidal area, shoreline and channel lengths, mouth cross-sectional area and width, valley width) to seemingly have much of an influence on the coast (e.g. West Bay, Cuckmere, Arun, Aberystwyth). Indeed, many of these estuaries are so very strongly affected by coastal processes that they only remain estuaries by virtue of management intervention (e.g. training works) that prevent spits developing across the estuaries mouths and either diverting the river courses or completely blocking their flow into the sea. In this context, there is a strong coastal influence on these estuaries.

In between these extremes lie a large number of estuaries that are of ‘medium’ physical size and therefore seemingly of some influence on the open coast. With these estuaries it is necessary to look at process-related factors to further determine scale of influence.

Table F2-1 Ranking of estuaries according to physical size parameters

Rank	Total Area	Intertidal Area	Marsh	Shoreline	Channel Length	Cross-section Area	Mouth Width	Valley Width	% Area
1	Wash	Humber	Wash	Dee	Humber	Wash	Wash	Morecambe	Traeth Dulas
2	Humber	Morecambe	Morecambe	Humber	Severn	Severn	Morecambe	Solway	Tawe
3	Severn	Wash	Solway	Wash	Wash	Morecambe	Severn	Wash	Blyth EA
4	Solway	Solway	Loughor	Severn	Thames	Solway	Solway	Poole	Neath
5	Morecambe	Severn	Ribble	Yare	Morecambe	Humber	Ribble	Severn	Deben
6	Thames	Thames	Dee	Neath	Yare	Dee	Dee	Colne	Aln
7	Mersey	Mersey	Humber	Morecambe	Solway	Thames	Humber	Carmarthen	Artro
8	Ribble	Ribble	Blackwater	Thames	Medway	Ribble	Alaw	Humber	Clwyd
9	Dee	Harwich	Chichester Harbour	Solway	Tees	Mersey	Duddon	Ore/Alde	Wootton Creek
10	Harwich	Medway	Severn	Plymouth	Arun	Plymouth	Swale	Dee	Tees
11	Medway	Loughor	Carmarthen	Milford Haven	Dee	Falmouth	Carmarthen	Parrett	Pagham Harbour
12	Loughor	Dee	Hamford	Crouch	Parrett	Duddon	Loughor	Portsmouth	Morecambe
13	Milford Haven	Duddon	Mersey	Medway	Milford Haven	Medway	Blackwater	Ribble	Rother
14	Blackwater	Carmarthen	Crouch	Falmouth	Stour-Pegwell	Blackwater	Chichester Harbour	Medway	Colne
15	Duddon	Blackwater	Medway	Tees	Plymouth	Loughor	Milford Haven	Rother	Carmarthen
16	Southampton	Hamford	Poole	Southampton	Tyne	Southampton	Thames	Duddon	Hayle
17	Plymouth	Swale	Colne	Ribble	Crouch	Carmarthen	Southampton	Loughor	Teifi
18	Poole	Crouch	Ore/Alde	Blackwater	Ribble	Harwich	Falmouth	Alaw	Parrett
19	Carmarthen	Chichester Harbour	Dovey	Mersey	Ore/Alde	Milford Haven	Harwich	Hamford	Wear
20	Swale	Ore/Alde	Duddon	Poole	Carmarthen	Kingsbridge	Traeth Melynog	Yare	Ribble

Rank	Total Area	Intertidal Area	Marsh	Shoreline	Channel Length	Cross-section Area	Mouth Width	Valley Width	% Area
21	Crouch	Poole	Parrett	Harwich	Loughor	Camel	Hamford	Blackwater	Newtown
22	Ore/Alde	Tees	Deben	Carmarthen	Blackwater	Dart	Mersey	Taw-Torridge	Duddon
23	Chichester Harbour	Plymouth	Harwich	Parrett	Conwy	Swale	Glaslyn	Stour-Pegwell	Blyth NE
24	Hamford	Milford Haven	Swale	Colne	Adur	Tyne	Colne	Adur	Hamford
25	Falmouth	Langstone Harbour	Milford Haven	Tyne	Ouse	Chichester Harbour	Medway	Esk	Yar
26	Tees	Colne	Plymouth	Chichester Harbour	Southampton	Gannel	Dovey	Arun	Traeth Melynog
27	Langstone Harbour	Southampton	Southampton	Arun	Waveney	Parrett	Tees	Swale	Foryd Bay
28	Exe	Taw-Torridge	Glaslyn	Stour-Pegwell	Harwich	Alaw	Crouch	Dovey	Esk
29	Taw-Torridge	Deben	Taw-Torridge	Swale	Duddon	Erme	Plymouth	Chichester Harbour	Bembridge
30	Colne	Glaslyn	Mawddach	Loughor	Dart	Taw-Torridge	Camel	Langstone Harbour	Cefni
31	Portsmouth	Exe	Beaulieu	Ore/Alde	Deben	Beaulieu	Erme	Harwich	Stour-Pegwell
32	Glaslyn	Portsmouth	Portsmouth	Dart	Dovey	Crouch	Taw-Torridge	Christchurch	Conwy
33	Yare	Blyth EA	Neath	Duddon	Taw-Torridge	Glaslyn	Beaulieu	Southampton	Chichester Harbour
34	Tyne	Tyne	Esk	Portsmouth	Swale	Portsmouth	Neath	Crouch	Lymington
35	Deben	Yare	Foryd Bay	Dovey	Falmouth	Fowey	Cefni	Newtown	Langstone Harbour
36	Dovey	Falmouth	Newtown	Deben	Wear	Hamford	Esk	Afan	Crouch
37	Alaw	Alaw	Cefni	Ouse	Poole	Bembridge	Gannel	Ouse	Swale
38	Blyth EA	Stour-Pegwell	Conwy	Kingsbridge	Colne	Langstone	Avon	Dysynni	Axe

Rank	Total Area	Intertidal Area	Marsh	Shoreline	Channel Length	Cross-section Area	Mouth Width	Valley Width	% Area
						Harbour			
39	Stour-Pegwell	Dovey	Langstone Harbour	Hamford	Exe	Esk	Helford	Tees	Harwich
40	Dart	Parrett	Stour-Pegwell	Conwy	Mersey	Colne	Foryd Bay	Traeth Melynog	Looe
41	Camel	Conwy	Falmouth	Adur	Camel	Mawddach	Kingsbridge	Tawe	Beaulieu
42	Conwy	Cefni	Blyth EA	Helford	Glaslyn	Dovey	Parrett	Glaslyn	Nyfer
43	Parrett	Camel	Exe	Langstone Harbour	Mawddach	Poole	Tweed	Mawddach	Ore/Alde
44	Cefni	Kingsbridge	Traeth Melynog	Camel	Cefni	Lymington	Lymington	Exe	Taw-Torridge
45	Kingsbridge	Beaulieu	Yar	Glaslyn	Fowey	Helford	Yealm	Milford Haven	Ogmore
46	Helford	Esk	Alaw	Esk	Portsmouth	eed	Nyfer	Cefni	Camel
47	Beaulieu	Wear	Rother	Exe	Blyth EA	Cefni	Medina	Thames	Medway
48	Mawddach	Blyth NE	Camel	Fowey	Alaw	Medina	Mawddach	Beaulieu	Pwllheli
49	Esk	Rother	Christchurch	Alaw	Beaulieu	Conwy	Stour-Pegwell	Falmouth	Humber
50	Yealm	Mawddach	Teifi	Mawddach	Teifi	Stour-Pegwell	Clwyd	Coquet	Gannel
51	Blyth NE	Traeth Melynog	Clwyd	Wear	Tweed	Deben	Exe	Pagham Harbour	Glaslyn
52	Wear	Dart	Tees	Yealm	Esk	Tees	Tyne	Foryd Bay	Loughor
53	Rother	Newtown	Axe	Tweed	Helford	Newtown	Aberystwyth	Mersey	Avon
54	Teign	Foryd Bay	Pagham Harbour	Cefni	Teign	Exe	Poole	Aberystwyth	Thames
55	Traeth Melynog	Pagham Harbour	Avon	Blyth EA	Cuckmere	Ore/Alde	Wootton Creek	Neath	Alaw
56	Foryd Bay	Teign	Dart	Rother	Kingsbridge	Wear	Fowey	Tyne	Kingsbridge
57	Newtown	Tawe	Aln	Blyth NE	Chichester Harbour	Yar	Dart	Plymouth	Solway

Rank	Total Area	Intertidal Area	Marsh	Shoreline	Channel Length	Cross-section Area	Mouth Width	Valley Width	% Area
58	Fowey	Lymington	Dysynni	Christchurch	Avon	Yealm	Portsmouth	Camel	Dovey
59	Pagham Harbour	Helford	Traeth Dulas	Teifi	Langstone Harbour	Traeth Dulas	Tawe	Erme	Esk
60	Christchurch	Clwyd	Erme	Teign	Yealm	Blyth NE	Bembridge	Nyfer	Mersey
61	Lymington	Bembridge	Gannel	Avon	Clwyd	Esk	Conwy	Clwyd	Mawddach
62	Bembridge	Teifi	Hayle	Medina	Medina	Wootton Creek	Wear	Bembridge	Tyne
63	Medina	Yealm	Otter	Erme	Neath	Avon	Deben	Deben	Portsmouth
64	Tawe	Fowey	Coquet	Cuckmere	Hamford	Weymouth	Langstone Harbour	Pwllheli	Coquet
65	Avon	Avon	Ogmore	Clwyd	Rother	Aberystwyth	Afan	Blyth EA	Teign
66	Teifi	Hayle	Teign	Coquet	Blyth NE	Rother	Hayle	Wear	Dysynni
67	Clwyd	Christchurch	Medina	Looe	Christchurch	Nyfer	Weymouth	Teign	Exe
68	Arun	Artro	Artro	Wansbeck	Erme	Neath	Teign	Blyth NE	Blackwater
69	Adur	Traeth Dulas	Nyfer	Hayle	Wansbeck	Teign	Adur	Teifi	Tweed
70	Hayle	Medina	Cuckmere	Tawe	Tawe	Aln	Pwllheli	Wansbeck	Poole
71	Erme	Yar	Adur	Traeth Melynog	Traeth Melynog	Yare	Ore/Alde	Ogmore	Otter
72	Waveney	Wootton Creek	Wear	Dysynni	Coquet	Clwyd	Blyth NE	Helford	Christchurch
73	Ouse	Aln	Looe	Pagham Harbour	Foryd Bay	Coquet	Newtown	Waveney	Yare
74	Gannel	Gannel	Helford	Foryd Bay	Dysynni	Waveney	Rother	Aln	Erme
75	Artro	Nyfer	Kingsbridge	Aln	Aln	Adur	Teifi	Tweed	Fowey
76	Dysynni	Erme	Tyne	Gannel	Looe	Teifi	Pagham Harbour	Gannel	Afan
77	Yar	Dysynni	Fowey	Esk	Esk	Looe	Yare	Avon	Medina
78	Traeth Dulas	Axe	Pwllheli	Axe	Axe	Arun	Yar	Yar	Plymouth

Rank	Total Area	Intertidal Area	Marsh	Shoreline	Channel Length	Cross-section Area	Mouth Width	Valley Width	% Area
79	Nyfer	Pwllheli	Yealm	Yar	Gannel	Wansbeck	Aln	Traeth Dulas	Wash
80	Wootton Creek	Neath	Aberystwyth	Artro	Newtown	Ogmore	Coquet	Kingsbridge	Dee
81	Aln	Adur	Yare	Aberystwyth	Yar	Christchurch	Wansbeck	Hayle	Dart
82	Pwllheli	Coquet	Blyth NE	Waveney	Nyfer	West Bay	Ouse	Lymington	Southampton
83	Wansbeck	Looe		Otter	Traeth Dulas	Blyth EA	Traeth Dulas	Yealm	Yealm
84	Axe	Tweed		Nyfer	Pagham Harbour	Cuckmere	Esk	Otter	Helford
85	Tweed	Waveney		Traeth Dulas	Wootton Creek	Axe	Looe	Medina	Cuckmere
86	Coquet	Ogmore		Afan	Afan	Otter	Ogmore	Wootton Creek	Milford Haven
87	Looe	Otter		Pwllheli	Lymington	Ouse	Waveney	Axe	Severn
88	Neath	Afan		Ogmore	Aberystwyth	Tawe	Christchurch	Fowey	Adur
89	Cuckmere	Wansbeck			Pwllheli	Afan	Arun	Esk	Falmouth
90	Afan	Esk			Hayle	Artro	Blyth EA	West Bay	Aberystwyth
91	Ogmore	Cuckmere			Artro	Hayle	Axe	Dart	Waveney
92	Otter	Ouse			Ogmore	Dysynni	Dysynni	Conwy	Wansbeck
93	Esk	Aberystwyth			Weymouth		West Bay	Looe	Weymouth
94	Aberystwyth	Arun			Otter		Cuckmere	Cuckmere	Ouse
95	Weymouth	Weymouth			Bembridge		Otter		Arun
96	West Bay				West Bay				

NB: Where cells are blank, no data were presented in the Futurecoast database.

Physical Processes

From the *Futurecoast* database, physical processes were represented by the following factors (these have been defined in *Futurecoast* report 'Estuarine Methodology'):

- Tidal range (m);
- Mean flow (cumecs);
- Maximum flow (cumecs);
- Dronkers' gamma (relative flood or ebb dominance).

The following relationships were also used:

- Flow ratio 1; } these ratios use different equations, but both
- Flow ratio 2; } present a measure of estuary stratification
- Spit ratio (ratio of mouth width to valley width).

A similar exercise has been undertaken to rank estuaries according to these processes, and results are presented in Figures F2-10 to F2-16, and Table F2-2. In addition to these parameters, the relative magnitude of different processes can be inferred from presence or absence of certain morphological features. For example, the presence of a strong littoral drift and a single spit indicates a preferential transport of sediment along the coast towards the estuary mouth. The presence of an ebb and flood tide delta indicate the process of sediment storage and complex transport linkages around the estuary mouth. Consequently, Table F2-3 has also been produced using the *Futurecoast* database. From this table it can be identified that fjards and rias generally are located in relatively hard rock areas, mostly with low drift along the adjacent coastlines, and therefore there is likely to be somewhat limited marine sediment exchange between the open coast and estuary. Additionally, due to their relatively steep valleys and the comparatively small-scale management intervention, there is relatively little scope for the hydrodynamics of a fjard or ria type estuary to change dramatically with future management. In contrast, spit-enclosed estuaries are dependent upon the continued supply of longshore drift to maintain the spits at their mouths. These spits offer a degree of shelter to the outer estuary from wave action.

Table F2-2 Ranking of estuaries according to physical process parameters

Rank	Tidal Range	River Flow		Dronkers' Gamma	Flow Ratio		Spit Ratio
		mean	max		1	2	
1	Severn	Humber	Solway	Adur	Tawe	Tawe	Arun
2	Parrett	Severn	Severn	Yealm	Afan	Afan	Dysynni
3	Mersey	Solway	Humber	Ribble	Tweed	Tweed	Yare
4	Ogmore	Thames	Morecambe	Aberystwyth	West Bay	West Bay	Rother
5	Neath	Tweed	Tweed	Wansbeck	Christchurch	Neath	Ore/Alde
6	Tawe	Morecambe	Tyne	Dovey	Aberystwyth	Aberystwyth	Christchurch
7	Afan	Mersey	Ribble	Swale	Neath	Aln	Ouse
8	Morecambe	Carmarthen	Mersey	Nyfer	Teifi	Otter	Poole
9	Solway	Tyne	Thames	Otter	Aln	Ogmore	Adur
10	Duddon	Wash	Carmarthen	Arun	Wear	Christchurch	Otter
11	Ribble	Ribble	Taw-Torridge	Teifi	Ogmore	Wear	Portsmouth
12	Esk	Plymouth	Plymouth	Avon	Otter	Wansbeck	Coquet
13	Dee	Taw-Torridge	Wash	Carmarthen	Axe	Axe	Newtown
14	Carmarthen	Christchurch	Conwy	Duddon	Weymouth	Tyne	Blyth EA
15	Taw-Torridge	Dee	Exe	Cefni	Rother	Rother	Langstone Harbour
16	Loughor	Teifi	Tees	Helford	Tyne	Conwy	Afan
17	Conwy	Dovey	Dovey	Ogmore	Wansbeck	Teifi	Parrett
18	Clwyd	Exe	Wear	Milford Haven	Arun	Esk	Pagham Harbour
19	Wash	Tees	Parrett	Axe	Conwy	Waveney	Ogmore
20	Thames	Conwy	Dart	Chichester Harbour	Dovey	Tees	Stour-Pegwell
21	Cuckmere	Southampton	Tawe	Colne	Waveney	Arun	Waveney
22	Gannel	Wear	Dee	Teign	Dysynni	Mawddach	Wansbeck

Rank	Tidal Range	River Flow		Dronkers' Gamma	Flow Ratio		Spit Ratio
		mean	max		1	2	
51	Kingsbridge	Otter	Harwich	Stour-Pegwell	Thames	Yealm	Crouch
52	Esk	Adur	Blackwater	Falmouth	Southampton	Foryd Bay	Clwyd
53	Stour-Pegwell	Aln	Erme	Severn	Pwllheli	Hayle	Loughor
54	Pwllheli	Foryd Bay	Rother	Beaulieu	Camel	Stour-Pegwell	Tees
55	Wear	Rother	Southampton	Camel	Foryd Bay	Colne	Nyfer
56	Glaslyn	Blyth NE	Waveney	Wash	Humber	Thames	Blackwater
57	Artro	Loughor	Cuckmere	Mawddach	Yealm	Bembridge	Morecambe
58	Tyne	Looe	Adur	Harwich	Mersey	Humber	Beaulieu
59	Dovey	Erme	Falmouth	Lymington	Medway	Medway	Harwich
60	Mawddach	Waveney	Coquet	Gannel	Colne	Ribble	Solway
61	Dysynni	Yealm	Colne	Poole	Bembridge	Solway	Chichester Harbour
62	Aberystwyth	Harwich	Foryd Bay	Clwyd	Solway	Mersey	Humber
63	Teign	Colne	Yealm	Humber	Ribble	Medina	Southampton
64	Chichester Harbour	Cuckmere	Stour-Pegwell	Rother	Dee	Milford Haven	Glaslyn
65	Langstone Harbour	Coquet	Poole	Wear	Milford Haven	Poole	Neath
66	Medina	Nyfer	Crouch	Hayle	Falmouth	Harwich	Duddon
67	Blyth NE	Hayle	Nyfer	Morecambe	Deben	Morecambe	Traeth Melynog
68	Wansbeck	Lymington	Lymington	Conwy	Medina	Duddon	Tweed
69	Portsmouth	Deben	Gannel	Fowey	Severn	Blackwater	Dee
70	Teifi	Chichester Harbour	Portsmouth	Plymouth	Wash	Ore/Alde	Wash
71	Tweed	Gannel	Blyth EA	Pagham Harbour	Morecambe	Southampton	Helford
72	Otter	Portsmouth	West Bay	Medway	Duddon	Falmouth	-

Rank	Tidal Range	River Flow		Dronkers' Gamma	Flow Ratio		Spit Ratio
		mean	max		1	2	
23	Traeth Dulas	Parrett	Teifi	West Bay	Exe	Exe	Traeth Dulas
24	Milford Haven	Tawe	Neath	Ouse	Tees	Dysynni	Tawe
25	Ouse	Medway	Mawddach	Glaslyn	Ouse	Dovey	Aln
26	Humber	Milford Haven	Medway	Alaw	Esk	Ouse	West Bay
27	Camel	Dart	Ogmore	Tees	Clwyd	Cuckmere	Axe
28	Adur	Clwyd	Milford Haven	Exe	Teign	Blyth EA	Yar
29	Arun	Neath	Teign	Looe	Cuckmere	Coquet	Colne
30	Falmouth	Teign	Clwyd	Taw-Torridge	Coquet	Blyth NE	Pwllheli
31	Rother	Yare	Duddon	Esk	Blyth EA	Weymouth	Teifi
32	Medway	Poole	Esk	Erme	Dart	Teign	Esk
33	Crouch	Ogmore	Christchurch	Loughor	Fowey	Clwyd	Blyth NE
34	Alaw	Esk	Axe	Christchurch	Adur	Dart	Teign
35	Hayle	Arun	Wansbeck	Solway	Yare	Erme	Taw-Torridge
36	Swale	Camel	Aberystwyth	Weymouth	Parrett	Parrett	Deben
37	Pagham Harbour	Aberystwyth	Afan	Tweed	Avon	Avon	Exe
38	Tees	Glaslyn	Glaslyn	Medina	Lymington	Lymington	Mawddach
39	Fowey	Afan	Arun	Dee	Blyth NE	Adur	Esk
40	Looe	Fowey	Loughor	Crouch	Erme	Fowey	Medway
41	Plymouth	Axe	Aln	Hamford	Taw-Torridge	Nyfer	Bembridge
42	Cefni	Duddon	Dysynni	Dysynni	Nyfer	Gannel	Wear
43	Helford	Esk	Blyth NE	Waveney	Plymouth	Taw-Torridge	Aberystwyth
44	Avon	Dysynni	Ouse	Cuckmere	Hayle	Pwllheli	Hamford
45	Yealm	Ouse	Camel	Wootton Creek	Carmarthen	Plymouth	Dovey

Rank	Tidal Range	River Flow		Dronkers' Gamma	Flow Ratio		Spit Ratio
		mean	max		1	2	
73	Southampto n	Pwllheli	Pwllheli	Mersey	Blackwater	Dee	-
74	Dart	Blyth EA	Ore/Alde	Esk	Harwich	Severn	-
75	Exe	West Bay	Langstone Harbour	Blyth NE	Portsmouth	Crouch	-
76	Nyfer	Ore/Alde	Bembridge	Ore/Alde	Ore/Alde	Portsmouth	-
77	Hamford	Crouch	Hayle	Kingsbridge	Cefni	Loughor	-
78	Wootton Creek	Bembridge	Medina	Parrett	-	Deben	-
79	Axe	Cefni	Chichester Harbour	Tyne	-	Wash	-
80	Harwich	Langstone Harbour	Deben	Portsmouth	-	Langstone Harbour	-
81	Coquet	Medina	Weymouth	Thames	-	Chichester Harbour	-
82	Aln	Weymouth	-	Dart	-	-	-
83	Deben	-	-	Blyth EA	-	-	-
84	Beaulieu	-	-	Langstone Harbour	-	-	-
85	West Bay	-	-	Aln	-	-	-
86	Bembridge	-	-	Bembridge	-	-	-
87	Newtown	-	-	Newtown	-	-	-
88	Yar	-	-	Neath	-	-	-
89	Lymington	-	-	Yar	-	-	-
90	Ore/Alde	-	-	Deben	-	-	-
91	Blyth EA	-	-	Tawe	-	-	-
92	Yare	-	-	-	-	-	-
93	Waveney	-	-	-	-	-	-
94	Weymouth	-	-	-	-	-	-
95	Poole	-	-	-	-	-	-

Rank	Tidal Range	River Flow		Dronkers' Gamma	Flow Ratio		Spit Ratio
		mean	max		1	2	
46	Erme	Blackwater	Otter	Blackwater	Poole	Glaslyn	Tyne
47	Traeth Melynog	Avon	Yare	Coquet	Esk	Yare	Hayle
48	Foryd Bay	Stour-Pegwell	Avon	Yare	Glaslyn	Carmarthen	Carmarthen
49	Blackwater	Wansbeck	Fowey	Afan	Gannel	Camel	Foryd Bay
50	Colne	Falmouth	Esk	Southampto n	Stour-Pegwell	Esk	Cefni

Rank	Tidal Range	River Flow		Dronkers' Gamma	Flow Ratio		Spit Ratio
		mean	max		1	2	
96	Christchurch	-	-	-	-	-	-

NB: Where cells are blank, no data were presented in the *Futurecoast* database.

Table F2-3 Presence of various processes or morphological features

ame	Type		Tides		Littoral Drift		Rock		River Flow		Weather Effects		Cliffs	Salt Marsh	Sand Flats	Rock Platform	Mud Flats	Linear Bank	Low Water	Ebb/ Flood	Spits	Deltas		Barrier beach
			Large	Small	Large	Small	Hard	Soft	Large	Small	Large	Small							Channels			Ebb	Flood	
Pwllheli	2	a	x		x			x		x		x			x						x			
Alaw	2	b	x			x	x			x		x	x	x	x	x	x							
Wear	3	a	x			x	x		x			x					x		x		x			
Christchurch	3	a		x	x		x		x			x		x			x				x			
Aberystwyth	3	a		x	x		x			x	x				x		x				x			
Dovey	3	a		x	x		x		x		x		x	x	x	x	x		x		x	x		
Mawddach	3	a		x	x		x			x	x		x	x	x		x		x		x	x		
Glaslyn	3	a		x	x		x			x	x		x	x	x	x	x				x	x		
Traeth Dulas	3	a	x		x		x			x		x	x	x	x	x	x				x			
Conwy	3	a	x			x	x		x			x	x	x	x		x				x	x		
Tweed	3	b	x			x	x		x			x	x		x	x	x							
Tyne	3	b	x			x	x		x			x					x		x					
Esk	3	b	x			x	x			x		x	x											

ame	Type		Tides		Littoral Drift		Rock		River Flow		Weather Effects		Cliffs	Salt Marsh	Sand Flats	Rock Platform	Mud Flats	Linear Bank	Low Water	Ebb/ Flood	Spits	Deltas		Barrier beach
			Large	Small	Large	Small	Hard	Soft	Large	Small	Large	Small							Channels			Ebb	Flood	
Medina	3	b	x			x	x			x		x		x			x		x					
Dart	3	b	x			x	x		x			x	x	x		x	x		x					
Kingsbridge	3	b	x			x	x			x		x	x			x	x		x					
Avon	3	b	x			x	x			x		x	x	x		x	x							
Erme	3	b	x			x	x			x		x	x	x	x	x	x							
Yealm	3	b	x			x	x			x		x	x			x	x		x					
Plymouth	3	b	x			x	x		x			x	x	x		x	x		x					
Looe	3	b	x			x	x			x		x	x	x		x	x							
Fowey	3	b	x			x	x			x		x	x			x	x		x					
Falmouth	3	b	x			x	x			x		x	x	x		x	x		x					
Helford	3	b	x			x	x			x		x	x			x	x		x					
Gannel	3	b	x			x	x			x		x	x	x	x		x		x					
Camel	3	b	x			x	x			x		x	x	x	x	x	x		x	x			x	
Severn	3	b	x			x	x		x			x	x	x	x	x	x	x	x	x		x	x	
Milford Haven	3	b	x			x	x			x	x		x	x		x	x		x					
Cefni	3	b	x			x	x			x		x	x	x	x	x								
Mersey	3	b	x			x	x		x			x	x	x	x		x		x			x	x	
Coquet	4	a		x	x		x			x		x		x			x				x	x		
Wansbeck	4	a		x	x			x		x		x					x				x			
Blyth NE	4	a	x		x		x			x		x				x	x				x			
Humber	4	a	x		x			x	x		x			x	x		x	x	x	x	x	x	x	
Yare	4	a		x	x			x		x		x			x		x		x		x	x		
Waveney	4	a		x	x			x		x		x			x		x		x		x	x		
Blyth EA	4	a		x	x			x		x		x		x			x							
Ore/Alde	4	a		x	x			x		x		x		x			x				x	x		
Harwich	4	a		x	x			x		x		x		x			x		x		x	x		

ame	Type		Tides		Littoral Drift		Rock		River Flow		Weather Effects		Cliffs	Salt Marsh	Sand Flats	Rock Platform	Mud Flats	Linear Bank	Low Water	Ebb/ Flood	Spits	Deltas		Barrier beach
			Large	Small	Large	Small	Hard	Soft	Large	Small	Large	Small							Channels			Ebb	Flood	
Blackwater	4	a	x			x		x		x		x		x			x		x		x			
Crouch	4	a	x			x		x		x		x		x			x		x		x			
Medway	4	a	x			x				x		x		x			x		x		x			
Swale	4	a	x			x		x		x		x		x	x		x		x		x			
Stour-Pegwell	4	a	x		x			x		x		x	x	x	x		x				x	x		
Ouse	4	a	x		x		x		x			x	x			x					x	x		
Adur	4	a	x		x		x			x		x					x				x	x		x
Arun	4	a	x		x			x	x			x									x	x		
Southampton	4	a		x		x		x		x		x		x	x		x		x		x			
Beaulieu	4	a		x	x			x		x		x	x	x			x				x			
Weymouth	4	a		x		x	x			x		x	x						x		x			
Exe	4	a	x		x		x		x			x		x	x		x		x	x	x	x	x	
Teign	4	a	x		x		x		x			x	x	x	x		x		x	x	x	x		
Ogmore	4	a	x			x	x			x		x		x	x						x			
Dysynni	4	a		x	x			x		x		x		x			x				x			
Dee	4	a	x			x		x	x	x		x	x	x	x		x		x	x	x	x	x	
Aln	4	b		x	x		x			x		x		x	x		x				x	x		x
Tees	4	b	x		x			x	x			x		x	x		x		x		x	x	x	
Deben	4	b		x	x			x		x		x					x		x		x	x	x	
Hamford	4	b		x	x			x		x	x			x			x		x		x			
Colne	4	b	x		x			x		x		x		x			x		x		x			
Bembridge	4	b		x	x			x		x	x			x			x				x			
Poole	4	b		x	x			x		x	x			x			x		x		x	x	x	x
West Bay	4	b		x	x			x	x		x								x		x	x		
Hayle	4	b	x		x			x		x		x		x	x		x			x	x	x		
Taw-	4	b	x		x		x		x		x		x	x	x		x		x		x	x	x	

ame	Type		Tides		Littoral Drift		Rock		River Flow		Weather Effects		Cliffs	Salt Marsh	Sand Flats	Rock Platform	Mud Flats	Linear Bank	Low Water	Ebb/ Flood	Spits	Deltas		Barrier beach
			Large	Small	Large	Small	Hard	Soft	Large	Small	Large	Small							Channels			Ebb	Flood	
Torridge																								
Loughor	4	b	x		x			x		x	x			x	x		x		x		x	x	x	
Carmarthen	4	b	x		x			x		x	x			x	x		x				x	x	x	
Clwyd	4	b	x		x			x		x		x		x			x				x			
Morecambe	4	b	x		x			x	x		x			x	x		x		x	x	x	x	x	
Duddon	4	b	x		x			x	x		x			x	x		x		x		x	x	x	
Esk	4	b	x		x			x		x		x		x	x		x				x	x		
Rother	4	b/c	x		x			x		x		x		x	x		x				x	x		x
Cuckmere	4	c	x		x		x			x		x	x	x		x						x		
Wootton Creek	4	c		x		x		x		x		x					x							
Newtown	4	c		x		x	x			x		x		x			x				x			
Yar	4	c		x		x		x		x		x		x			x				x			
Lymington	4	c		x		x		x		x		x		x			x				x			
Axe	4	c		x	x		x		x			x	x	x			x				x			
Otter	4	c	x		x		x		x			x	x	x			x				x			
Parrett	4	c	x		x			x	x		x			x			x				x	x		
Neath	4	c	x		x		x		x			x		x	x		x				x	x		x
Tawe	4	c	x		x		x		x			x					x					x		
Nyfer	4	c		x		x	x			x	x		x	x	x	x					x			
Teifi	4	c		x		x	x			x	x		x	x	x	x	x				x			
Thames	5		x			x		x	x			x					x		x					
Ribble	5		x		x			x	x		x			x	x		x	x	x	x		x	x	
Solway	5		x			x		x	x		x		x	x	x		x		x	x		x	x	
Wash	6		x			x		x		x	x			x	x		x	x	x	x				
Pagham	7	a	x		x			x		x	x			x	x		x			x	x	x	x	x

ame	Type		Tides		Littoral Drift		Rock		River Flow		Weather Effects		Cliffs	Salt Marsh	Sand Flats	Rock Platform	Mud Flats	Linear Bank	Low Water	Ebb/ Flood	Spits	Deltas		Barrier beach
			Large	Small	Large	Small	Hard	Soft	Large	Small	Large	Small							Channels			Ebb	Flood	
Harbour																								
Chichester Harbour	7	a	x		x			x		x	x			x	x		x		x	x	x	x	x	x
Langstone Harbour	7	a	x		x			x		x	x			x	x		x		x	x	x	x	x	x
Portsmouth	7	a	x		x			x		x	x			x	x		x		x	x	x	x	x	x
Artro	7	a		x	x			x		x		x		x	x						x			
Foryd Bay	7	b	x		x		x			x	x			x	x						x			
Traeth Melynog	7	b	x		x		x			x	x			x	x						x			
Afan	7		x		x			x		x		x			x						x			x

Management Intervention

The *Futurecoast* database also provides an indication of whether each estuary has previously been extensively reclaimed and whether there are any structures at its mouth. These two types of management intervention are important controls on estuarine-open coast interaction. Reclamation of an estuary means that its present tidal prism is smaller than it once was: there exists potential for a future management decision within the estuary (i.e. realignment or further reclamation) to alter the prism further. Changes to the prism of an estuary can influence both the tidal flow velocities and the volume of sediment stored in the ebb tide delta close to the mouth. The presence of shore-normal structures (commonly referred to as jetties, breakwaters, piers or harbour arms) at the mouth of an estuary tend to indicate that longshore drift would, in the absence of the structures, act to block or deflect the mouth.

Taking the examples of the River Humber and River Arun previously mentioned, the open coast exerts a strong influence on both of these estuaries, with sediment released through erosion along the updrift open coast being transported alongshore towards the estuary mouth where it accumulates in a spit. Due to the physical size of the Humber, the spit does not fully block the estuary mouth. In contrast, if management intervention were absent from the river mouth of the River Arun and a sufficient sediment supply existed, the mouth could potentially be progressively deflected eastwards by an elongating spit.

The management intervention within estuaries is presented in Table F2-4.

Table F2-4 Management intervention

Name	Type		Reclamation	Jetty
Pwllheli	2	a	x	x
Alaw	2	b		
Wear	3	a		x
Christchurch	3	a	x	x
Aberystwyth	3	a	x	
Dovey	3	a	x	
Mawddach	3	a	x	
Glaslyn	3	a	x	
Traeth Dulas	3	a		
Conwy	3	a		
Tweed	3	b		x
Tyne	3	b		x
Esk	3	b		x
Medina	3	b		
Dart	3	b		
Kingsbridge	3	b		
Avon	3	b		
Erme	3	b		
Yealm	3	b		
Plymouth	3	b		
Looe	3	b		x
Fowey	3	b		
Falmouth	3	b		
Helford	3	b		
Gannel	3	b		
Camel	3	b		
Severn	3	b	x	
Milford Haven	3	b		
Cefni	3	b	x	
Mersey	3	b	x	
Coquet	4	a		x
Wansbeck	4	a		
Blyth NE	4	a		x
Humber	4	a	x	
Yare	4	a	x	x
Waveney	4	a	x	x
Blyth EA	4	a	x	x
Ore/Alde	4	a	x	
Harwich	4	a	x	x
Blackwater	4	a	x	
Crouch	4	a	x	
Medway	4	a	x	
Swale	4	a	x	
Stour-Pegwell	4	a	x	
Ouse	4	a	x	x
Weymouth	4	a	x	x
Exe	4	a	x	
Teign	4	a		
Ogmore	4	a		
Dysynni	4	a	x	
Dee	4	a	x	
Aln	4	b		
Tees	4	b	x	x
Deben	4	b	x	
Hamford	4	b	x	
Colne	4	b	x	
Bembridge	4	b	x	
Poole	4	b		
West Bay	4	b	x	x
Hayle	4	b	x	
Taw-Torridge	4	b	x	
Loughor	4	b		
Carmarthen	4	b		
Clwyd	4	b	x	x
Morecambe	4	b	x	
Duddon	4	b		
Esk	4	b		
Rother	4	b / c	x	x
Cuckmere	4	c	x	
Wootton Creek	4	c		
Newtown	4	c		
Yar	4	c		x
Lymington	4	c	x	
Axe	4	c	x	
Otter	4	c	x	
Parrett	4	c	x	
Neath	4	c	x	
Tawe	4	c	x	x
Nyfer	4	c		
Teifi	4	c		
Thames	5		x	
Ribble	5		x	
Solway	5		x	
Wash	6		x	
Pagham Harbour	7	a	x	
Chichester Harbour	7	a	x	
Langstone Harbour	7	a	x	
Portsmouth	7	a	x	
Artro	7	a		
Foryd Bay	7	b		

Name	Type		Reclamation	Jetty
Adur	4	a	x	x
Arun	4	a	x	x
Southampton	4	a	x	
Beaulieu	4	a		

Name	Type		Reclamation	Jetty
Traeth Melynog	7	b		
Afan	7		x	x

Figure F2-1 Ranking of estuaries by total area

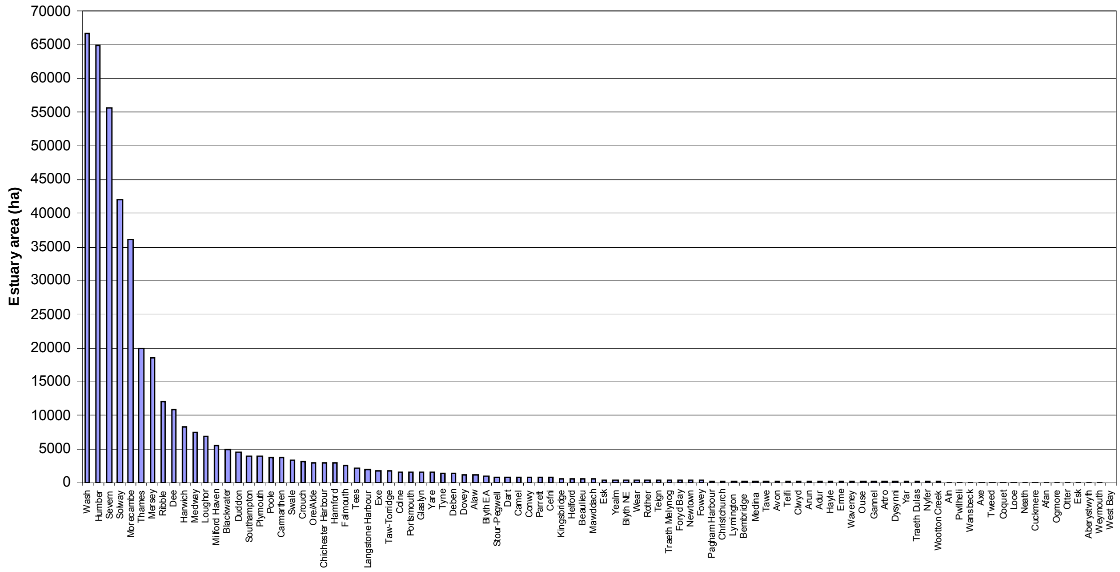


Figure F2-2 Ranking of estuaries by inter-tidal area

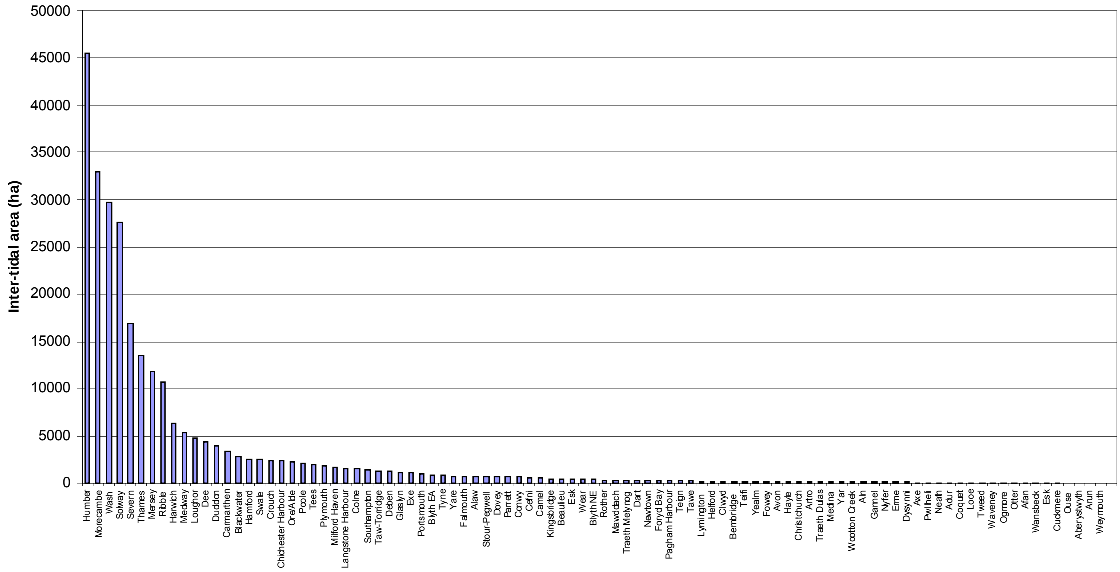


Figure F2-3 Ranking of estuaries by marsh area

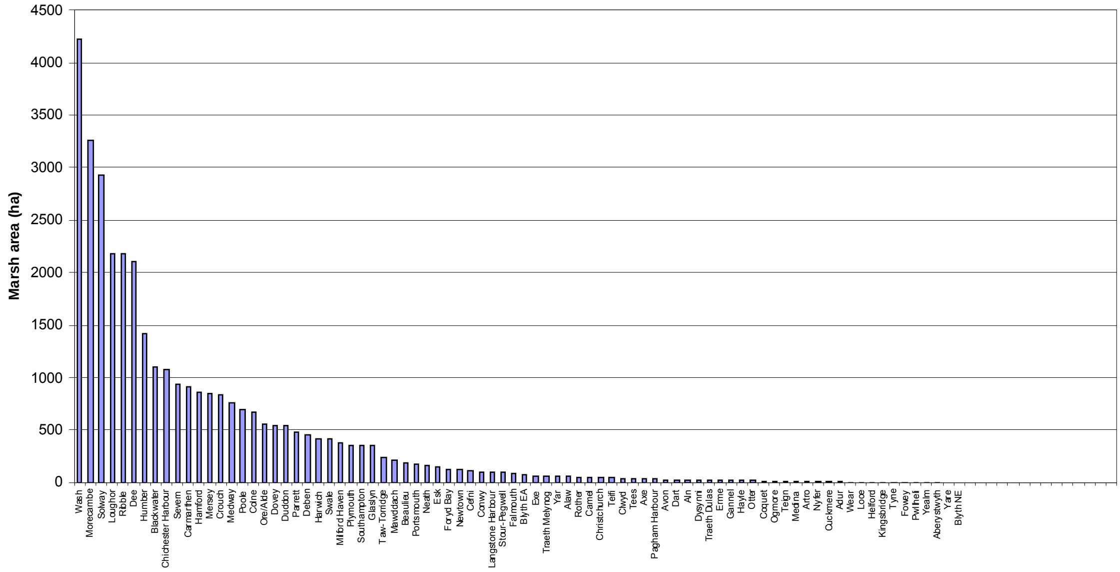


Figure F2-4 Ranking of estuaries by shoreline length

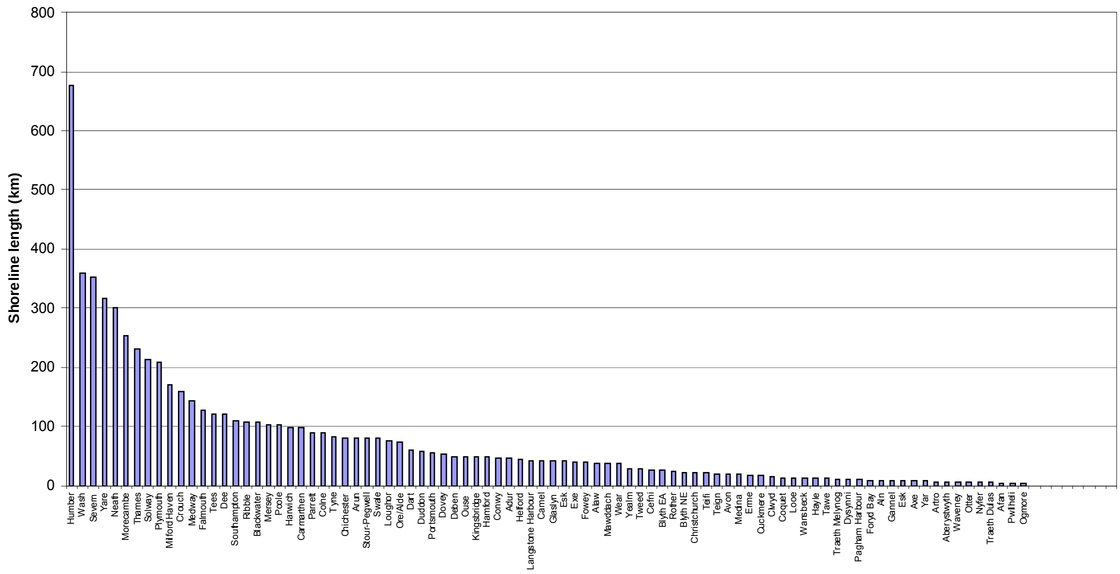


Figure F2-5 Ranking of estuaries by channel length

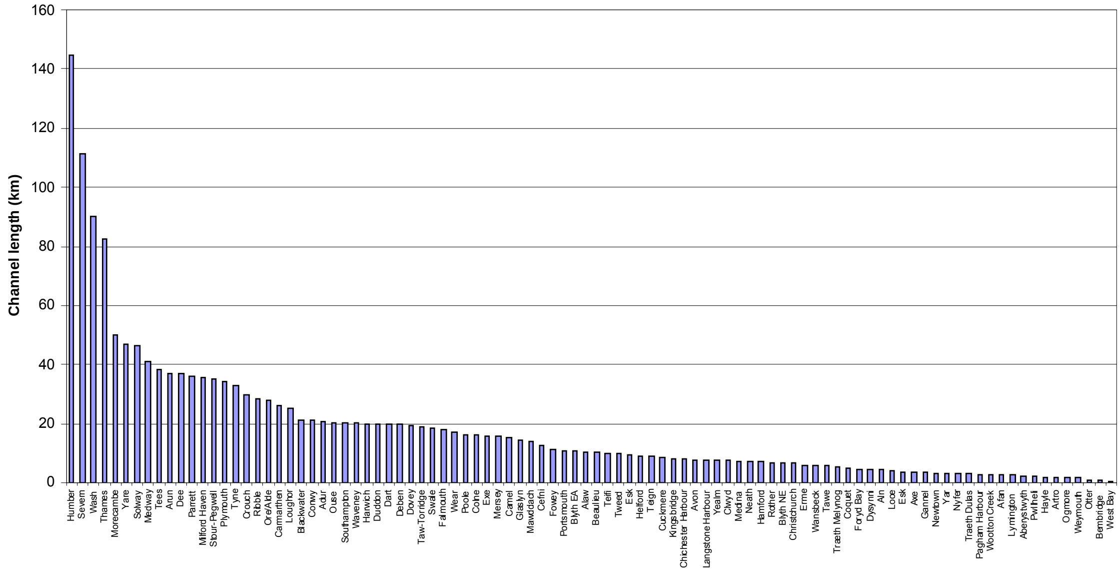


Figure F2-6 Ranking of estuaries by mouth area

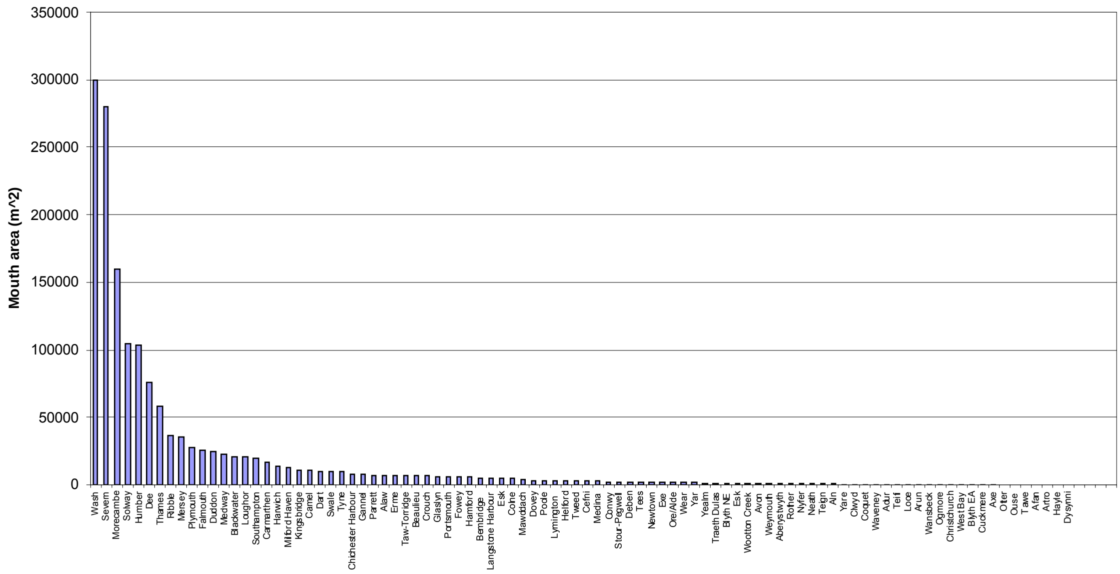


Figure F2-7 Ranking of estuaries by mouth width

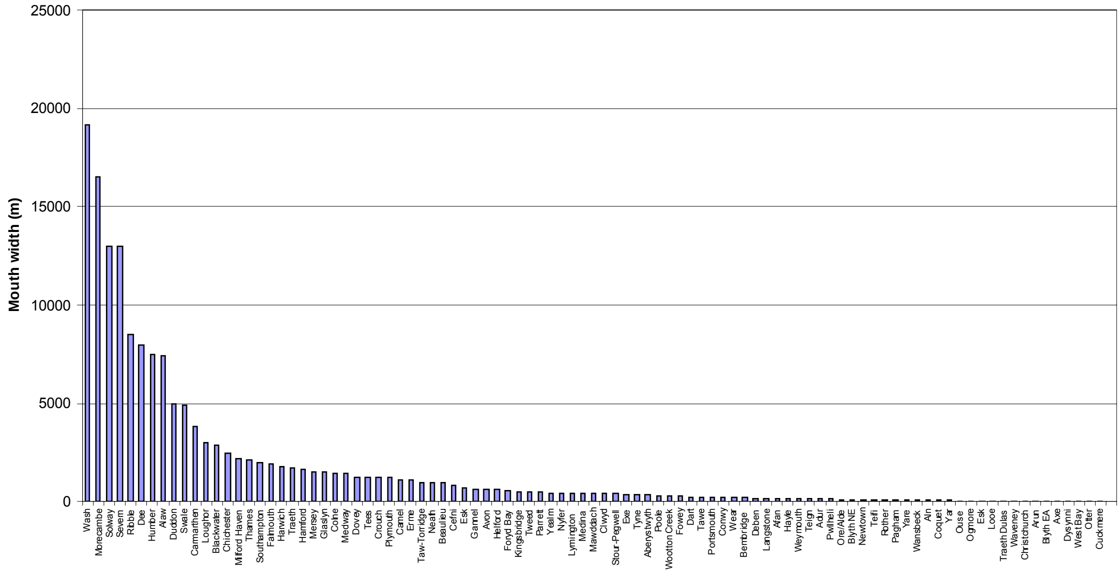


Figure F2-8 Ranking of estuaries by valley width

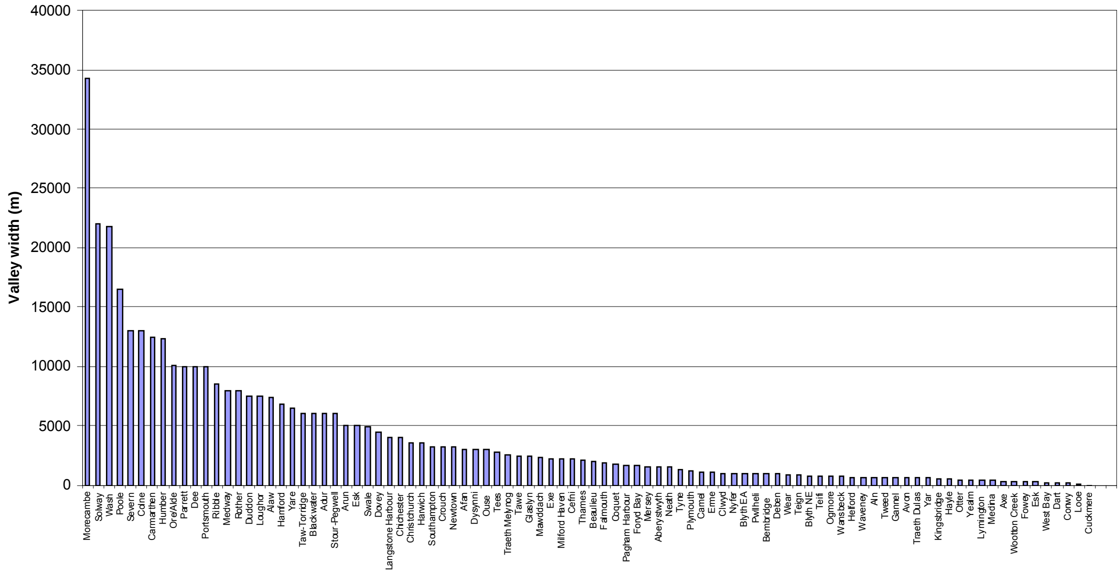


Figure F2-9 Ranking of estuaries by percentage area

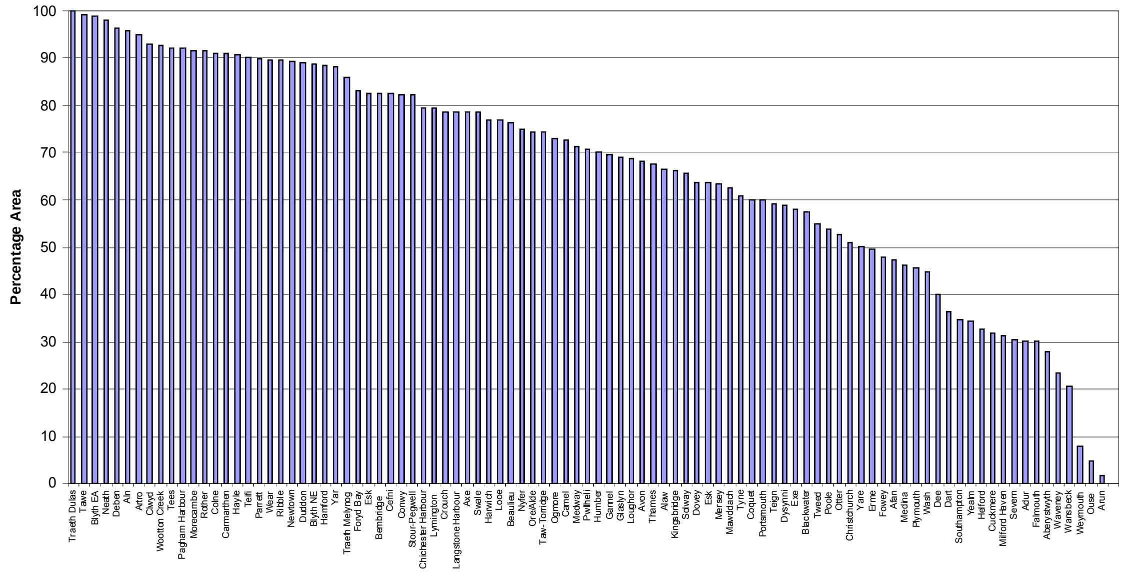


Figure F2-10 Ranking of estuaries by tidal range

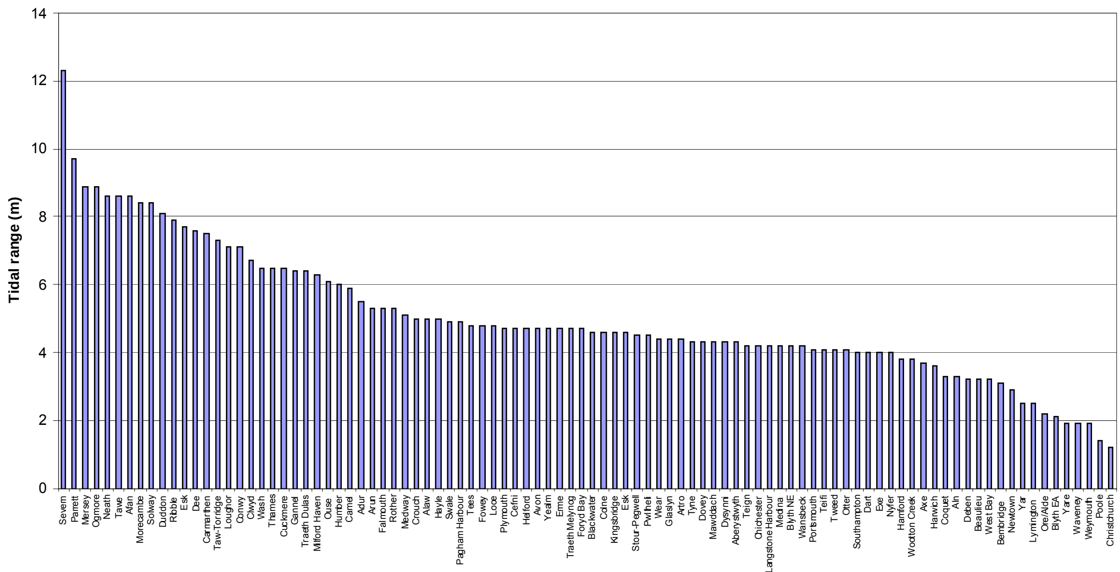


Figure F2-11 Ranking of estuaries by mean flow

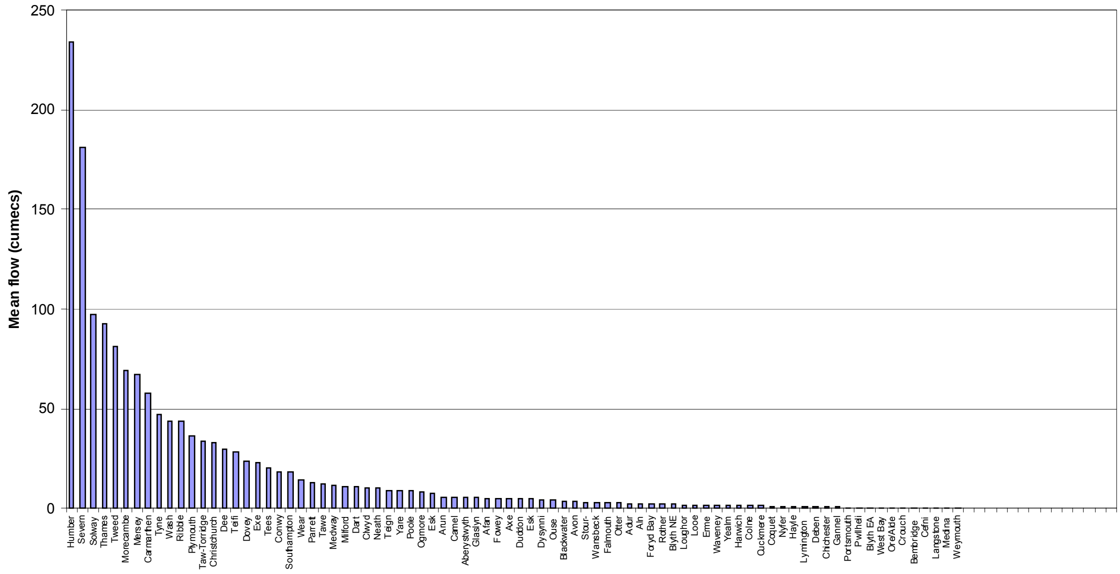


Figure F2-12 Ranking of estuaries by maximum flow

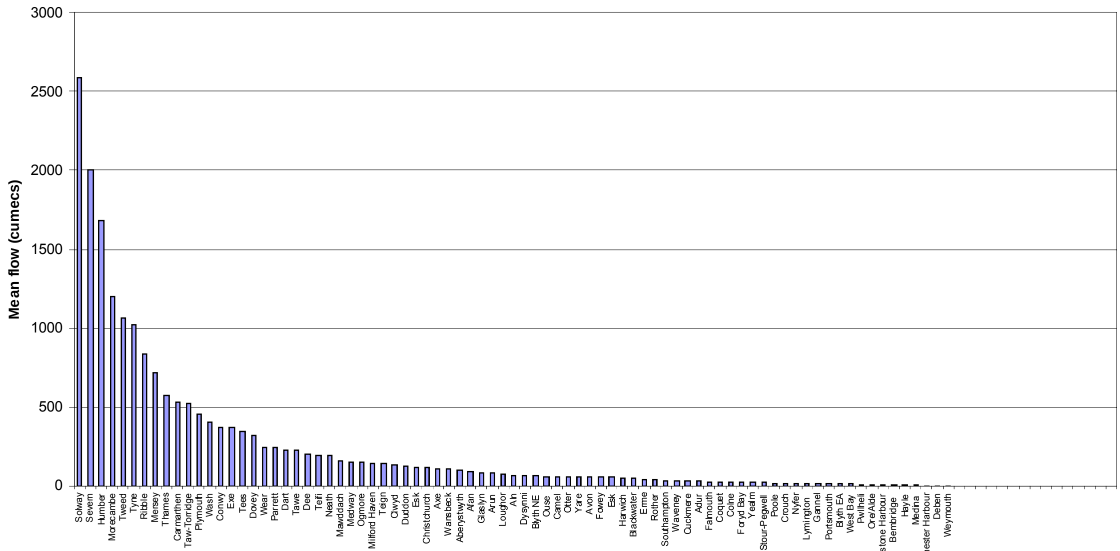


Figure F2-13 Ranking of estuaries by Dronker's Gamma

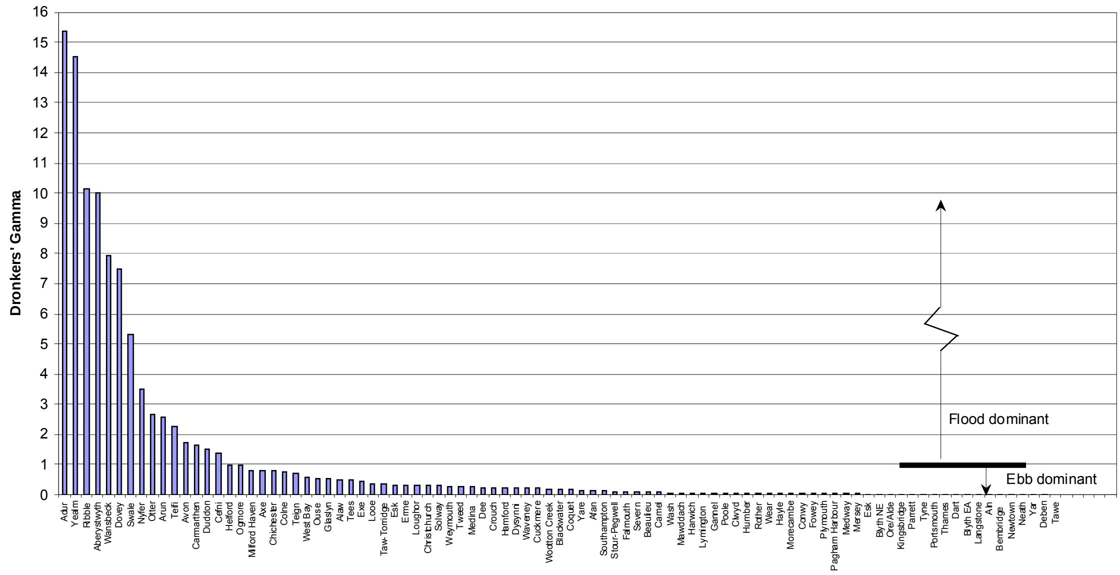


Figure F2-14 Ranking of estuaries by flow ratio (1)

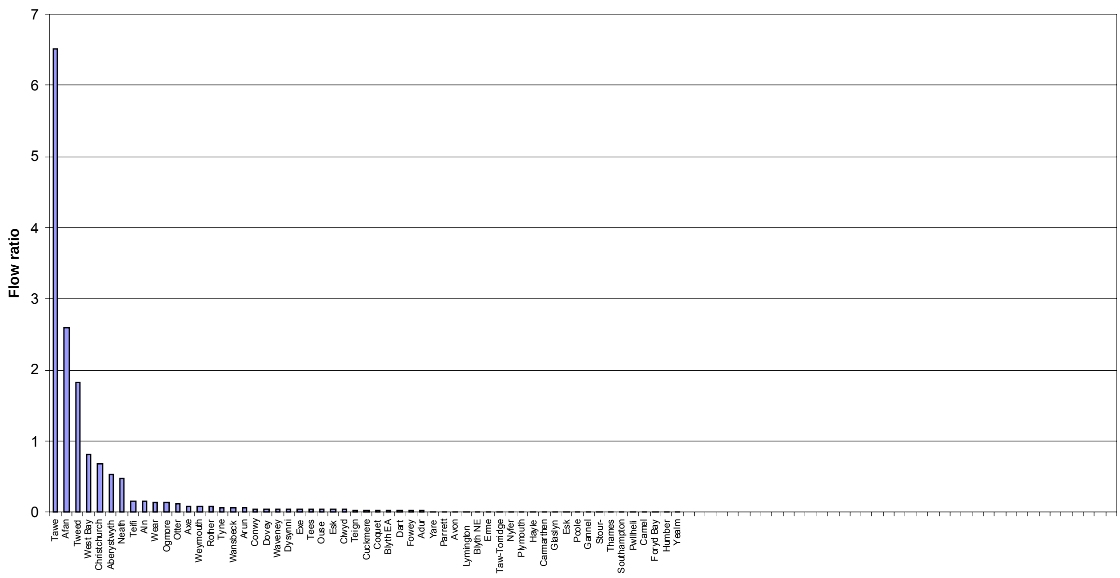


Figure F2-15 Ranking of estuaries by flow ratio (2)

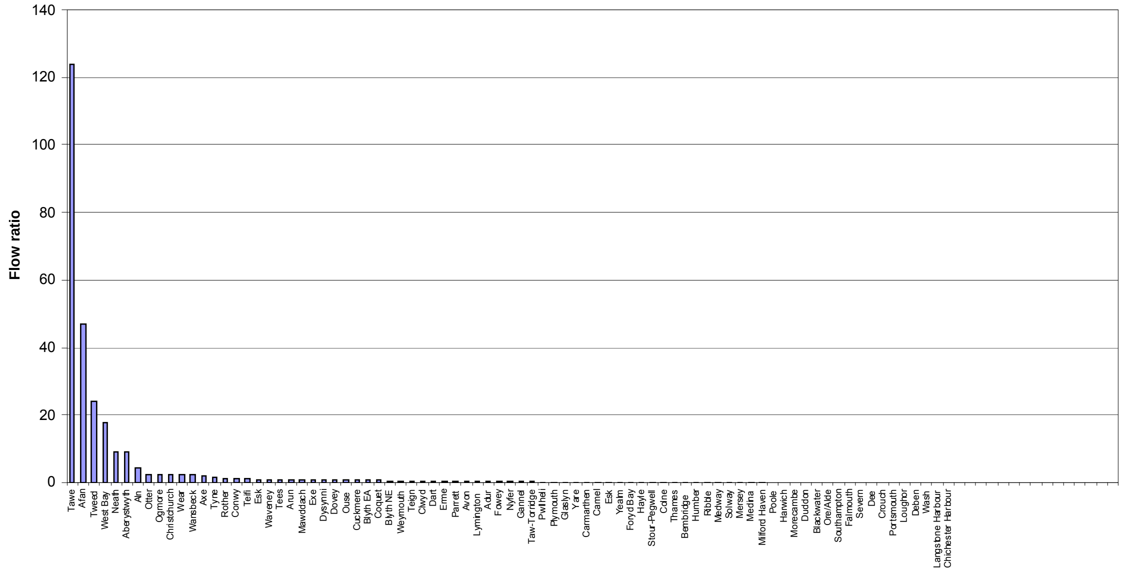
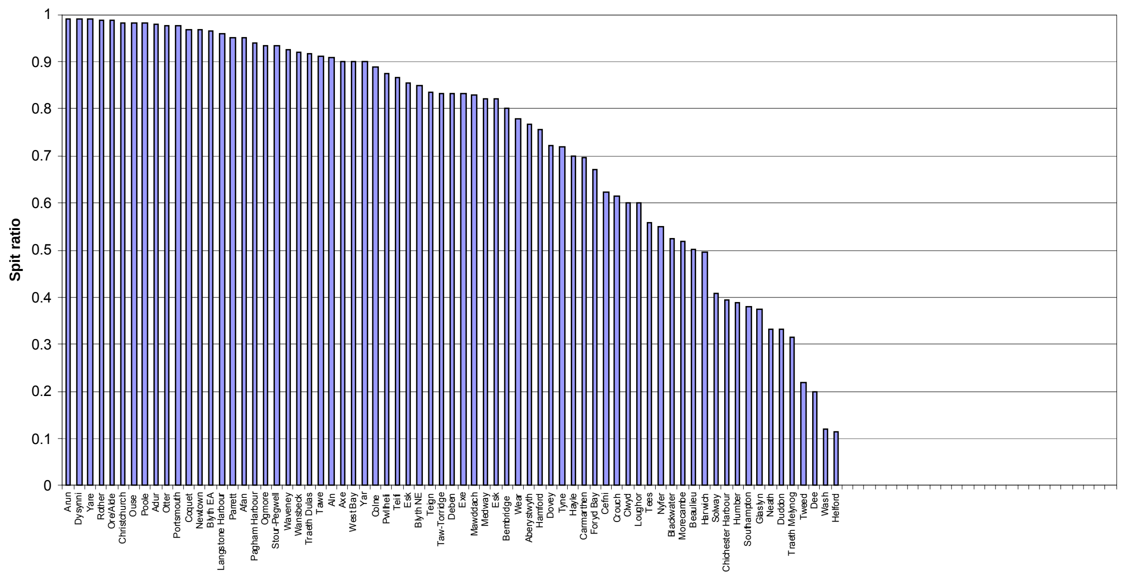


Figure F2-16 Ranking of estuaries by spit ratio



Annex F3: Example application of guidance

In order to exemplify the applicability and usefulness of the guidance it has, in this appendix, been tested on a selection of estuaries from around England and Wales. The estuaries included in this example application were selected to cover a range of geographical areas, a range of physical sizes, and a range of estuarine types. The estuaries included in the trail application are:

- Chichester Harbour (Type 7a estuary);
- Humber (Type 4a estuary);
- Afon Artro (Type 7a estuary);
- Mersey (Type 3b estuary);
- Yar (Type 4c estuary)

It should be noted that the purpose of the example application is to rapidly test the guidance with information readily to hand in order to determine whether its principles are valid, and not necessarily to define absolute rules concerning the inclusion or otherwise of these five estuaries. Instead, it is recommended that the guidance is re-applied to these estuaries with the benefit of all available local information relating to each estuary. Such local information may include: knowledge of processes and geomorphology; content and recommendations of existing estuary SMPs (eSMPs), SMPs and Strategy Plans; existing CHaMPs (if relevant); location of CFMP boundaries; position of tidal limits; knowledge of new developments (or proposals) and management activities; estuary-specific research reports and papers; EMPHASYS research; historic changes; etc.

Efforts were made to standardise the example application through use of a pro-forma table, and results are presented in the following sections.

Estuarine Assessment Pro-forma

<table>
<tr><td>Estuary</td><td></td></tr>
<tr><td>Location</td><td></td></tr>
<tr><td>Main characteristics</td><td></td></tr>
<tr><td>Data availability</td><td></td></tr>
<tr><td rowspan="2">Stage 1
Step 1: Significance of water exchange (EGT2)</td><td>Total area:
Inter-tidal area:
Channel length:
Mouth area:
Mouth width:
Tidal range:
Mean freshwater flow:
Estuary-specific knowledge of other parameters:</td></tr>
<tr><td>Verdict on significance:</td></tr>
<tr><td rowspan="2">Stage 1
Step 2: Significance of sediment exchange (EGT3)</td><td>Tidal asymmetry:
Morphological features:
Source/sink relationship:
Plume generation:
Estuary-specific knowledge of other parameters:</td></tr>
<tr><td>Verdict on significance:</td></tr>
<tr><td>Stage 1
Step 3: Relevance of process issues (EGT5)</td><td>Verdict on relevance of process issues:</td></tr>
<tr><td rowspan="2">Stage 1
Step 4: Significance of management issues (EGT4)</td><td>Historic reclamation:
Presence / absence of jetties:
Estuary-specific knowledge of other issues:</td></tr>
<tr><td>Verdict on significance:</td></tr>
<tr><td rowspan="2">Stage 1
Step 5: Recommendation on whether the estuary should be included in the SMP process (EGT5)</td><td></td></tr>
<tr><td>Verdict:</td></tr>
<tr><td rowspan="2">Stage 2
Recommendation on how the estuary should be included in the SMP process (EGT6)</td><td></td></tr>
<tr><td>Verdict:</td></tr>
<tr><td rowspan="2">Stage 3
Recommendation on how far upstream the estuary should be included (EGT7)</td><td></td></tr>
<tr><td>Verdict:</td></tr>
</table>

Example 1: Chichester Harbour

Estuary	Chichester Harbour.
Location	Hampshire, south coast of England.
Main characteristics	Meso-tidal, medium-sized estuary, low freshwater flow, limited development within estuary (mainly for leisure use), extensive mud and sand flats
Data availability	*Futurecoast* assessment of estuaries. Previous studies into the erosion of East Head spit at the harbour entrance (ABP Research, 2001a, 2001b)
Stage 1 **Step 1: Significance of water exchange (EGT2)**	Total area: Chichester Harbour is relatively large in terms of total estuary area, within the whole range of estuaries in England and Wales. Inter-tidal area: Chichester Harbour is relatively large in terms of inter-tidal estuary area. Channel length: The estuary does not have a particularly large channel length (although this is due to its multi-channel dendritic shape). Mouth area: Chichester Harbour is towards the upper end of the estuaries in terms of mouth area, although values are significantly less than largest estuaries. This is questionable since the mouth is constrained by the presence of a spit. Mouth width: The estuary reportedly has a wide estuary mouth. This is questionable since the mouth is constrained by a spit, although it widens significantly landwards of this. Tidal range: The estuary falls within a middle class of estuaries in terms of tidal range. Mean freshwater flow: The estuary has a very low mean flow. Estuary-specific knowledge of other parameters:
	Verdict on significance: The ratio of total area to channel length is high, implying that the estuary is likely to be subject to some wave processes. However, this is somewhat misleading since the estuary mouth is in fact constrained by spits which would limit wave protection. The ratio of tidal range to mean freshwater is high since the freshwater flow is low. Thus in terms of water exchange the estuary is assessed as lying towards the lower end of the 'Significant' range.

<table>
<tr><td rowspan="2">Stage 1
Step 2: Significance of sediment exchange (EGT3)</td><td><u>Tidal asymmetry</u>: The estuary is ebb dominant according to Dronkers’ Gamma, but not especially so.
<u>Morphological features</u>: Chichester harbour mouth is framed by spits on either side. Importantly the eastern spit, East Head has rotated around a hinge point over the last 150 years. This has resulted in a spit that was once parallel to the coastal orientation, now being orientated into the harbour itself. The estuary has pronounced flood and ebb tidal deltas formed from sandy material.
<u>Source/sink relationship</u>: Futurecoast ‘Assessment of estuaries’ - the estuary is believed to be a strong sediment sink. This is in agreement with more detailed assessment made in ABP research (2001b)
<u>Plume generation</u>: The estuary is not believed to be capable of generating a major sediment plume under high freshwater flow. This is substantiated by fact that estuary has a low freshwater flow from chalk aquifers.
<u>Estuary-specific knowledge of other parameters</u>: . The estuary may be ebb dominant for coarse grained material such as sand, but detailed studies by ABP Research (2001a) indicate that estuary may be flood dominant with regard to fine grained material, thereby explaining the net accretion of marine derived mud sediment over the Holocene. Furthermore, detailed modelling shows that sand sized sediment is driven into the harbour under storm conditions. This suggests that Dronkers’ Gamma is only one measure which should be used to assess flood/ebb dominance with regard to sediment transport. Usefully, Futurecoast estuaries assessment report does note that since the value of Dronkers’ Gamma is close to 1, weather induced currents might be important. This is borne out to some extent by fact that storm waves from SSW increase movement of sand into the harbour. A more detailed appreciation of flood-ebb dominance in terms of current speeds is made by ABP Research (2001a). This illustrates that the estuary is characterised by the Solent flood still stand. This leads to the flood tide being substantially longer than the ebb tide, plus an extended period of slack water before ebb. The former means that ebb currents are substantially stronger than flood currents, whilst the latter results in an increased tendency for the deposition of fine sediment within the estuary.</td></tr>
<tr><td>Verdict on significance: ‘Significant’</td></tr>
<tr><td>Stage 1
Step 3: Relevance of process issues (EGT5)</td><td>Verdict on relevance of process issues:
Step 1 – shows significant water exchange
Step 2 – shows significant sediment exchange
Step 3 – therefore from EGT5, process issues are assessed as grade ‘A’</td></tr>
</table>

Stage 1 **Step 4: Significance of management issues (EGT4)**	Historic reclamation: There has been reclamation within the estuary. Presence / absence of jetties: There is no jetty present. Estuary-specific knowledge of other issues: ABP Research (2001b) indicates that the estuary in fact has substantial management issues since East Head spit at the harbour mouth is in danger of breaching. This has the potential to form a permanent breach with implications for siltation in the harbour mouth as well as more direct consequences for the spit itself. In the terms used in EGT4 this represents continuity of 'at risk areas' from the coast to the estuary. Assessing the scope for large-scale anthropogenic intervention would indicate that the opportunity for managed realignment exists in a number of areas which have been previously reclaimed, possibly influencing the tidal prism and hence estuary-open coast interactions. The reclamation of new areas is unlikely. The residual life of the defences is not known for the whole estuary. However, it is known from site visits to a number of areas that some flood defences are in a poor state of repair and could potentially be subject to change in shoreline management policy. There is also a need for a consistent approach with Portsmouth and Langstone Harbours, both of which are included within the relevant SMPs.
	Verdict on significance: 'Significant'
Stage 1 **Step 5: Recommendation on whether the estuary should be included in the SMP process (EGT5)**	**Verdict:** Step 3 – process issues assessed as grade 'A' Step 4 – management issues assessed as 'significant' Therefore from Step 5 of EGT5, the estuary scores '1' in terms of overall significance and should be included within the SMP process.
Stage 2 **Recommendation on how the estuary should be included in the SMP process (EGT6)**	It is considered practicable for the estuary to be considered within the relevant open coast SMP.
	Verdict: Include within open coast SMP.
Stage 3 **Recommendation on how far upstream the estuary should be included (EGT7)**	Inclusion up to the tidal limit is practical since the freshwater inputs are believed to be sluiced and not extend too far inland.
	Verdict: Chichester Harbour should be included up to the tidal limit.

Example 2: Humber Estuary

Estuary	Humber Estuary.
Location	Yorkshire, east coast of England.
Main characteristics	One of the major estuaries in England and Wales, with a very large catchment area and high river flows. Flood embankments throughout its length and extensive inter-tidal mudflats and salt marsh. Spurn Head spit extends across its mouth from the north and extensive sand flats and linear banks exist close to the mouth.
Data availability	*Futurecoast* database and assessment of estuaries. Considerable previous work exists, for example that associated with the Humber Geomorphological Studies and Land-Ocean Interaction Study (LOIS). This is one of the most heavily researched estuaries in the UK.
Stage 1 **Step 1: Significance of water exchange (EGT2)**	Total area: Humber Estuary is extremely large in terms of total estuary area, within the whole range of estuaries in England and Wales. Inter-tidal area: Humber Estuary has the largest inter-tidal estuary area. Channel length: The estuary has the largest shoreline length of all estuaries in England and Wales. Mouth area: Humber Estuary has an extremely large mouth area. Mouth width: Humber Estuary has a large mouth width. Tidal range: The estuary has a relatively large tidal range. Mean freshwater flow: The estuary has a very high mean freshwater flow. Estuary-specific knowledge of other parameters: Large tidal prism.
	Verdict on significance: Ratio of mouth area to mouth width is large. The coastal and estuarine sediments are soft and erodible. ‘Significant’

Stage 1 **Step 2: Significance of sediment exchange (EGT3)**	<u>Tidal asymmetry</u>: The estuary has a low Dronkers' Gamma, implying strong ebb dominance. A more detailed assessment of flood-ebb dominance is made in the *Futurecoast* estuary assessment. Here it is stated that landward of the constriction at the Humber Bridge, the tidal asymmetry switches to flood dominance. <u>Morphological features</u>: The Humber has a spit and both flood and ebb tide deltas. <u>Source/sink relationship</u>: The estuary is believed to be a strong sediment sink for both coarse and fine sediment, and further sediment deposition is likely with a rise in sea level. <u>Plume generation</u>: The estuary produces a significant plume of suspended sediment. <u>Estuary-specific knowledge of other parameters</u>: Results from the LOIS study indicate that the sediment plume can extend considerable distances seaward of the estuary mouth, out across the southern North Sea. The estuary has a very large catchment area. There is a plentiful source of sediment from both the eroding Holderness coast and the river input to the estuary.
	Verdict on significance: The presence of various morphological features indicates both a strong dependence on littoral drift from the updrift coast (to control spit evolution) and a strong inter-dependence between the estuary morphology and the tidal deltas, which offer a natural sheltering effect to the estuary mouth and adjacent open coast. 'Significant'
Stage 1 **Step 3: Relevance of process issues (EGT5)**	**Verdict on relevance of process issues:** Step 1 – shows significant water exchange Step 2 – shows significant sediment exchange Step 3 – therefore from EGT5, process issues are assessed as grade 'A' '
Stage 1 **Step 4: Significance of management issues (EGT4)**	<u>Historic reclamation</u>: There has been reclamation within the estuary. <u>Presence / absence of jetties</u>: There is no jetty at the estuary mouth. <u>Estuary-specific knowledge of other issues</u>: The scale of reclamation has been extensive. Possible future shoreline management policies may be to allow reclaimed areas to revert to salt marsh through 'managed realignment'. This would have implications for the size of the tidal delta and natural protection afforded to the open coast adjacent to the estuary mouth. There are numerous major ports, and dredging and spoil disposal occurs within the estuary. Such activities could potentially affect shoreline management policies. Additionally, the document makes reference to training walls and occasional channel switching at the confluence of the Rivers Trent and Ouse. There is considerable management pressure in relation to both industrial and nature conservation issues. The management policies along the updrift open coast are of critical importance to sediment supply to the estuary.

	Verdict on significance: 'Significant'
Stage 1 **Step 5: Recommendation on whether the estuary should be included in the SMP process (EGT5)**	**Verdict:** Step 3 – process issues assessed as grade 'A' Step 4 – management issues assessed as 'significant' Therefore from Step 5 of EGT5, the estuary scores '1' in terms of overall significance and should be included within the SMP process.
Stage 2 **Recommendation on how the estuary should be included in the SMP process (EGT6)**	The estuary is physically very large and the adjacent open coast SMP extends over a considerable distance, making it difficult to incorporate the estuary within the open coast SMP.
	Verdict: The Humber Estuary should have its own eSMP, but it is vital that this links strongly with the adjacent open coast SMP.
Stage 3 **Recommendation on how far upstream the estuary should be included (EGT7)**	It is necessary to consider the estuary to the tidal limit since there is potential for large-scale change in strategic management policy, and hence a large scale of impact upon estuarine processes and estuary-open coast process interactions. However, it may not necessarily be practicable or necessary to consider shoreline management policies into the tributaries of the Humber (the Rivers Ouse, Derwent, Trent, Don and Aire).
	Verdict: The estuary needs to be included in a manner that enables a robust assessment of tidal processes, although it may not be necessary to extend policy selection to the tidal limit of the tributaries of the Humber.

Example 3: Afon Artro

Estuary	Afon Artro.
Location	Gywnedd, Wales.
Main characteristics	Small estuary with sand and mudflats, seasonally variable freshwater flow, no industrial development, some reclamation and dredging for leisure use.
Data availability	*Futurecoast* assessment of estuaries. Limited previous work - SMP, Management plan for Pen Llyn a'r Sarnau cSAC.
Stage 1 **Step 1: Significance of water exchange (EGT2)**	Total area: The Artro is very small in terms of total area. Inter-tidal area: The Artro is very small in terms of inter-tidal area. Channel length: The Artro is small in terms of channel length. Mouth area: The estuary has a small mouth cross sectional area. Mouth width: There is no information presented on mouth width. Tidal range: The estuary has a moderate tidal range. Mean freshwater flow: There is no flow information presented. Estuary-specific knowledge of other parameters:
	Verdict on significance: The geology of the adjacent coast is soft. However, the water exchange is assessed as 'Insignificant' since the scale of exchange is so small.
Stage 1 **Step 2: Significance of sediment exchange (EGT3)**	Tidal asymmetry: Dronkers' Gamma is not presented, therefore it is difficult to make statements about present day tidal asymmetry. Morphological features: The existence of a spit and associated bar are indicative of strong northerly longshore drift on the open coast. Source/sink relationship: The estuary is largely in sedimentary balance although estuary is likely to be a small supplier of sediment to coastal zone. Plume generation: No information presented. Estuary-specific knowledge of other parameters: The majority of the estuary is in-filled with sandy sediments derived from marine sources. Other estuaries in the area have similar characteristics, indicating some exchange of sediment between the coast and estuary, although whether this is a relic or contemporary process is not known.
	Verdict on significance: There clearly is some interaction of sediment between the open coast and the estuary mouth since a spit is present, but the scale of sediment exchange with the estuary is unknown and therefore a 'Marginal' classification is ascribed under a precautionary principle.
Stage 1 **Step 3: Relevance of process issues (EGT5)**	**Verdict on relevance of process issues:** Step 1 – shows insignificant water exchange Step 2 – shows marginal sediment exchange Step 3 – therefore from EGT5, process issues are assessed as grade 'C'

Stage 1 **Step 4: Significance of management issues (EGT4)**	Historic reclamation: There has been no significant reclamation. Presence / absence of jetties: There is no jetty at the mouth. Estuary-specific knowledge of other issues: At the mouth of the estuary there is a breakwater on the northern shore. This limits wave penetration into the estuary at high water levels. This is contrary to the information in the Futurecoast database. Previous experience with the area indicates that marina dredging represents an important management issue for CCW, the local council and the Environment Agency Wales. These dredging operations are not documented in the *Futurecoast* database. It is also known from other sources that deposition of dredged material on the sand flat has created an artificial island. Additionally, earth works around the rear of Mochras Island and at the mouth of the estuary have constructed embankments that potentially have reduced the tidal prism.
	Verdict on significance: There does not appear to be large scope for anthropogenic intervention in the area since the areas is relatively undeveloped. There are some reported management issues, but overall, the assessment has been categorised as 'Marginal'.
Stage 1 **Step 5: Recommendation on whether the estuary should be included in the SMP process (EGT5)**	**Verdict:** Step 3 – process issues assessed as grade 'C' Step 4 – management issues assessed as 'insignificant' Therefore from Step 5 of EGT5, the estuary scores '3' in terms of overall significance and there is no need to include the estuary within the SMP.

Note: This example highlights the importance of local considerations, since if these had led to either (i) the consideration that management issues were 'significant', or (ii) that coastal processes were grade 'B', then the recommendation would have been reached that the estuary should be included in the SMP.

Example 4: Mersey Estuary

Estuary	Mersey Estuary.
Location	Lancashire, north-west England.
Main characteristics	Large macro tidal estuary characterised by narrow mouth and extensive port and industrial development.
Data availability	*Futurecoast* assessment of estuaries. 'Grey literature' reports.
Stage 1 **Step 1: Significance of water exchange (EGT2)**	Total area: The Mersey is the 7th largest estuary in England and Wales, as defined by total area. Inter-tidal area: The Mersey is also the 7th largest estuary in England and Wales, as defined by inter-tidal area. Channel length: The Mersey is medium-sized in terms of channel length. Mouth area: The Mersey has a medium mouth area. Mouth width: The Mersey has a medium mouth width. Tidal range: The Mersey has a high tidal range (8.4m at Liverpool on Spring tides). Mean freshwater flow: The Mersey has a relatively high mean flow. Estuary-specific knowledge of other parameters:
	Verdict on significance: 'Significant'
Stage 1 **Step 2: Significance of sediment exchange (EGT3)**	Tidal asymmetry: The estuary is strongly ebb dominant according to Dronkers' gamma. However, reference to the Futurecoast 'Assessment of estuaries' states that the estuary is also flood dominant in parts. Reference to other work indicates that the estuary is flood dominant overall, although it may be showing a tendency towards increasing ebb dominance near mouth and increasing flood dominance in the Inner Reaches. Morphological features: The estuary is a ria without spits, but has a strong littoral drift and both flood and ebb tidal deltas. Source/sink relationship: There are extensive sand banks and flats outside the mouth and extensive training walls. The estuary is assessed as being able to undergo more sedimentation and is therefore considered as acting as strong sink for both mud and sand. Plume generation: Estuary-specific knowledge of other parameters: Reference to previous more detailed work (HR, 1999; Thomas, 2000) suggests that the estuary may be in a state of equilibrium at present, having undergone accretion until 1970, followed by slight erosion after 1980.
	Verdict on significance: 'Significant'
Stage 1 **Step 3: Relevance of process issues (EGT5)**	**Verdict on relevance of process issues:** Step 1 – shows significant water exchange Step 2 – shows significant sediment exchange Step 3 – therefore from EGT5, process issues are assessed as grade 'A'

Stage 1 **Step 4: Significance of management issues (EGT4)**	Historic reclamation: The estuary has experienced reclamation. Presence / absence of jetties: There is no jetty at the mouth, but the river has been extensively trained. Estuary-specific knowledge of other issues: A number of other management issues include: ▪ navigation dredging ▪ construction of the Manchester Shipping Canal the role of which decreased fluvial freshwater and sediment supply; ▪ construction of various crossings which may have influenced the mobility of low water channels; ▪ a history of high industrial discharges and poor water quality; ▪ construction of various port facilities.
	Verdict on significance: 'Significant'
Stage 1 **Step 5: Recommendation on whether the estuary should be included in the SMP process (EGT5)**	**Verdict:** Step 3 – process issues assessed as grade 'A' Step 4 – management issues assessed as 'significant' Therefore from Step 5 of EGT5, the estuary scores '1' in terms of overall significance and should be included within the SMP process.
Stage 2 **Recommendation on how the estuary should be included in the SMP process (EGT6)**	It remains practicable to consider the estuary within the open coast SMP.
	Verdict: Include the estuary within the open coast SMP.
Stage 3 **Recommendation on how far upstream the estuary should be included (EGT7)**	The tidal limit lies at Howley Weir some 46 km upstream of the estuary mouth. In other studies the Mersey estuary has been subdivided into 3 reaches, the Inner, the Middle and the Outer. The Inner reach was taken to extend up to the tidal limit. For the Mersey this limit is probably practical for an SMP boundary, but this needs to be confirmed by local knowledge of processes.
	Verdict: The Mersey should be considered to the tidal limit.

Example 5: Yar Estuary

Estuary	Yar Estuary.
Location	Isle of Wight, central southern England.
Main characteristics	Small meso-tidal estuary that is undeveloped but has a history of reclamation and is enclosed by a breakwater.
Data availability	*Futurecoast* assessment of estuaries. Local knowledge.
Stage 1 **Step 1: Significance of water exchange (EGT2)**	Total area: In the context of all estuaries in England and Wales, the Yar has a small total area. Inter-tidal area: The Yar also has a small inter-tidal area. Channel length: The Yar has a small channel length. Mouth area: The Yar has a small-medium sized mouth area. Mouth width: The mouth width is small. Tidal range: The tidal range is relatively low (around 2.5m on spring tides). Mean freshwater flow: There is no data for the mean or maximum flow. The *Futurecoast* 'Assessment of Estuaries' reports that the freshwater flow is likely to be low and that the estuary is being subject to strong weather effects. Estuary-specific knowledge of other parameters:
	Verdict on significance: The geology of the adjacent coast is soft. However, the water exchange is assessed as 'Insignificant' since the scale of exchange is so small.
Stage 1 **Step 2: Significance of sediment exchange (EGT3)**	Tidal asymmetry: The Yar is strongly ebb dominant according to Dronker's Gamma. Morphological features: The estuary is a filled valley with marshes and mudflats enclosed by a spit. The estuary does not have any tidal deltas. Source/sink relationship: The Futurecoast 'Assessment of Estuaries' reports that the estuary mouth has adjusted to the reclamations which have taken place. The report also states that fine sediment may not penetrate further than the mouth of the estuary and that the spit may be a sink for sand sized sediment. Plume generation: Estuary-specific knowledge of other parameters:
	Verdict on significance: 'Insignificant'.
Stage 1 **Step 3: Relevance of process issues (EGT5)**	**Verdict on relevance of process issues:** Step 1 – shows insignificant water exchange Step 2 – shows insignificant sediment exchange Step 3 – therefore from EGT5, process issues are assessed as grade 'C'

Stage 1 **Step 4: Significance of management issues (EGT4)**	<u>Historic reclamation</u>: According to Table C.4, there has been no significant reclamation in the estuary. The point is known from local knowledge to be incorrect. Indeed, there has been substantial reclamation around the estuary since around 1850. These reclamations have involved the road crossing, construction of a railway embankments and enclosure of a number of small tributary valleys. <u>Presence / absence of jetties</u>: There is a jetty at the mouth <u>Estuary-specific knowledge of other issues</u>: The Futurecoast 'Assessment of Estuaries' reports that the estuary has been subject to dredging, a road crossing, a breakwater enclosure and a road causeway at the head of the estuary. There is a perception that the marshes within the Yar estuary are eroding due to a reduction is sediment supply caused by the dredged harbour at the entrance to the estuary. However, work being undertaken at present suggests that the marshes are relatively healthy and have not undergone significant change since around 1940.
	Verdict on significance: There is scope for small-scale realignment within the estuary, but the impact of this on the coastal system is considered to be minimal. 'Insignificant'.
Stage 1 **Step 5: Recommendation on whether the estuary should be included in the SMP process (EGT5)**	**Verdict:** Step 3 – process issues assessed as grade 'C' Step 4 – management issues assessed as 'insignificant' Therefore from Step 5 of EGT5, the estuary scores '3' in terms of overall significance and there is no need to include the estuary within the SMP. The estuary does not need to be included in the SMP process.

Annex F4: Previous attempts to provide generic definition of estuarine limits

Attempts have been made under the EU Urban Waste-Water Treatment Directive, the EU Habitats and Species Directive, and the EU Water Framework Directive to generically define the limits of an estuary. These efforts have resulted in very ambiguous definitions that allow a wide degree of flexibility in their application.

Elliott and McLusky (2002) recently published a paper entitled *"The need for definitions in understanding estuaries"*. In a section entitled *"Where does an estuary start and end?"* the authors identified that the limit of tidal rise within an estuary is divisible into three sectors:

- marine or lower estuary, in free connection with the open sea;
- middle estuary, with strong salt and freshwater mixing; and
- upper or fluvial estuary , characterised by freshwater, but subject to strong tidal action.

The authors recognised that the limits between these sectors are variable and subject to constant changes in river discharges and lunar cycles. They additionally made reference to the fact that the seaward limit of an estuary is equally difficult to define, since sub-tidal physical features, such as tidal deltas and linear sandbanks, can extend seaward of the mouth. Consequently, it has been stated that whilst this approach inevitably provokes debate, defining the limit of an estuary is best addressed by an 'expert view' (Elliott and Dewailly, 1995).

In order to provide guidance for those needing to delimit an estuary, whilst still acknowledging the inherent variability of such systems, Elliott and McLusky (2002) produced an 'Expert Judgement Checklist Approach', which contains questions such as:

- Is there the presence of erosion-deposition cycles in the channels and on the flats?
- Is there an asymmetrical flood and ebb tidal flow due to constricting effects and bottom profile of the estuary?
- Is there a turbidity maximum zone as found in the upper reaches of most macro-tidal estuaries?
- Where does the salinity penetrate on high, medium and low river flows?
- Is it possible to differentiate the inter-tidal fauna into marine, transitional and estuarine zones?