Cyfoeth Naturiol Cymru
Natural Resources Wales

# Advice on Assessment and Monitoring of Coastal and Estuarine Habitat Creation Schemes

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Christine Adnitt

Report No 162

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## Crynodeb Gweithredol

Gwnaeth CNC gomisiynu'r adroddiad hwn i ddarparu cyngor wedi'i seilio ar dystiolaeth ar gyfer asesiadau ffisegol a gofynion gwaith monitro ffisegol ac ecolegol er mwyn llywio datblygiad cynlluniau creu cynefinoedd llwyddiannus ar hyd aberoedd ac arfordiroedd agored Cymru. Mae'r cyngor yn cefnogi Rhaglen Genedlaethol Creu Cynefinoedd CNC drwy ddarparu fframwaith ar gyfer monitro prosiectau creu cynefinoedd a'r asesiad sydd ei angen er mwyn llywio'r gwaith gwerthuso prosiectau ar gyfer cyflawni amcanion creu cynefinoedd.

Mae'r cyngor a gynhwysir yn yr adroddiad hwn yn gwahaniaethu rhwng y gofynion lleiaf a'r gofynion optimwn ar gyfer asesu a monitro unrhyw gynllun penodol sydd wedi'i seilio ar set o feini prawf detholedig sydd yn hanfodol i'w lwyddiant. Mewn aberoedd, y rhain yw:

- ardal y cynllun o gymharu ag ardal yr aber mae wedi'i leoli ynddo;
- lleoliad y cynllun mewn aber; a
- sensitifrwydd y lleoliadau gwarchod natur o'i gwmpas.

Ar gyfer arfordiroedd agored, y rhain yw:

- maint prism llanw y cynllun o gymharu â chyflymdra cludo gwaddod ar hyd yr arfordir agored;
- lleoliad y cynllun ar hyd arfordir agored; a
- sensitifrwydd y lleoliadau gwarchod natur o'i gwmpas.

Yn y ddogfen gyngor hon, mae'r elfennau allweddol hyn wedi'u strwythuro'n 'goed penderfyniadau' sydd yn y pen draw yn arwain at set o wyth sefyllfa ddamcaniaethol o ran creu cynefinoedd rhynglanw ar gyfer pob un o'r cynlluniau hynny mewn aberoedd ac ar hyd arfordiroedd agored. Yna darperir cyngor ar yr asesiadau ffisegol lleiaf ac optimwn a gwaith monitro ffisegol ac ecolegol ar gyfer pob sefyllfa ddamcaniaethol, gan ddefnyddio egwyddorion cymesuredd. Mae cyngor ar asesiadau ffisegol yn cynnwys gwirio esblygiad y cynllun rhagweledig ac effeithiau rhagweledig ar yr amgylchedd o'i gwmpas, er mwyn llywio'r broses asesu ar gyfer yr effaith amgylcheddol a'r Rheoliadau Cynefinoedd. Darperir cyngor ar fonitro er mwyn mesur y cynnydd tuag at gyflawni amcanion cynlluniau ac er mwyn sicrhau bod unrhyw effeithiau rhagweledig ar yr amgylchedd sydd o'u cwmpas yn cael eu gwirio, a bod mesurau lliniaru (os nodir y rhain) yn effeithiol, ac os bydd angen mesurau lliniaru pellach.

Mae'r defnyddiwr yn cael ei dywys drwy ddull i ddiffinio'r gofynion asesu a monitro gan ddefnyddio'r elfennau allweddol sy'n benodol i'w gynllun. Disgrifir set o dechnegau asesu a monitro ac, o'u plith, argymhellir y rhai sy'n fwyaf priodol er mwyn eu gweithredu ar gyfer pob un o'r sefyllfaoedd damcaniaethol y gall y defnyddiwr eu cyrraedd drwy weithredu'r goeden benderfyniadau. Darperir hefyd amcangyfrif o gostau ar gyfer pob elfen o'r gwaith monitro. Gallai'r goeden benderfyniadau roi cyngor ar un asesiad neu gyfuniad o asesiadau gan ddibynnu ar y sefyllfa ddamcaniaethol dan sylw.

Cyn y gweithredir y goeden benderfyniadau, dylid bob amser datblygu model geomorffolegol cysyniadol cychwynnol er mwyn diffinio'r prif broblemau ffisegol ac ecolegol, a sut mae'r cynllun yn debyg o esblygu.  Yna gellid defnyddio canlyniadau'r model cysyniadol er mwyn dod o hyd i lwybr drwy'r goeden benderfyniadau. Dylid cynnal model cysyniadol yn ystod cyfnod cynharaf gwerthusiad y prosiect a'i ailystyried ar ôl nodi gofynion asesu er mwyn nodi unrhyw fylchau gwybodaeth mae angen rhoi sylw iddynt.

Disgrifir tri math arbennig o asesiad:

- barn broffesiynol (a all gynnwys defnydd model geomorffolegol cysyniadol);
- o'r gwaelod i fyny (dulliau rhagfynegi tymor byr, sy'n cynrychioli prosesau ffisegol ar raddfeydd gofod lleol dros raddfeydd amser byr); ac
- o'r brig i lawr (dulliau rhagfynegi hirdymor, sydd wedi'u seilio ar syniadau cysyniadol ac yn gweithredu ar raddfeydd gofod mwy o faint a graddfeydd amser hirach).

Disgrifir tri math arbennig o fonitro:

- Hydrolegol: llanwau a cheryntau llanw, a hinsawdd tonau;
- Morffolegol: ffurf esblygol o'r cynllun creu cynefinoedd mewn ymateb i brosesau gwaddodi ac erydu; ac
- Ecolegol: cynefinoedd (h.y. dosbarthiad cynefin ar raddfa fawr/is-haen, proffil, uchder llanw), llystyfiant (h.y. dosbarthiad rhywogaethau morfeydd heli/morwellt a'u helaethrwydd) a ffawna benthig (h.y. dosbarthiad rhywogaethau di-asgwrn-cefn a'u helaethrwydd) gan gynnwys nodweddion cymhwyso ar gyfer safleoedd Natura 2000.

Drwy weithredu'r cyngor, bydd CNC yn ystyried sut y gellir gweithredu'r cyngor o ran gofynion lleiaf ac optimwn i unrhyw brosiect penodol sydd wedi'i seilio ar farn arbenigwyr a chyfyngiadau ariannol neu dechnegol. Bydd angen hefyd ystyried materion penodol i gynlluniau fel rhan o unrhyw werthusiad ac arfarniad cynllun.

Gwnaeth CNC ddatblygu set benodol o ofynion i lywio cwmpas y cyngor hwn, ac felly mae ganddo gyfyngiadau o ran yr hyn mae'n ei gynnwys. Mae blaenoriaeth wedi cael ei rhoi i asesiadau ffisegol a gwaith monitro ffisegol ac ecolegol ar y cam hwn. Mae'n bosibl y bydd CNC yn ceisio sicrhau cyngor a datblygu canllawiau ar agweddau eraill o ddatblygu a chyflawni prosiectau creu cynefinoedd yn y dyfodol.

Gellid gweithredu'r dulliau a ddisgrifir yn y cyngor hwn i gamau eraill o werthuso cynlluniau creu cynefinoedd. Er enghraifft, gallai hyn gynnwys defnyddio'r model cysyniadol yn ystod y camau cynnar o gadarnhau dewis o safle dewisol (h.y. dethol safle). Gellid hefyd defnyddio cyngor yn yr adroddiad hwn i lywio  ystyriaeth ac asesiad o opsiynau dylunio, yn ogystal â'r gofynion ar gyfer asesu effeithiau opsiwn dewisol. Ar ôl dethol opsiwn dewisol, gellir defnyddio'r cyngor i lywio gofynion ac opsiynau o ran monitro ffisegol ac ecolegol. Gall yr allbynnau felly lywio penderfyniadau ynglŷn â chwmpas gwaith asesu a monitro y prosiect mewn gwahanol gyfnodau ym maes cynllunio a datblygu prosiectau gan gynnwys trafodaeth â rhanddeiliaid cyhoeddus a phreifat.

Bwriedir i staff CNC ddefnyddio'r cyngor hwn yn bennaf, ynghyd â'u partneriaid sy'n ymwneud â datblygu a chyflawni cynlluniau creu cynefinoedd arfordirol. Er gwaethaf y ffocws ar ddatblygu cyngor sy'n berthnasol i brosiectau tebygol yng Nghymru, efallai y byddai hefyd o fudd i lywio prosiectau y tu allan i Gymru. Mae CNC yn bwriadu rhoi prawf ar y cyngor ar gyfer prosiectau sydd ar y gweill, a byddent yn croesawu adborth ar ba mor berthnasol yw'r cyngor ar gyfer unrhyw brosiectau lle y'i gweithredir y tu allan i Gymru.

## Executive Summary


Natural Resources Wales (NRW) commissioned this report to provide evidence-based advice on physical assessments and physical and ecological monitoring requirements to inform the development of successful habitat creation schemes along the estuaries and open coasts of Wales. The advice supports NRWs National Habitat Creation Programme (NHCP) by providing a framework for monitoring of habitat creation projects and the assessment required to inform project appraisal for achieving habitat creation objectives.

The advice contained in this report differentiates between the minimum requirements and the optimum requirements for both assessing and monitoring any particular scheme based on a selected set of criteria that are critical to their success. In estuaries, these are:

- area of the scheme relative to the area of the estuary in which it sits;
- location of the scheme in an estuary; and
- sensitivity of the surrounding nature conservation designations.

For open coasts, these are:

- size of the scheme tidal prism relative to sediment transport rate along an open coast;
- location of the scheme along an open coast; and
- sensitivity of the surrounding nature conservation designations.

In this advice, these critical elements are structured into ‘decision trees’ that ultimately lead to a set of eight hypothetical intertidal habitat creation scenarios each for those schemes in estuaries and along open coasts. Advice on the minimum and optimum physical assessments and physical and ecological monitoring is then provided for each hypothetical scenario, using the principles of proportionality. Advice on physical assessments covers verification of predicted scheme evolution and predicted impacts to the surrounding environment, to inform the Environmental Impact Assessment and Habitats Regulations Assessment process. Advice on monitoring is provided for both measurement of progression towards achieving scheme objectives and to ensure that any predicted impacts on the surrounding environment are verified, and mitigation measures (if identified) are effective, and if any further mitigation is required.

The user is taken through a method to define the assessment and monitoring requirements using the critical elements that are specific to their scheme. A set of assessments and monitoring techniques are described from which the most appropriate are recommended for implementation for each of the hypothetical scenarios where the user may end up through application of the decision tree. An estimation of costs for each element of the monitoring is also provided. The decision tree could advise on one assessment or a combination of assessments depending on hypothetical scenario in question.

Before the decision tree is applied, an initial geomorphological conceptual model should always be developed to define the key physical and ecological issues, and how the scheme is likely to evolve. The outcomes of the conceptual model can then be used to support a route through the decision tree. A conceptual model should be undertaken at the earliest stages of project appraisal and revisited following identification of assessment requirements to identify any evidence gaps that need to be addressed.

Three main types of assessment are described:

- professional judgement (which may include use of a geomorphological conceptual model);
- bottom-up (short-term predictive methods, which represent detailed physical processes at local space scales over short timescales); and
- top-down (long-term predictive methods, which are based on conceptual ideas and operate at larger space and longer timescales).

Three main types of monitoring are described:

- Hydrological: tides and tidal currents, and wave climate;
- Morphological: evolving form of the habitat creation scheme in response to sedimentation and erosion; and
- Ecological: habitats (i.e. broad-scale habitat distribution/substrate, profile, tidal elevation), vegetation (i.e. saltmarsh/seagrass species distribution and abundance) and benthic fauna (i.e. invertebrate species distribution and abundance) including Natura 2000 qualifying features.

In applying the advice, NRW will consider how the advice regarding minimum and optimum requirements can be applied to any particular project based on expert judgement and financial or technical constraints. Scheme specific considerations will also need to be considered as a part of any scheme appraisal and evaluation.

NRW developed a specific set of requirements to inform the scope of this advice, and therefore it does have limitations as to what it covers. Priority has been given to physical assessments and physical and ecological monitoring at this stage. NRW may look to secure advice and develop guidance on other aspects of developing and delivering habitat creation projects in future.

The methods described in this advice could be applied to other stages of habitat creation scheme appraisal. For example, this could include use of the conceptual model at the early stages of confirming choice of preferred site (i.e. site selection). Advice in the report could also be used to inform the consideration and assessment of design options, in addition to requirements for impact assessment of a preferred option. Once a preferred option has been selected the advice can be used to inform physical and ecological monitoring requirements and options. The outputs can therefore inform decisions regarding the scope of project assessment and monitoring at various stages in project planning and development including discussion with public and private stakeholders.

This advice is intended primarily for use by NRW staff and their partners who are involved in the development and delivery of coastal habitat creation schemes. Despite the focus on developing advice which is applicable to likely Welsh projects, it may be considered helpful to inform projects outside Wales. NRW intend to test the advice on forthcoming projects, and would welcome feedback on the applicability of the advice for any projects where it is applied outside Wales.

# 1. Introduction

The second round of Shoreline Management Plans (SMPs) in Wales have recently been approved by Welsh Government. These plans set out the preferred policy for management of the shoreline over the next 100 years. All SMPs have been subject to a Habitats Regulations Assessment (HRA). The HRAs of all four plans wholly or partly within Wales concluded that their implementation would result in adverse effects to Natura 2000 sites, arising from loss of habitat due to coastal squeeze as a result of Hold The Line policies.

Each plan was subject to a test of alternatives and an imperative reasons of overriding public interest test, as set out in the Habitats Regulations. If these tests are satisfied, as they were for each of the SMPs, then a plan may proceed in spite of its negative effects. However, this may only occur if compensatory measures can be secured to ensure the coherence of the European site network is maintained. Welsh Government, as the competent authority for the SMPs has asked NRW to establish a National Habitat Creation Programme (NHCP) to secure the compensatory habitat required. This report looks to provide advice to NRW on physical assessments and physical and ecological monitoring requirements for habitat creation schemes in Wales to help support the delivery of the NHCP.

Whilst there is an increasing amount of guidance and experience available to support design and implementation of habitat creation schemes, there is a lack of clarity on the levels of detail to be applied to assessment and monitoring. Specifically, this advice looks to establish the minimum and optimum physical assessment, and physical and ecological requirements based on a range of hypothetical scenarios for estuarine and open-coast sites. NRW prioritised the development of advice on these key aspects as it is important to make the correct judgement in balancing the cost and time implications of assessments with the need to ensure that sufficient physical information is provided to reduce project risks to an appropriate level. The advice requirements have also been driven by the need to ensure a robust evidence base is secured and that there is a consistent approach to assessment and monitoring to inform habitat creation schemes in Wales.

The advice contained in this report is structured into six sections, including this one. An overview of the information detailed in Sections 2 to 6 is provided below.

Section 2 documents the approach to determine the minimum and optimum assessments and monitoring requirements.

- A first step of the approach involves the development of a conceptual geomorphological model which aims to identify baseline processes, issues to be considered, and how a scheme is likely to evolve and function within its wider setting.
- The process of defining hypothetical habitat creation scenarios for estuarine and open coast sites is then described which is based on critical elements such as the

size and location of a scheme and the sensitivity of the surrounding environment. A total of eight hypothetical scenarios are identified guided by the use of decision matrices.
- For each scenario the minimum and optimum physical assessment methods are identified. These assessments are aimed at predicting potential scheme evolution and impacts to the surrounding environment with the primary purpose of informing the Environmental Impact Assessment and Habitats Regulations Assessment part of scheme appraisal.
- Minimum and optimum physical and ecological monitoring requirements are also identified for each scenario, which relate to tracking scheme progress/reaching scheme objectives, and identifying impacts to the surrounding environment.
- Assessments and monitoring identified for the hypothetical scenarios are presented within look-up tables.

Section 3 provides a methodology for developing an initial conceptual geomorphological model in greater detail, including the information required and where it is likely to be available. Section 4 defines the range of physical assessments (top-down and bottom-up) which may apply to the hypothetical scenarios identified to support the understanding of a habitat creation scheme. Section 5 summarises the monitoring methods including the range of techniques, the associated frequency and timescale for their application. Section 6 estimates monitoring costs to help gauge the scale of potential spend associated with monitoring of a habitat creation scheme.

Whilst the purpose of the assessments and monitoring described in this advice relates to specific stages of habitat creation scheme appraisal, the methods described could be applied to several other stages; for example, site selection and evaluation of design options. Outputs can therefore inform decisions regarding the scope of project assessment and monitoring at various stages in project planning and development, including discussion with public and private stakeholders.

At this stage NRW has prioritised advice on physical assessments and physical and ecological monitoring only. However, within a habitat creation scheme appraisal a wider set of considerations is likely to be required including a range of other topic receptors. Scheme specific considerations will also need to be considered which cannot be identified within this advice.

Physical parameters accounted for in this advice relate to hydrodynamic and geomorphological processes. Consideration of water quality, physico-chemical parameters (such as temperature, salinity, dissolved oxygen, nutrients, pH and turbidity), hydrology and sediment contamination are outside the scope of this advice which may need to be considered once a specific project is identified.

Advice in this report will need to be reviewed by NRW following testing its application on future habitat creation schemes including consideration of any lessons learnt. There may also be future developments in assessment and monitoring techniques which may be appropriate to build into the advice. The advice contained within this report is therefore not definitive. NRW will consider how the advice regarding minimum and optimum requirements can be applied to any particular project based on expert judgement and financial or technical constraints. NRW may look to secure advice and develop guidance on other aspects of developing and delivering habitat creation projects in future.

This advice is Welsh specific and is based on the coastal and estuarine environment and habitat creation requirements of Wales. The report is intended to inform NRW staff and their partners who are involved in the development and delivery of coastal habitat creation schemes. There may be elements of the advice which are also relevant to habitat creation scheme appraisal outside Wales and NRW would welcome feedback on its applicability elsewhere.

# 2. Approach

Creation of intertidal habitat can be achieved using two main approaches; managed realignment and regulated tidal exchange. Managed realignment can be defined as setting back the line of actively-maintained defence to a new line inland of the original, or preferably to rising ground, and promoting the creation of habitat on the land between the old and new defences (or rising ground). Removal of the front-line defence is typically achieved in two ways; bank realignment where the defence is totally removed or breach realignment where a section of the defence is either lowered or removed. The tide can then inundate the exposed land during each tidal cycle allowing the floodplain to expand until it meets the new inland line. Depending on many factors, the flooded land will over time be occupied by tidal wetland environments including mudflat and saltmarsh.

Regulated tidal exchange is used to regulate the inflow and outflow of water to a scheme behind fixed sea defences, through engineered structures such as sluices, tide-gates or pipes. This allows control of the flood regime through design and operation of the structures. The manipulation of water levels across the scheme can then be used to create (as far as possible) the desired habitats through gradual adjustment of vegetation colonisation.

These two approaches can be supported by a variety of design techniques in order to create and sustain the particular form or structure that supports the desired wetland ecological functions. These include placement of material to create a higher intertidal profile, excavation of material to create a lower intertidal profile and sculpting smaller areas to achieve micro-topography for specific purposes.

In most cases, physical processes are the major influence on the form and function of a habitat creation scheme. Tidal wetland species have the opportunity to colonise the newly created physical habitat that is available and particular species are able to tolerate the variable conditions that are formed by the physical processes. This means that creating the suitable physical and hydrological conditions (with adequate tidal exchange) for a particular habitat offers the best opportunity to create the desired ecological features.

The objective of this report is to provide structured advice to NRW on minimum and optimum physical assessments and physical and ecological monitoring for potential intertidal habitat creation schemes of various sizes and locations that could be implemented in Welsh estuaries and along its open coast. A generic approach is adopted, using professional judgement to identify the level of risk to the two main issues of a habitat creation scheme; impacts on the surrounding environment and failure to develop a fully functioning scheme which has the best chance of naturally evolving to support the required compensatory habitat with minimum intervention or ongoing maintenance.

## 2.1. Conceptual Geomorphological Model

Prior to defining the minimum and optimum assessments and monitoring, an initial geomorphological conceptual model (qualitative) should be developed to have a clear understanding of the physical and ecological issues to be addressed, and how the scheme is likely to evolve and function within the context of its wider setting. A conceptual model, which is defined as a report that describes the issues by collation of previous work, should always be completed regardless of the scale and location of the scheme under consideration. The model should identify the different physical process areas of the scheme and its surrounding environment, such as morphology, sediment dynamics, hydrodynamics, and human activities, and how they interact. Ecological aspects should also be considered in the conceptual model where they are directly linked to morphological processes, and to support the requirement for more detailed ecological monitoring at a later stage. These issues will be at a whole estuary or whole coast level and at a more local level. The aims of the conceptual model are three-fold:

- describe the baseline physical environment;
- predict qualitatively how the habitat creation scheme is likely to evolve and function over the short-term (first 5-10 years), medium-term (10-20 years) and longer-term (greater than 20 years) within the context of its wider setting, sea-level rise and sediment supply; and
- predict potential changes in the surrounding environment caused by the scheme and how these might impact on the wider interests in the estuary or along the coast. At the conceptual model stage, there could be several scheme options under consideration and each one should be considered as to how they may cause future environmental change.

Taking account of the outcomes of the conceptual model and applying the principles of proportionality, the key minimum and optimum assessments and monitoring can be scoped to inform scheme success and determine environmental impacts. Once the conceptual model has been developed and used to inform appropriate levels of assessment and monitoring, it should also be used to determine if there are any data gaps which require addressing to apply the identified assessments. How to develop a conceptual model using a wide range of information types is presented in Section 3.

## 2.2. Impacts on the Surrounding Environment

To define the level of detail of assessments and monitoring required to understand the impacts on the environment surrounding a scheme, a set of hypothetical habitat creation scenarios are created by variously combining three critical elements of a scheme:

- the size of the tidal prism of the scheme relative to that of the surrounding environment. Higher risk of impact will typically occur where the tidal prism of the scheme is large relative to the estuary tidal prism or where open coast longshore sediment transport rates are low relative to the scheme tidal prism. In this advice, the area of the scheme compared to the area of the estuary are used as proxies for tidal prism (see Section 2.3.1);
- the location of the scheme within the estuary or along the coast. A scheme in the upper reaches of an estuary may have relatively higher risk of impact than a scheme (of the same size) in the lower reaches. Similarly, a scheme located at the end of a coastal sediment transport pathway will have lower risk of impact than a scheme at the start of the pathway; and
- the sensitivity of the environment in which the scheme is situated. Higher risk of impact will occur where the habitat creation scheme occurs in an estuary or along an open coast with nationally and/or internationally designated nature conservation sites.

Each of these three elements is discussed separately in relation to estuaries (see Section 2.3) and open coasts (see Section 2.4).

## 2.3. Estuarine Habitat Creation Schemes

Summary advice on how to define habitat creation schemes in estuaries with respect to their relative level of risk of impact to the surrounding environment is provided in Table 1. Details of the rationale behind the chosen parameters and their risks are provided in Sections 2.3.1 to 2.3.3.

Table 1: Definitions of schemes with respect to their relative level of impact in estuaries

| Parameter | Relative Risk of Impact | |
|---|---|---|
| | Low | High |
| Area of the habitat creation scheme | scheme area is less than 2% of the estuary area | scheme area is greater than 2% of the estuary area |
| Location of the habitat creation scheme | scheme is in the lower estuary defined by an upstream point where the estuary width reduces significantly or a point midway between the mouth and the tidal limit | scheme is in the upper estuary defined by a downstream point where the estuary width increases significantly or a point midway between the mouth and the tidal limit |
| Sensitivity of the surrounding estuary | scheme is in an estuary that does not contain designated sites with features that could potentially be affected | scheme is in an estuary that contains designated sites with features that could potentially be affected |

### 2.3.1. Area of the Scheme Relative to the Area of the Estuary

In general, larger schemes in estuaries will require more detailed assessment and monitoring, since the potential impacts are likely to be of greater significance to the existing baseline conditions. With no habitat creation, the geomorphology, or shape of the estuary, that dictates the extent and mix of physical habitats, will continue to change in response to long-term erosional and depositional processes. With large-scale habitat creation, alterations in the physical processes and sediment dynamics within the estuary are expected that will affect this mix of habitats and the ecological functions dependent on them. Large scale habitat creation would result in a significant increase in the amount of water entering and leaving the estuary on each tide (tidal prism), potentially affecting estuary processes and putting pressure on the estuary mouth. Also, the newly created scheme would present new sediment demand or a sink that will affect estuary bathymetry and the extent of mudflats and saltmarshes over the long-term. If the scheme is relatively small and inundated by water from an adjacent large estuary, then its absolute size may be of little overall consequence to the continued functioning of the system.

Tidal prism can be defined as the volume of water that enters an estuary or a habitat creation scheme on each tidal cycle (the volume difference between high water and low water). Leggett *et al*. (2004a, b) suggested that there is an approximate threshold for the scheme tidal prism of around 10% of the tidal prism of the estuary, above or below which the level of risk of impact to its surroundings changes. If a habitat creation scheme will contain less than 10% of the volume of water entering the existing or projected system (usually measured on a spring tide) then it will have relatively low risk of impact. Conversely, if a scheme will have a tidal prism that is greater than 10% of the estuary tidal prism, it will be relatively high risk.

The proposition of Leggett *et al*. (2004a, b) to use a 10% tidal prism threshold is based on previous experience alone with no scientific rationale, either theoretical or empirical. For this reason, a 10% threshold is not recommended in this advice. Although prediction of the initial tidal prism in a habitat creation scheme is straightforward if topography data is available, it will change as the scheme evolves and in response to sea-level rise. Hence, the use of proposed habitat creation area, which is an easily measured parameter, is favoured as a proxy for tidal prism. This is considered a reliable alternative, because in mature saltmarsh (elevations between approximately mean high water neap and mean high water spring tide) there is an approximate linear relationship between scheme area and tidal prism (Williams *et al*., 2002) (Figure 1).

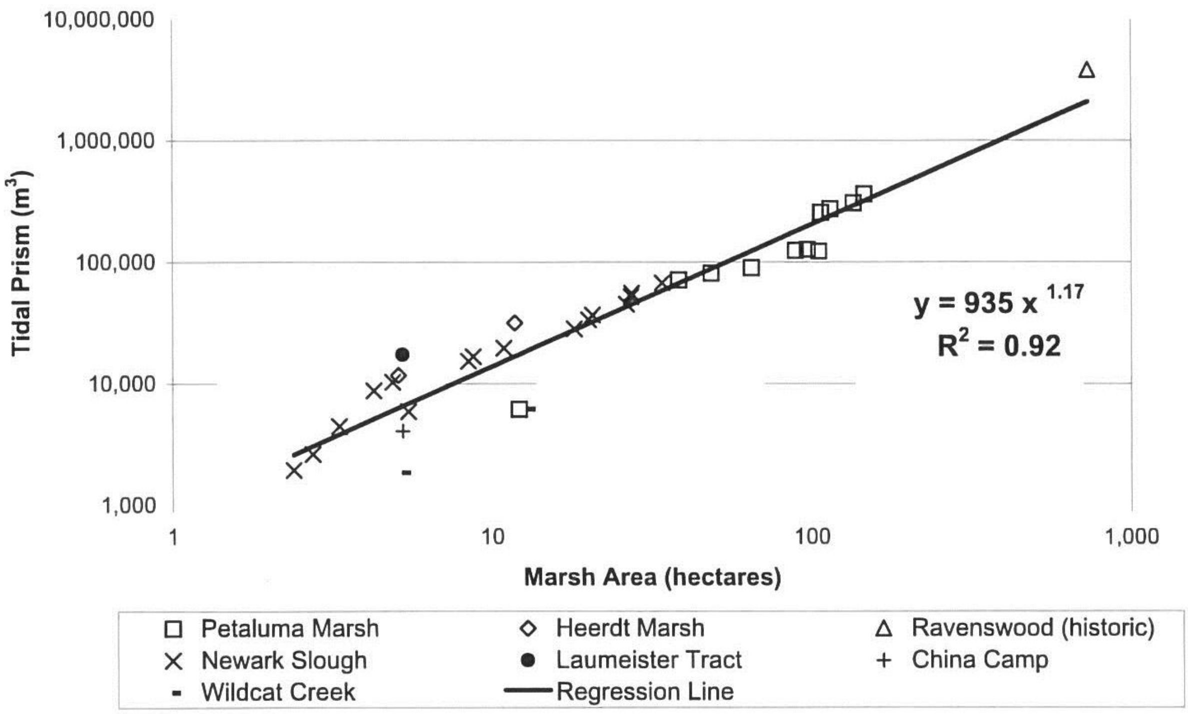


Figure 1: Relationship between tidal prism and saltmarsh area for mature ancient saltmarshes in San Francisco Bay (Williams et al., 2002). Note the exponent is close to 1, indicating an almost linear relationship. The tidal prism is relative to mean higher high water in California which is the approximate elevation of the mature marsh plain, equivalent to mean high water spring in the United Kingdom.

To define a scheme area to estuary area threshold, analysis of 42 candidate habitat creation schemes (provided by NRW) along the west coast of Wales has been undertaken. This analysis shows that an arbitrary threshold is at a scheme area of around 2% of the area of the estuary (Figure 2) for these examples. Hence, for the purposes of this advice and as a broad precautionary principle, when the area of a habitat creation scheme is greater than 2% of the area of the adjacent estuary, more detailed assessment and monitoring is likely to be needed. Given this rationale, two alternatives that reflect size (area) in estuaries are recommended in this advice (Table 1):

- large scheme area relative to estuary area (greater than 2%) where the risk of impact is considered to be relatively high; and.
- small scheme area relative to estuary area (less than 2%) where the risk of impact is considered to be relatively low.

The 2% threshold is estimated based on analysis of a limited number of potential small schemes in west Wales (Figure 2). Although these potential schemes are likely to be representative of sites elsewhere in Wales, the threshold value may be different outside Wales. Also, it may not be applicable for large schemes (e.g. Steart) in large estuaries (e.g. Severn Estuary) and in these cases, expert judgement may be required to define which area scenario the potential scheme fits into. It is possible that significant uncertainties and risks may still be apparent if a scheme is not fully assessed and/or monitored, even though it falls below the 2% threshold.

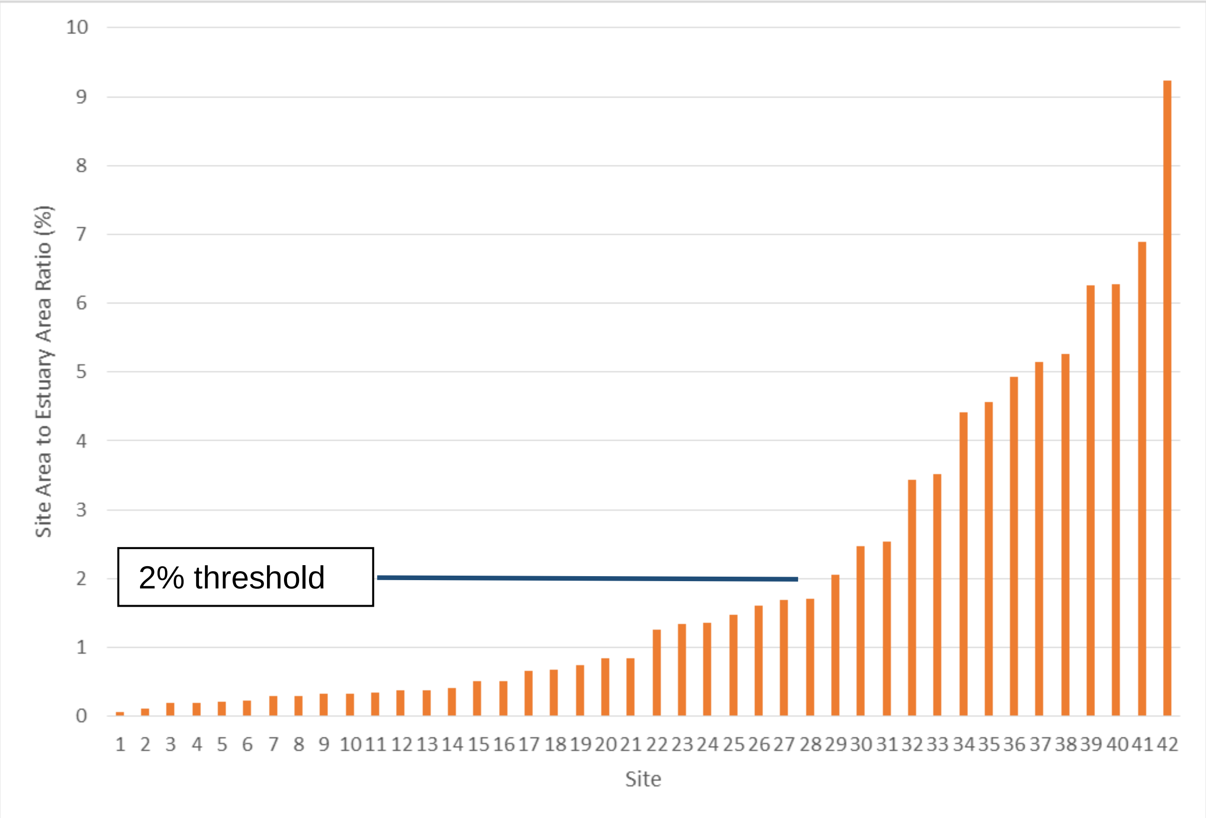


Figure 2: Scheme area to estuary area ratio for 42 candidate habitat creation schemes in west Wales.

### 2.3.2. Location of the Scheme in an Estuary

In general, habitat creation schemes that are located in the upper parts of an estuary will have potential for higher risk of impact than schemes further downstream in the lower parts. This is because schemes in the upper reaches may exert relatively more influence on water levels than schemes (of the same size) in the lower reaches. The tidal prism of the estuary increases approximately exponentially from the normal tidal limit to the mouth and so the effect of opening a new area to tidal inundation could potentially be much greater in the upstream reaches compared to the downstream reaches. Two methods are recommended in this advice to define the boundary between the upper and lower reaches of an estuary:

- choose a point in the estuary where the width changes significantly (i.e. the tidal prism changes significantly); or.
- choose a point midway between the mouth (defined by the transition to an unconfined open coast; effectively a straight line between the last two constrained points in the estuary) and the normal tidal limit (the point at which the level of an estuary ceases to be affected by tidal flow).

Although the natural shape of an estuary is funnel-shaped, many have a ‘pinch-point’ where the estuary becomes significantly wider downstream compared to upstream (Figure 1). This is the case in many Welsh estuaries and the boundary between the upper and lower reaches can be taken at this point.

If there is no distinct ‘pinch-point’ then the boundary is more arbitrary and can be taken as mid-way between the mouth and the normal tidal limit. However, if a scheme is located adjacent to the ‘pinch-point’ defined in this way, then the conceptual model together with expert judgment should be used to decide whether the scheme is in the upper or lower estuary (i.e. the boundary should be adjusted accordingly).

The appropriate level of detail of assessment and monitoring can then be applied. It may be reasonable in these types of case to adopt a precautionary approach (i.e. define the scheme as upper estuary).

Two alternatives that reflect the location of the scheme in an estuary are recommended in this advice (Table 1):

- schemes in the upper estuary where the risk of impact is considered to be relatively high; and
- schemes in the lower estuary where the risk of impact is considered to be relatively low.

Figure 3: 'Pinch-point' in the Teifi Estuary

### 2.3.3. Sensitivity of the Surrounding Nature Conservation Designations

A prime driver in determining the scale of assessment and monitoring required is the nature conservation interest in the vicinity of the scheme. In many cases, these interests will be protected under a range of national and international conservation designations including Special Protection Areas (SPA), Special Areas of Conservation (SAC), Ramsar Sites and Special Sites of Scientific Interest (SSSI). The enforcement of these designations by the relevant conservation authority will often define the scale of assessment and monitoring required for a given scheme. This will largely be governed by the need to demonstrate no adverse effects to designated features.

The recommended definition of sensitivity is based on whether an estuary (or open coast) within which the habitat creation scheme is situated contains designated sites with features that could be impacted by the creation of new habitat. Key physical process issues will usually include the potential for erosion of designated areas such as saltmarsh, mudflat, beach, shingle, or dune habitats. The specificity of such issues will often require the application of some of the more robust and accepted techniques along with professional judgement. So, two alternatives that reflect the sensitivity of the surrounding environment are recommended in this advice (Table 1):

- relatively high sensitivity estuaries (or open coasts) that contain designated sites with features that could potentially be affected by a habitat creation scheme; and
- relatively low sensitivity estuaries (or open coasts) with no designated sites that contain features that could potentially be affected by a habitat creation scheme.

## 2.4. Open Coast Habitat Creation Schemes

Summary advice on how to define habitat creation schemes along open coasts with respect to their relative level of risk of impact to the surrounding environment is provided in Table 2. Details of the rationale behind the chosen parameters and their risks are provided in Sections 2.4.1 and 2.4.2 (note the environmental sensitivity of the open coast is described alongside estuary sensitivity in Section 2.3.3).

Table 2: Definitions of schemes with respect to their relative level of impact along open coasts

| Parameter | Relative Risk of Impact | |
|---|---|---|
| | Low | High |
| Area of the habitat creation scheme | scheme has a small tidal prism relative to longshore sediment transport rate ($K_c$ value less than 75*) | scheme has a large tidal prism relative to longshore sediment transport rate ($K_c$ value greater than 75*) |
| Location of the habitat creation scheme | scheme is located at the end of a longshore sediment transport pathway | scheme is located within a longshore sediment transport pathway |
| Sensitivity of the adjacent coast | scheme is along a coast that does not contain designated sites with features that could potentially be affected | scheme is along a coast that contains designated sites with features that could potentially be affected |

*the definition of $K_c$ is described in section 2.4.1

### 2.4.1. Size of Scheme Tidal Prism Relative to Sediment Transport Rate along an Open Coast

Along open coasts, the physical effects of the extra tidal prism created by a habitat creation scheme will be less significant than in estuaries. However, the discharge through the scheme entrance is important to consider with respect to its potential effect on longshore sediment transport. Relatively low discharges compared to longshore sediment transport rates could result in the entrance to the scheme becoming blocked by sediment transported (as a bar or spit) into it from alongshore. Relatively high discharges could potentially transport longshore sediment into the offshore and/or could interrupt sediment transport from one side of the entrance to the other.

The recommended definition of a threshold from which the level of assessment and monitoring can be gauged is through the use of inlet stability analysis. Stability is primarily determined by the balance between the rate of sediment supply (rate of longshore sediment transport) to the inlet (the habitat creation scheme entrance) and tidal flows through the entrance. Gao and Collins (1994) defined a coefficient of inlet stability (Kc) based on a relationship between tidal prism, freshwater flow and longshore sediment transport rate:

- $K_c = [P+(0.5.T_p.Q_f)]/M$

where:
- Kc = coefficient of inlet (entrance) stability
- M = longshore sediment transport rate (m3/year)
- P = tidal prism (m3)
- Qf = freshwater flow (m3/s)
- Tp = duration of the tidal period (s)

Typically, habitat creation schemes will have no freshwater inflow and the relationship can be reduced to:
- Kc = P/M

Gao and Collins (1994) categorised stability according to the $K_c$ ranges and classifications presented in Table 3.

Table 3: Coefficient of inlet stability ($K_c$) values and stability classification (Gao and Collins, 1994)

| $K_c$ range | Stability Classification | |
|---|---|---|
| >150 | Good conditions, good flushing, minor bar | Extremely high stability |
| 100-150 | Bar is usually more offshore | High stability |
| 50-100 | Large bar by the entrance, but usually a channel through the bar | Moderate stability |
| 20-50 | Typically the bar bypasses and storm events provide flushing | Low stability |
| <20 | Very unstable entrance, mainly just outflow channels | Highly unstable |

Using the values of Kc for a potential habitat creation scheme as a guide, two alternatives that reflect size are recommended for open coast schemes (Table 2):
- open coast schemes with small tidal prism relative to longshore sediment transport rate ($K_c$ values less than 75; mid-range of moderate stability); and
- open coast schemes with large tidal prism relative to longshore sediment transport rate ($K_c$ values greater than 75; mid-range of moderate stability).

If circumstances arise where there is a freshwater input to a habitat creation scheme, then the full equation would need to be applied.

### 2.4.2. Location of the Scheme along an Open Coast

The coast of Wales can be divided into numerous littoral cells and sub-cells, which are defined lengths of shoreline within which the cycle of bedload sediment erosion, transport and deposition is essentially self-contained. The boundaries of a littoral sub-cell are typically headlands or sinks such that transport of sediment into the sub-cell from the adjacent compartments is restricted. Sediment enters a sub-cell from rivers draining the coastal watersheds and is then transported alongshore and cross-shore within the sub-cell.

Littoral cells are important in understanding regional sediment processes and sediment budgets and the potential impacts an open coast habitat creation scheme might have on them. Two alternatives that reflect the location of a scheme relative to its encompassing littoral sub-cell are recommended in this advice (Table 2):

- a scheme located at the end of a longshore sediment transport pathway within a sediment sub-cell with relatively low risk of impact on sedimentary processes; and
- a scheme located within a longshore sediment transport pathway within a sediment sub-cell with relatively high risk of impact on sedimentary processes.

### 2.5. Hypothetical Scenarios

This advice to NRW applies the principle of proportionality as a means of determining the types of assessments and monitoring and their level of detail that are appropriate in habitat creation schemes. Leggett *et al*. (2004a, b) defined proportionality as applying an extent of investigation, implementation or monitoring to reflect the size (physically and/or in relation to the importance, risks, or functional consequence) of the scheme in question. Assessments and monitoring of eight hypothetical scenarios for estuaries and eight hypothetical scenarios for open coasts are provided in Figures 2.4 and 2.5. These hypothetical scenarios have been developed using all combinations of the three critical elements of habitat creation schemes.

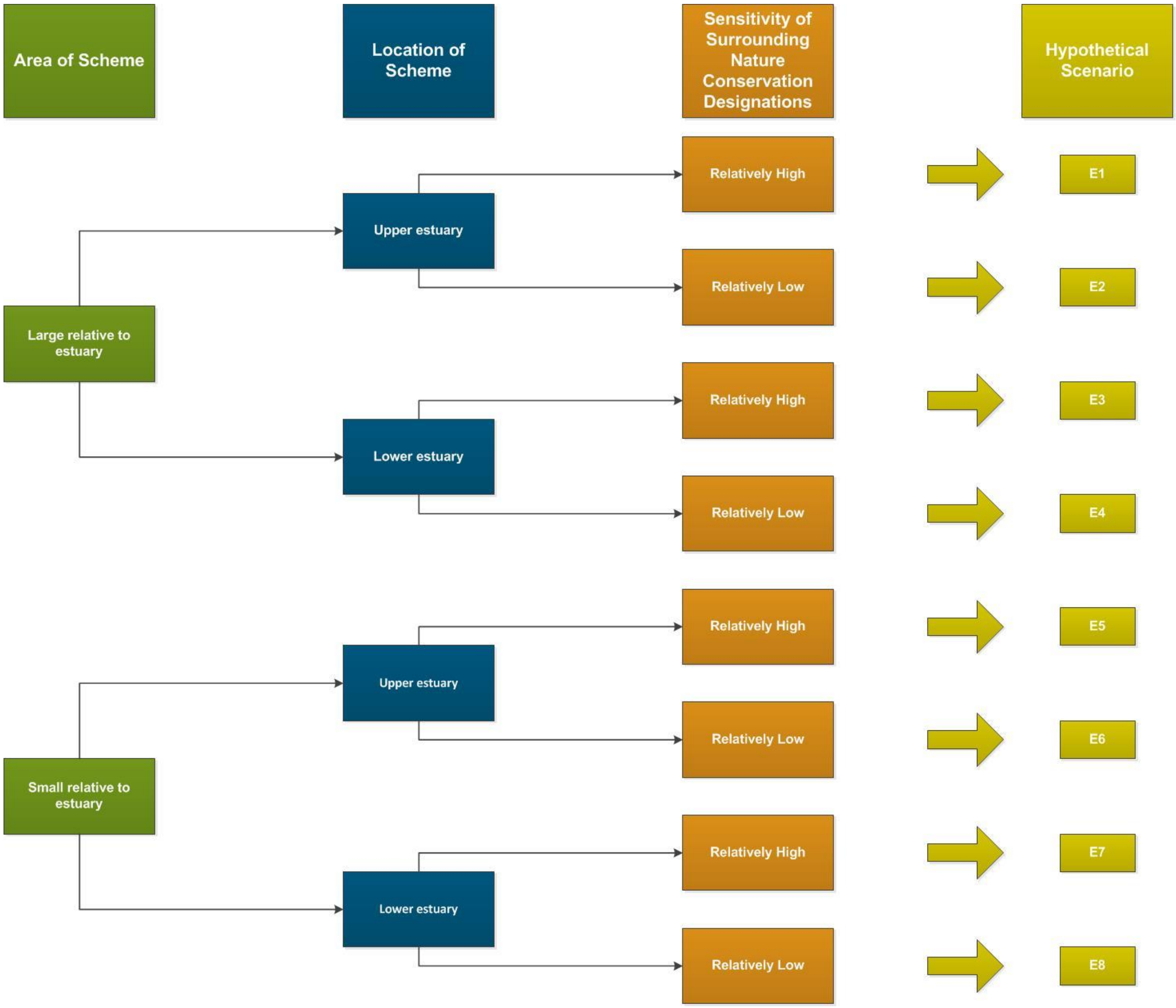


Figure 4: Eight hypothetical scenarios for estuary schemes used to define minimum and optimum assessments and monitoring. For Tables 4, 5,10 and 11 the following acronyms are used: LA = Large relative to estuary, SA = Small relative to estuary, UE = Upper estuary, LE= Lower estuary, HS= Relatively high sensitivity of surrounding nature conservation designations, LS= Relatively high sensitivity of surrounding nature conservation designations.

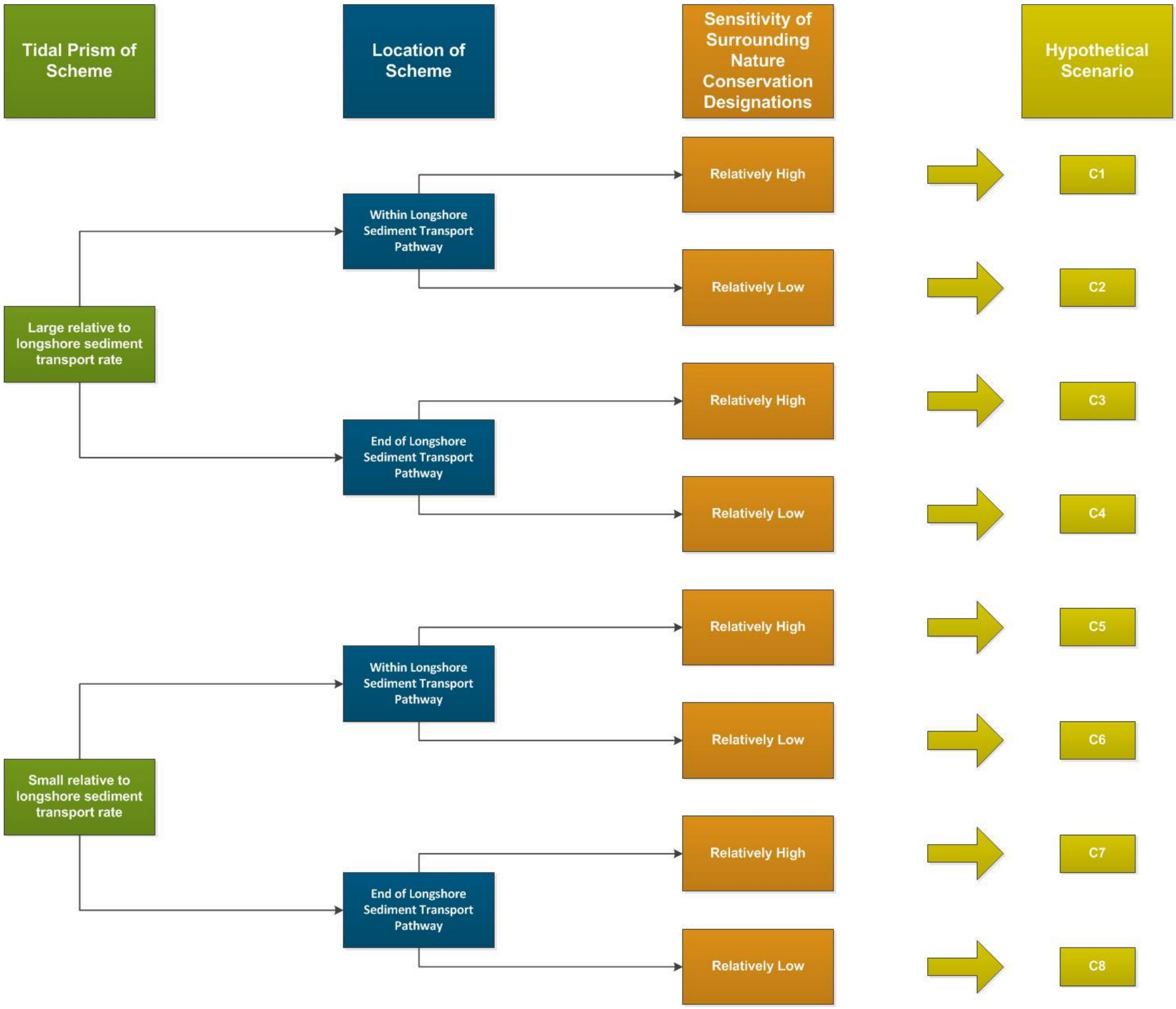


Figure 5: Eight hypothetical scenarios for open coast schemes used to define minimum and optimum assessments and monitoring. For Tables 6, 7 and 12 the following acronyms are used: LA = Large relative to longshore sediment transport rate, SA = Small relative to longshore sediment transport rate, WP = Within longshore sediment transport pathway, EP = End of longshore sediment transport pathway, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively high sensitivity of surrounding nature conservation designations.

## 2.6. Physical Assessments

There is a range of tools to assess physical and sedimentary process issues associated with habitat creation schemes. These tools can be categorised as ‘bottom-up’ or ‘top-down’ according to how they deal with physical changes in space and time. Bottom-up methods are short-term predictive methods, which represent detailed physical processes at local space scales over short timescales, which are typically hydrodynamic (tidal current and wave modelling) and sediment transport modelling. Top-down methods are long-term predictive methods, which are based on conceptual ideas and operate at larger space and longer timescales (typically historical trend analysis/expert geomorphological assessment and regime theory/rollover).

The number and sophistication of assessments to be applied to physical and geomorphological process issues will vary between habitat creation schemes. For the hypothetical scenarios under consideration, it may be possible to assess using only professional judgement based on the conceptual model (and analogue sites) and expert knowledge of how to interpret the model or, depending on the size of the scheme, its location and the sensitivity of the surrounding environment, it may warrant more detailed and costly numerical modelling. For example, investigation of small schemes with low environmental sensitivity may not need to be expansive and might be achieved proportionately through use of professional judgement only, using the outcomes of the conceptual model. It would be disproportionate to run a numerical model of the creek system and detailed monitoring over subsequent years post-implementation. If the estuary has statutory nature conservation designations of national or international importance, then a more proportionate approach (even for a small scheme) might be needed to complete detailed numerical assessments.

Minimum and optimum assessments for each of the hypothetical scenarios for estuaries and open coasts are provided in the decision matrices in Tables 4 to 7. They are set out with no hierarchy so that no one particular factor (size, location or environmental sensitivity) dominates the decision about the technique(s) required to be used for scheme assessment (i.e. applying proportionality). Further advice on physical assessments is presented in Section 4. Wave modelling and river modelling are not included in the estuary assessments, as they are unlikely to be needed on most potential estuarine habitat creation schemes in Wales. However, their potential use should be investigated on a site-by-site basis.

Table 4: Minimum assessments for each of the eight hypothetical scenarios for estuaries and where they can be found in this report. LA = large relative to estuary, SA = small relative to estuary, UE = Upper estuary, LE = Lower estuary, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively high sensitivity of surrounding nature conservation designations.

| Assessment Method | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | UE | UE | LE | LE | UE | UE | LE | LE |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Conceptual Model | Professional Judgement (Section 3) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Top-down | Historical Trend Analysis/Expert Geomorphological Assessment (Section 4.1.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Regime Theory/Rollover (Section 4.1.2) | ✓ | | | | | | | |
| Bottom-up | Water Level Modelling (Section 4.2.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Tidal Current Modelling (Section 4.2.1) | ✓ | | ✓ | | | | | |
| | Sediment Transport Modelling (Section 4.2.2) | ✓ | | ✓ | | | | | |

Table 5: Optimum assessments for each of the eight hypothetical scenarios for estuaries and where they can be found in this report. LA = large relative to estuary, SA = small relative to estuary, UE = Upper estuary, LE = Lower estuary, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively high sensitivity of surrounding nature conservation designations.

| Assessment Method | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | UE | UE | LE | LE | UE | UE | LE | LE |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Conceptual Model | Professional Judgement (Section 3) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Top-down | Historical Trend Analysis/Expert Geomorphological Assessment (Section 4.1.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Regime Theory/Rollover (Section 4.1.2) | ✓ | ✓ | | | | | | |
| Bottom-up | Water Level Modelling (Section 4.2.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Tidal Current Modelling (Section 4.2.1) | ✓ | | ✓ | | ✓ | | ✓ | |
| | Sediment Transport Modelling (Section 4.2.2) | ✓ | | ✓ | | ✓ | | | |

Table 6: Minimum assessments for each of the eight hypothetical scenarios for open coasts and where they can be found in this report. LA = large relative to longshore sediment transport rate, SA = small relative to longshore sediment transport rate, WP = Within longshore sediment transport pathway, EP = End of longshore sediment transport pathway, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively high sensitivity of surrounding nature conservation designations.

| Assessment Method | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | WP | WP | EP | EP | WP | WP | EP | EP |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Conceptual Model | Professional Judgement (Section 3) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Top-down | Historical Trend Analysis/Expert Geomorphological Assessment (Section 4.1.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bottom-up | Water Level Modelling (Section 4.2.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Tidal Current Modelling (Section 4.2.1) | ✓ | | | | | | | |
| | Wave Modelling (Section 4.2.1) | ✓ | ✓ | | | ✓ | ✓ | | |
| | Sediment Transport Modelling (Section 4.2.2) | ✓ | ✓ | | | ✓ | ✓ | | |

Table 7: Optimum assessments for each of the eight hypothetical scenarios for open coasts and where they can be found in this report. LA = large relative to longshore sediment transport rate, SA = small relative to longshore sediment transport rate, WP = Within longshore sediment transport pathway, EP = End of longshore sediment transport pathway, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively high sensitivity of surrounding nature conservation designations.

| Assessment Method | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | WP | WP | EP | EP | WP | WP | EP | EP |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Conceptual Model | Professional Judgement (Section 3) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Top-down | Historical Trend Analysis/Expert Geomorphological Assessment (Section 4.1.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bottom-up | Water Level Modelling (Section 4.2.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Tidal Current Modelling (Section 4.2.1) | ✓ | | ✓ | | ✓ | | ✓ | |
| | Wave Modelling (Section 4.2.1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Sediment Transport Modelling (Section 4.2.2) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

## 2.7. Physical and Ecological Monitoring

A wide variety of monitoring tools are available, which can be applied in a number of ways, for each of the defined hypothetical scenarios. Within the context of a habitat creation scheme, monitoring comprises measurements taken on a regular basis in order to:

- determine whether progression is being made towards an objective or goal to meet performance criteria and hence scheme success, and comply with permit and statutory requirements; and
- allow the impacts of the scheme on the wider environment to be tested against the predicted effects, to ensure that mitigation is effective, and check whether any unforeseen effects are occurring that might require adaptive management.

To rationalise the monitoring scope, and keep costs down, the survey work should be tailored to the specific requirements of the habitat creation scheme. For example, the temporal frequency of sampling needs careful consideration. In general terms, sampling work is usually undertaken on a quarterly to annual basis so that any sudden changes can be responded to. However, for habitat creation schemes, it is not always necessarily to provide detailed information on a regular basis. Instead there is a need to confirm end-point delivery and to highlight any significant areas for concern along the way. Taking this into account, selected studies could be carried out at lower frequency. Similarly, the detail of any sampling analysis should be tailored to need. For example, the sampling of benthic fauna may not need to be assessed in a quantitative and more costly way during each annual survey. Instead, the analysis could be done qualitatively (i.e. approximate guide to species present) at lower frequency. This would still provide information on the success of the scheme’s ecological development without unnecessary extra analysis and data processing.

Minimum and optimum monitoring requirements for each of the hypothetical scenarios for estuaries and open coasts are provided in the decision matrices in Tables 8 to 12. The decision matrices provide advice on monitoring that is appropriate to measure progression of the scheme (based on the relative size of the scheme alone) and monitoring which enables an understanding of the potential impacts on the surrounding environment. Further advice on monitoring techniques is presented in Section 5. It is important to note that ecological monitoring requirements are dependent on the surrounding sensitives and sites and/or features of conservation importance, and/or specific scheme objectives, which will need to be considered on a case-by-case basis. For any scheme, additional case/site-specific considerations will therefore need to be taken into account, in addition to the monitoring measures suggested in this report.

Table 8: Minimum monitoring to track scheme progress and reach scheme objectives for estuaries and open coasts and where they can be found in this report. The parameters used to define hypothetical scenarios E1-E8 and C1-C8 are described in Figures 4 and 5, respectively and in the captions of Tables 4-7.

| Monitoring Method | | Hypothetical Scenario (using size element only) | | | |
|---|---|---|---|---|---|
| | | E1-E4 | E5-E8 | C1-C4 | C5-C8 |
| Hydrological | Water Levels (Section 5.1.1) | ✓ | ✓ | ✓ | ✓ |
| | Tidal Currents (Section 5.1.2) | | | | |
| | Waves (Section 5.1.3) | | | | |
| Geomorphological | Planform Development (Section 5.2.1) | ✓ | ✓ | ✓ | ✓ |
| | Cross-sectional Development (Section 5.2.2) | ✓ | ✓ | ✓ | ✓ |
| Ecological | Habitat Type (Section 5.3.4) | ✓ | ✓ | ✓ | ✓ |
| | Vegetation (Section 5.3.5)* | ✓ | ✓ | ✓ | ✓ |
| | Benthic Fauna (Section 5.3.6) | | | | |

*Minimum monitoring requirement is dependent on the objective of the scheme which may in certain circumstances be to create a particular habitat type as compensation habitat

Table 9: Optimum monitoring to track scheme progress and reach scheme objectives for estuaries and open coasts and where they can be found in this report.

| Monitoring Method | | Hypothetical Scenario(using size element only) | | | |
|---|---|---|---|---|---|
| | | E1-E4 | E5-E8 | C1-C4 | C5-C8 |
| Hydrological | Water Levels (Section 5.1.1) | ✓ | ✓ | ✓ | ✓ |
| | Tidal Currents (Section 5.1.2) | ✓ | | ✓ | |
| | Waves (Section 5.1.3) | ✓ | | ✓ | |
| Geomorphological | Planform Development (Section 5.2.1) | ✓ | ✓ | ✓ | ✓ |
| | Cross-sectional Development (Section 5.2.2) | ✓ | ✓ | ✓ | ✓ |
| Ecological | Habitat Type (Section 5.3.4) | ✓ | ✓ | ✓ | ✓ |
| | Vegetation (Section 5.3.5) | ✓ | ✓ | ✓ | ✓ |
| | Benthic Fauna (Section 5.3.6) | ✓ | ✓ | ✓ | ✓ |

Table 10: Minimum monitoring for impacts to the surrounding estuary environment and where they can be found in this report. LA = large relative to estuary, SA = small relative to estuary, UE = Upper estuary, LE = Lower estuary, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively low sensitivity of surrounding nature conservation designations.

| Monitoring Method | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | UE | UE | LE | LE | UE | UE | LE | LE |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Hydrological | Water Levels (Section 5.1.1) | ✓ | ✓ | ✓ | ✓ | | | | |
| | Tidal Currents (Section 5.1.2) | | | | | | | | |
| Geomorphological | Cross-sectional Development (Section 5.2.2) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ecological | Habitat Type (Section 5.3.4)* | ✓ | | ✓ | | ✓ | | ✓ | |
| | Vegetation (Section 5.3.5) | | | | | | | | |
| | Benthic Fauna (Section 5.3.6) | | | | | | | | |

*Minimum requirement will depend on the sensitivity and vulnerability of the surrounding environment but there may be instances where monitoring of surrounding habitat type will be adequate to confirm actual effects (i.e. potential for erosion or accretion of mudflats adjacent to a scheme). Minimum ecological monitoring requirements for impacts to the surrounding estuary environment will also be dependent on the sensitivity and the designated nature conservation features present, which will need to be considered on a site/case specific basis.

Table 11: Optimum monitoring for impacts to the surrounding estuary environment and where they can be found in this report. LA = large relative to estuary, SA = small relative to estuary, UE = Upper estuary, LE = Lower estuary, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively low sensitivity of surrounding nature conservation designations.

| Monitoring Method | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | UE | UE | LE | LE | UE | UE | LE | LE |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Hydrological | Water Levels (Section 5.1.1) | ✓ | ✓ | ✓ | ✓ | | | | |
| | Tidal Currents (Section 5.1.2) | ✓ | ✓ | | | ✓ | ✓ | | |
| Geomorphological | Cross-sectional Development (Section 5.2.2) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ecological | Habitat Type (Section 5.3.4) | ✓ | | ✓ | | ✓ | | ✓ | |
| | Vegetation (Section 5.3.5) | ✓ | | ✓ | | ✓ | | ✓ | |
| | Benthic Fauna (Section 5.3.6) | ✓ | | ✓ | | ✓ | | ✓ | |

(Minimum and) optimum ecological monitoring requirements for impacts to the surrounding estuary environment will also be dependent on the sensitivity and the designated nature conservation features present, which will need to be considered on a site/case specific basis.

Table 12: Minimum and optimum monitoring for impacts to the adjacent open coast environment and where they can be found in this report. LA = large relative to longshore sediment transport rate, SA = small relative to longshore sediment transport rate, WP = Within longshore sediment transport pathway, EP = End of longshore sediment transport pathway, HS = Relatively high sensitivity of surrounding nature conservation designations, LS = Relatively low sensitivity of surrounding nature conservation designations.

| Monitoring Method* | | Hypothetical Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
| | | LA | LA | LA | LA | SA | SA | SA | SA |
| | | WP | WP | EP | EP | WP | WP | EP | EP |
| | | HS | LS | HS | LS | HS | LS | HS | LS |
| Geomorphological | Cross-sectional Development (Section 5.2.2) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ecological | Habitat Type (Section 5.3.4) | ✓ | | ✓ | | ✓ | | ✓ | |
| | Vegetation (Section 5.3.5) | | | | | | | | |
| | Benthic Fauna (Section 5.3.6) | I | | | | | | | |

*it is not necessary to monitor regional water levels or tidal currents along open coasts outside the scheme as they would not change after implementation. Minimum and optimum ecological monitoring requirements for impacts to the surrounding estuary environment will also be dependent on the sensitivity and the designated nature conservation features present, which will need to be considered on a site/case specific basis.

# 3. Initial Geomorphological Conceptual Model

This section describes how an initial conceptual model is formulated, what information should be included in it and where that information can be found. This would include desk-based reviews of scientific and professional ‘grey’ literature and analysis of existing data/information and field measurements for the area of interest. For most coastal or estuarine areas, there are likely to be a number of available reports, papers and datasets that can be reviewed for more specific detail on physical and sedimentary processes in the vicinity of the habitat creation scheme. The initial conceptual model could also include analysis of data using historical trend analysis and expert geomorphological assessment (see Section 4.1.1). Any existing data/information and field measurements that may be available will be site dependent, but key organisations that hold monitoring data include coastal groups, universities and local authorities.

| Literature |
| --- |
| **Shoreline Management Plans**<br>A Shoreline Management Plan (often known as a 'SMP') provides a large-scale assessment of the risks associated with sea flooding and coastal erosion to people and the developed, natural and historic environments, and then presents a high-level policy framework to manage these risks. They cover the coastline of England and Wales and parts of Scotland, and are 'living documents', which will be updated around the whole coastline at appropriate future intervals. SMPs were developed for sections of coastline called 'coastal cells' (or sub-cells thereof) which were defined by a large-scale assessment of the limits of significant sediment transfer. The general principal is that management decisions within one SMP area would not have adverse effects on another SMP area. Given their physical process basis (Appendix C of most SMPs contains the baseline understanding of coastal processes), they contain much useful information for the initial conceptual model about coastal processes and risks, and the policies to manage those risks into the future. The Welsh SMPs are:<br><br>SMP19 Anchor Head to Lavernock Point (Severn Estuary)<br>(http://www.severnestuary.net/secg/smpr.html)<br><br>SMP20 Lavernock Point to St Ann's Head (South Wales)<br>(http://www.southwalescoast.org/content.asp?id=58)<br><br>SMP21 St Ann's Head to Great Ormes Head (West of Wales)<br>(http://www.westofwalessmp.org/)<br><br>SMP22 Great Orme's Head to Scotland (North West England and North Wales) (www.mycoastline.org.uk)<br><br>**Futurecoast**<br>The first round of SMPs was completed between 1995 and 2000. Although, these plans represented a significant step forward in long-term strategic planning, comparative reviews of some of the 49 SMP's indicated inconsistencies in the consideration given to coastal processes, geomorphology and the prediction of future coastal evolution. Hence, Futurecoast was completed providing the first nationwide assessment of likely future coastal evolution. The key outputs of value to the initial conceptual model are a series of Shoreline Behaviour Statements, which describe both the current understanding of coastal behaviour and the predictions of future coastal evolution at both the large-scale and local-scale. In addition to these statements is a series of thematic reports, which were produced to assist in the development of the Shoreline Behaviour Statements. These reports, some of which are also accompanied by mapped data, cover the subjects of onshore and offshore geology, coastal processes, estuaries and climate change.<br><br>**Peer Reviewed Publications and 'Grey' Literature**<br>Much useful information can be found in the scientific peer-reviewed published papers or professional 'grey' literature and through linkages with local universities who may have specific research projects in the vicinity of the scheme. Grey literature includes technical reports, theses, conference proceedings, bibliographies, and government reports and documents not published commercially. |

The conceptual model does not take account of the results of future assessments and monitoring, rather it is a starting point from which the correct choice of assessment methods and monitoring is made (both temporally and spatially). An incomplete or incorrectly focused conceptual model may lead to inappropriate assumptions about the system and, in turn, poor selection of physical assessments and physical and ecological monitoring. Hence, it is an important first step to effectively screen-out unnecessary future work.

A conceptual model is relatively cost-effective and quick to undertake, but is dependent upon the quality and availability of existing literature and data sources. It is possible that for many of the more remote sites in Wales, there will only be limited information available, and not all elements of the conceptual model can be completed. In these cases, the process of developing the conceptual model will identify where the data gaps are, and these can be filled through bespoke assessment and monitoring.

## 3.1. Generic Conceptual Model of Habitat Creation Scheme Evolution

When tidal action is restored to a habitat creation scheme, physical processes are set in motion that dictate the rate and manner in which the scheme will evolve. As long as the scheme is sheltered from significant wind-wave action and is at the appropriate elevations, it will evolve in response to coastal sedimentation processes, from intertidal mudflat (and potentially sandflat), to initial mudflat colonization by salt-tolerant marsh plants, to ultimately a fully mature vegetated saltmarsh plain. Subtidal (lagoon) habitats could also form across lower parts of the scheme, if the scheme is low relative to the tidal frame.

Flood tides carry in suspended sediments that deposit in the wave-protected slack waters of the flooded site. As sediment accumulates, intertidal mudflats are formed. As they build to higher elevations, the period of tidal-water inundation decreases and the rate of sedimentation decreases. Once the mudflats reach a high enough elevation relative to the tidal frame, pioneer vegetation colonization can occur. Schemes that have relatively high initial elevations will reach colonization elevation more quickly than those that are more deeply subsided. After vegetation colonization has occurred, build-up of the saltmarsh continues through sediment trapping and organic accumulation. As the saltmarsh rises within the tidal frame, sediment accretion slows until a mature saltmarsh plain develops at an elevation around high water.

The rate at which the mudflat and saltmarsh build up is dependent on the amount of sediment carried into the scheme and deposited by the flood tide, the amount of wind-wave action that erodes the deposited sediments, the tidal range and the rate of relative sea-level rise (product of global sea-level rise and land motion). The higher the average suspended sediment concentration in the flood tide entering the scheme, the quicker the habitat creation scheme will evolve. Average concentrations are ultimately determined by the long-term sediment budget of the region (see Section 3.1), which dictates how much sediment is available to the scheme and the hydrodynamics that determine how the sediment moves and where it is concentrated. It is possible that locally generated wind waves within the scheme can inhibit deposition of suspended sediment from the water column and re-suspend deposited sediment. Wind-wave action can reduce the net accretion rate or 'trap efficiency' in a scheme, slowing the evolution of the system. Wind-waves could limit the equilibrium elevation of the scheme, resulting in a permanent mudflat (or lagoon) too low to be colonized by vegetation to create saltmarsh.

Concurrently with the physical evolution of the mudflat and saltmarsh, the tidal drainage system starts to form. Tidal creeks first form in the mudflat, and as vegetation becomes established, they become imprinted in the saltmarsh, eventually forming a tidal channel system. The rate of sedimentation is influenced by the development of channel networks across the scheme. The channels serve three principal functions; introduction and dispersal of fine-grained sediment, surface drainage and substrate dewatering, and dissipation of tidal energy. Sedimentation rates on intertidal areas generally increase in relation to higher density channel networks. Within this system, the tidal prism of the saltmarsh ‘watershed’ upstream mainly dictates the size and shape of the tidal channel at any given point.

The initial scheme will create a tidal wetland form in an immature state. The hope is that it will evolve as rapidly as possible towards a mature state to provide similar ecological functions to those in ancient wetlands (including Atlantic salt meadows and mudflats and sandflats not covered by seawater at low tide). However, it should be cautioned that the mature restored wetland may differ from, or take a very long time to achieve, the same functions as ancient wetlands. In addition, the human as well as the ecological landscape has to be considered in habitat creation. This means that non-ecological constraints often have a major influence and usually preclude returning a scheme to its pre-disturbance condition, even where the physical processes have not changed significantly.

## 3.2. Contents of the Conceptual Model

The generic conceptual model of a habitat creation scheme presented in Section 3.2 shows that its success is dependent on a large number of physical factors and variables. Hence, for a specific scheme, a conceptual model should be developed that incorporates an understanding of as many of the controlling factors as possible. The optimum elements that should be included in the conceptual model are:

- topography of the scheme and surrounding areas (from these data the scheme area, gradient and level can be determined as well as the potential template for drainage, and post-scheme changes in topography can be assessed using Historical Trend Analysis);
- bathymetric representation of the estuary (this enables post-scheme changes in the estuary to be compared against a pre-existing baseline condition and historic bathymetries using Historical Trend Analysis);
- tidal levels and tidal range in the vicinity of the scheme (this, combined with topographic information, can be used to determine the extent and frequency of tidal inundation of the scheme);
- tidal prism and hydraulic geometry in the estuary (an important parameter in determining the discharges from a scheme and the surrounding estuary);
- tidal current velocities in the vicinity of the scheme (an important factor in suspended and bedload sediment transport, accretion and erosion rates and locations);
- wave climate in the vicinity of the scheme (may influence the erosion and deposition rates of sediment within the scheme and the degree to which deposited sediment may be re-suspended);
- sediment dynamics and sediment budget of the scheme and surrounding areas (this has implications for the supply of sediments to the scheme to enable vertical accretion);
- climate change and sea-level rise (important in determining future scheme tidal prism and if the rate of accretion can keep pace with the future rate of relative sea-level rise).

A flow chart describing how a conceptual model can be developed is presented in Figure 6.

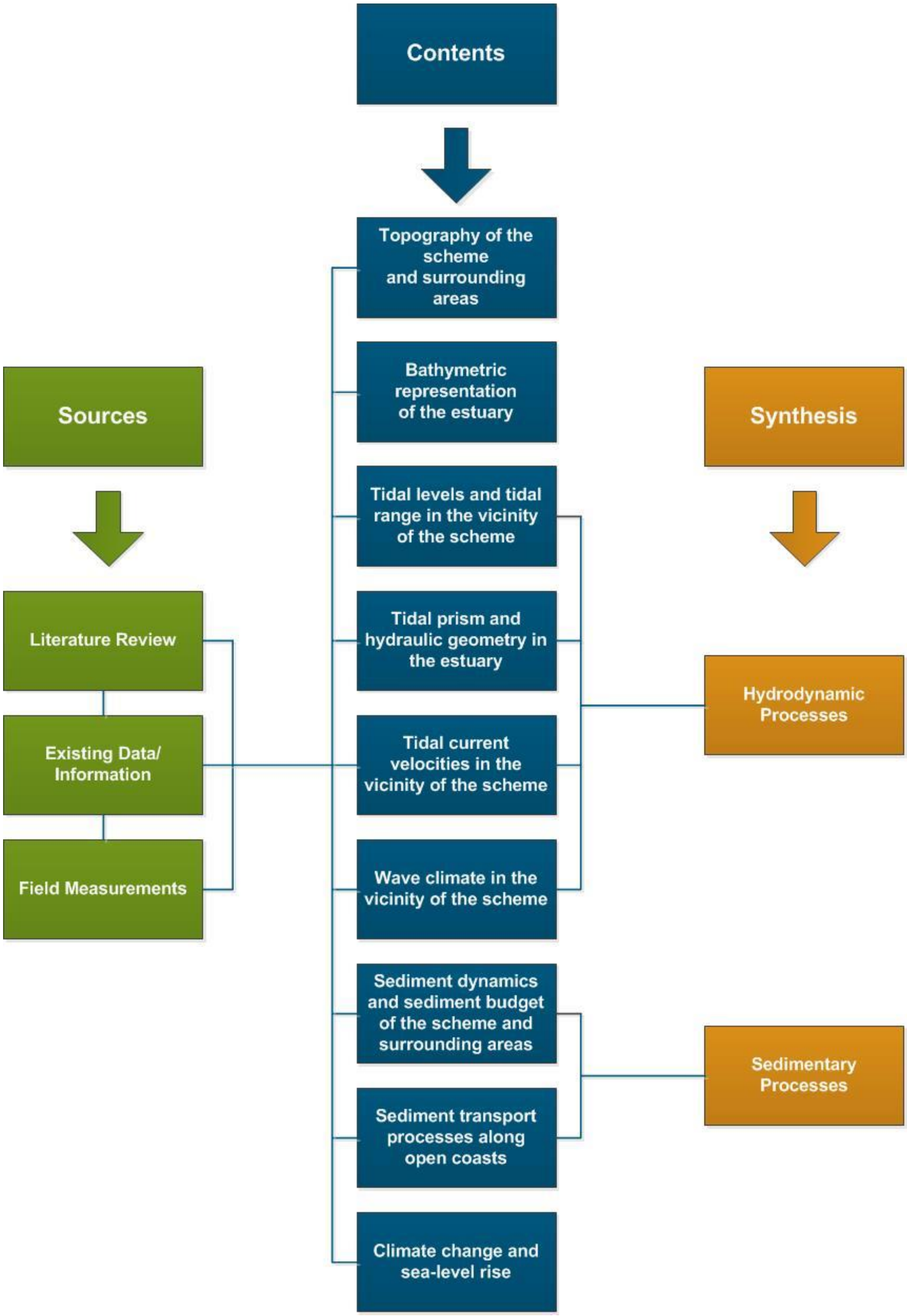


Figure 6: Flow chart explaining the elements of a conceptual model for habitat creation schemes.

Figure 6 describes the optimum information for the construction of a robust conceptual model to support decisions regarding assessment methods and monitoring. However, if some of these elements are not available (i.e. the scheme may be remote and/or small), the key minimum information required would be topography, bathymetry and tidal water levels. Using these elements as the baseline, assumptions regarding scheme evolution can be made, from which the appropriate assessment methods for further data collection can be determined.

### 3.2.1. Topography

A description of topography in the conceptual model is important for two reasons; to determine the overall elevation of the scheme relative to tidal levels, and to assess how the drainage system in the scheme might develop. Topographic data is typically available as processed LiDAR data that can be imported directly into a GIS for presentation purposes or further analysis. Aerial data may also have been collected using drones (unmanned aerial vehicles) fitted with a Global Positioning System (GPS). However, ground survey data that has been collected using a Real Time Kinematic (RTK) GPS or other profiling methods (e.g. total station) may also be available. Ground data may also have been collected using a laser scanner.

**LiDAR to Collect Topography Data**

Airborne Light Detection and Ranging (LiDAR) is a remote sensing technique for the collection of topography data. It uses laser technology to 'scan' the ground surface, taking up to 10,000 observations per square kilometre. These observations are then converted to the local co-ordinate and elevation datum by the use of differential GPS. The system routinely achieves vertical accuracy of 11-25cm and plan accuracy of 45cm with a very rapid speed of data capture (up to 50km$^2$ per hour). This rapid data capture, coupled with the relatively automatic processing system can result in quick delivery of results. It can operate on intertidal areas but care needs to be taken in areas of water as with the normal settings the laser beam is absorbed by water rather than reflected. Other surveyors of LiDAR may include Associated British Ports and aggregate companies.

*Overall Elevation of Scheme Relative to Tidal Levels*

The evolution of intertidal habitat will largely depend on the achievement of appropriate elevations with respect to the tide. In general terms, the height of a habitat creation scheme relative to the tidal frame is used as an initial indicator of the habitats that could evolve. Saltmarsh colonises areas approximately above mean high water neap (MHWN) tide to mean high water spring (MHWS) tide (and potentially higher), with areas between MHWN and mean low water spring (MLWS) forming mudflat (Allen, 2000). Hence, the topography of a scheme and the tidal levels adjacent to it are two of the principal issues to be considered in the initial conceptual model.

*Development of a Drainage Network*

When a habitat creation scheme is freshly inundated by the tides, the tidal flows will tend to focus in existing ditches or depressions that can fix the location and geometry of the drainage system. As the scheme develops through sedimentation, mudflats accrete and develop into saltmarshes in which the pre-existing drainage system can persist and control the nature of the tidal channel system. Often, in agricultural land, the existing drainage consists of straight field drains or ditches. However, sinuous channel systems provide a more complex habitat and support a wider range of tidal wetland functions than linear channels. Hence, knowledge about the antecedent channel network, which may be reflected in the topography, is an important aspect of the conceptual model. Across some habitat creation schemes the original 'natural' channel system may still be expressed in the land surface, even though it has been partially or wholly filled in. Analysis of vertical aerial photographs can provide data on the location of antecedent channel features within reclaimed land.

### 3.2.2. Bathymetry in Estuaries

A description of bathymetry is a fundamental component of the conceptual model as it is the underlying controlling factor for many of the physical and sedimentary processes operating in estuaries and along coasts (Figure 7). Bathymetry data is collected in three main ways; single beam echo sounder, multibeam echo sounder and LiDAR. The best available bathymetry should be used in the conceptual model. To be considered as the 'best available', the bathymetry data in the estuary should cover the estuary mouth to the tidal limit, including full coverage of subtidal and intertidal areas up to the seaward face of the front-line defence or up to MHWS tide where the coastal plain rises naturally into higher ground (Royal HaskoningDHV, 2015). In an estuary, the data should ideally stretch from the upstream normal tidal limit to the mouth. Bathymetry data can be obtained from a variety of organisations including the United Kingdom Hydrographic Office (UKHO) (Admiralty Charts), Environment Agency, Harbour Authorities and Conservancy's and Associated British Ports. Bathymetry may not be available for less well studied estuaries and a bespoke survey would need to be completed (if feasible) to support the conceptual model and subsequent assessments.

| Marine Geophysical Techniques to Collect Bathymetry Data |
| --- |
| **Single Beam Echo Sounder**<br>Single beam echo sounding is a commonly used technique for collecting bathymetric data. The technique involves using a transducer attached either to the hull of a vessel, or to a pole mounted over the side or bow of the vessel. The echo sounder calculates the water depth beneath the transducer, by transmitting a sound pulse that is returned to the vessel via reflection off the sea bed. The density of soundings is dependent on the survey line spacing, vessel speed and the echo sounder ping rate. Standard single beam echo sounders collect data for a narrow zone along the track of the vessel and hence the main limitation of the system, compared to multibeam systems, is the limited sea bed coverage. The data are presented as points (x, y, z) along the transect from which spatial interpolation in the GIS is required in order to provide full bathymetry coverage.<br><br>**Multibeam Echo Sounder**<br>A multibeam echo sounder survey provides an alternative to a single beam survey in bathymetric data collection. The main difference between a single beam echo sounder and a multibeam echo sounder is that the latter produces a number of beams forming a 'fan' of sound pulses or acoustic energy. A multibeam system essentially consists of a receiver and transmitter that emit and detect multiple beams of sound energy in a swathe (producing swathe bathymetry). These multiple soundings are taken at right angles to vessel track, as opposed to a single sounding directly underneath a vessel with a single beam echo sounder. This means that a multibeam system can provide a greater density of soundings allowing faster coverage of a site. The main advantage of multibeam systems is that they can provide 100% coverage of the sea bed without the need to interpolate between lines. A disadvantage of multibeam systems is that in shallow water (less than 10m), the swathe width is significantly reduced and so in small estuaries, this type of data is not common. |

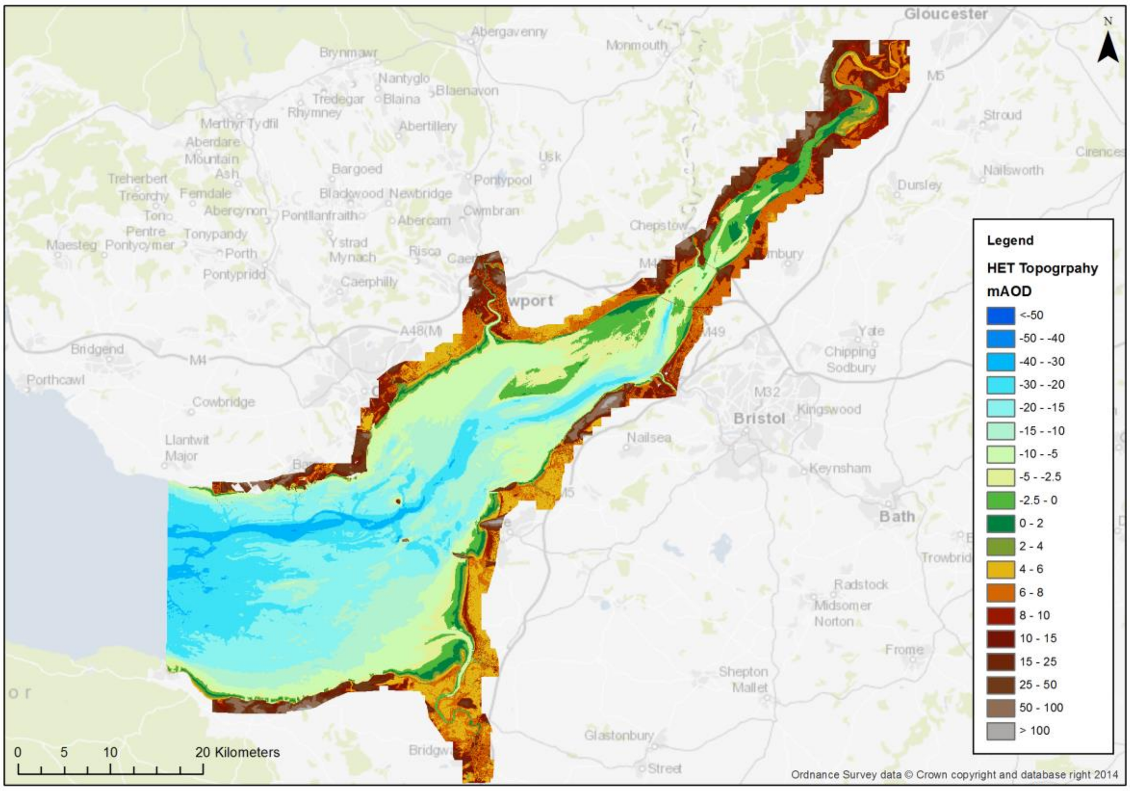

Figure 7: Bathymetry of the Severn Estuary and its major tributaries compiled from a combination of Admiralty Chart and LiDAR data (Royal HaskoningDHV, 2015).

### 3.2.3. Tidal Levels and Tidal Range

A narrative on tidal levels and tidal range in the conceptual model is important because within the scheme boundaries of a habitat creation scheme, the water levels and periods of inundation represent one of the most important controls (along with elevation) of the type and extent of different habitats. Tidal data can be obtained from the UKHO from their standard or secondary ports. Real-time data is also available for the Severn Estuary from a radar device attached to the Second Severn Crossing since June 2011 (http://www.channelcoast.org/data_management/real_time_data/charts/?chart=106&tab=tides&start=&end=&disp_option=). Admiralty Tide Tables provide annual astronomical tidal level predictions (for example in the Severn Estuary, Figure 8). If the scheme is mid-way between UKHO ports, linear interpolation can be undertaken to estimate indicative tidal levels. Although interpolation may be possible for larger estuaries with ports (Figure 8), it may present a problem in smaller estuaries where there may be paucity or absence of ports. In such locations, it may be necessary to derive data from existing river/estuary models or previous study reports if available (e.g. feasibility studies for flood embankment construction or maintenance).


Figure 8: MHWS relative to Chart Datum in the Severn Estuary (Royal HaskoningDHV, 2015).

*Hypsometric Analysis*

The topography (Section 3.2.1) and tidal level data provides the opportunity to complete a simple analysis using hypsometry (the measurement of land area relative to water level) to define the relationship between elevation, scheme area and the tidal frame to broadly predict the potential for intertidal habitat creation and the area of intertidal mudflat and saltmarsh that could be created. To undertake the analysis, the topography data and the heights of MHWS, MHWN and MLWS tides for a location corresponding as closely as possible to the potential habitat creation scheme should be uploaded into a GIS. In order to compare the variation in elevation across the scheme with the tidal datums, a hypsometric curve (the relationship between area and elevation with area on the x-axis and elevation on the y-axis) can be produced at 0.1m vertical intervals. The tidal datums can then be superimposed on to the curve to determine the area of the scheme that would be inundated at a particular state of the tide, and to define the area of the scheme that has the most potential to form saltmarsh (approximately MHWN to MHWS) and mudflat (approximately MLWS to MHWN). Examples of LiDAR data and a hypsometric curve for Wentlooge on the Severn Estuary with superimposed tidal datums are shown in Figures 9 and 10, respectively.

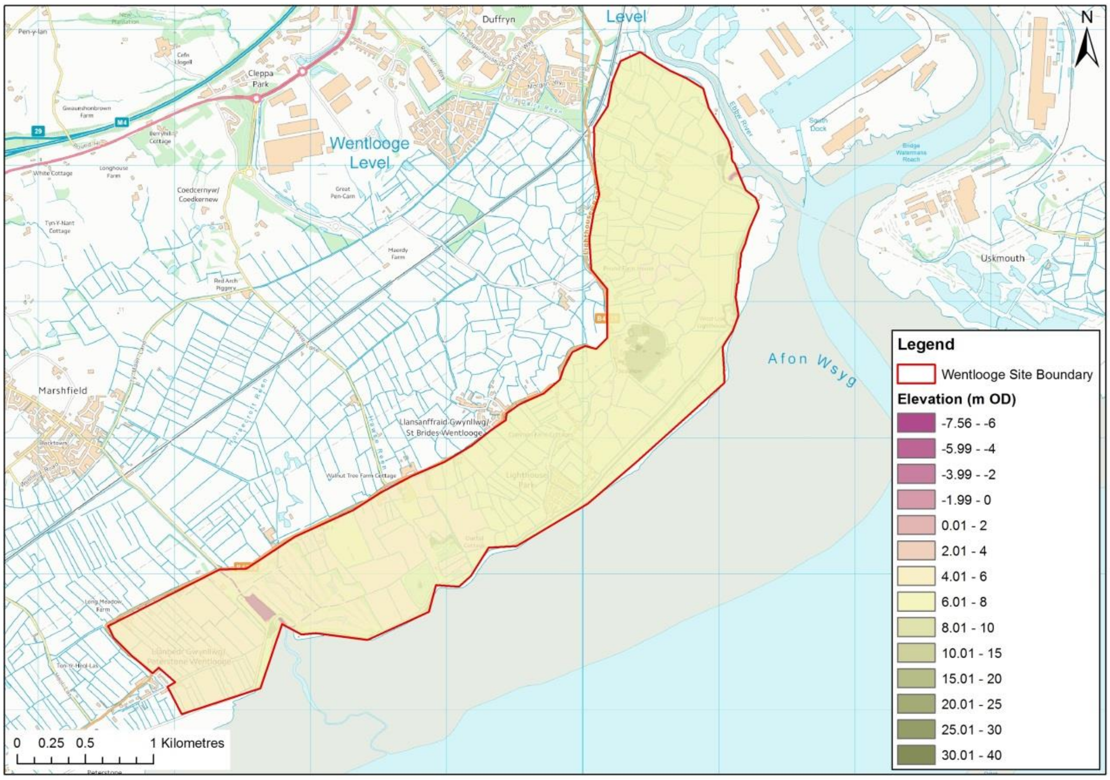


Figure 9: LiDAR data of a coastal lowland area at Wentlooge on the Severn Estuary.

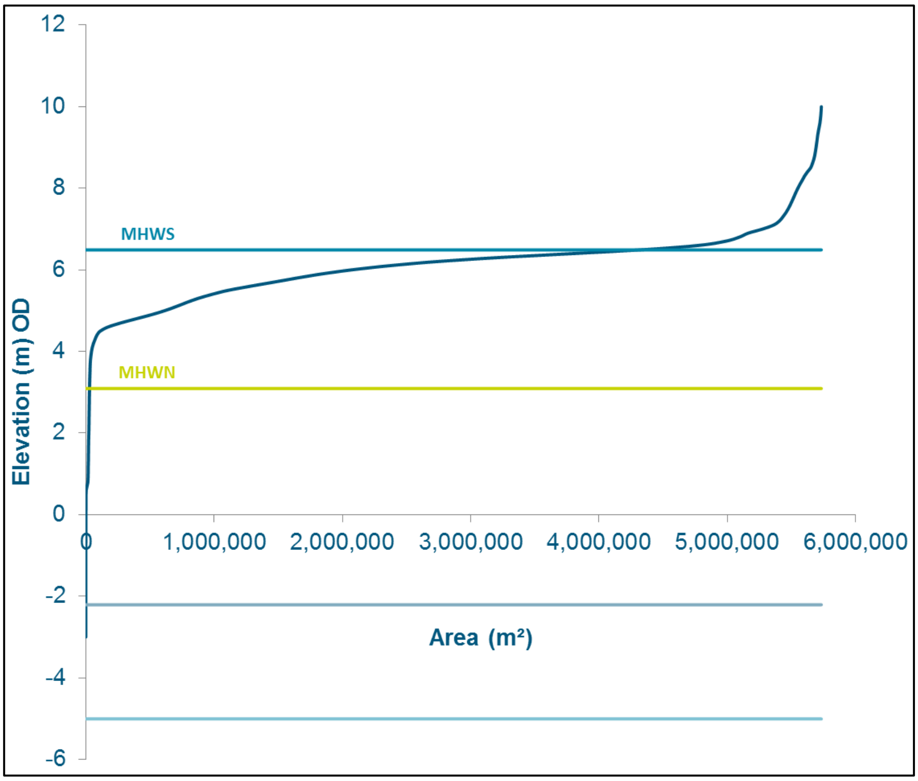


Figure 10: Hypsometric curve that represents the area-elevation relationship of the Wentlooge coastal lowland shown in Figure 10.

### 3.2.4. Tidal Prism and Hydraulic Geometry in Estuaries

Tidal prism can be defined as the volume of water that enters an estuary on each tidal cycle (the volume difference between high water and low water), excluding any contribution from freshwater inflow. It is usually calculated as a mean spring volume or a mean neap volume. Tidal prism can also be calculated at any point along the length of an estuary, or within a habitat creation scheme, where it is the volume of tidal water upstream of that point.

Tidal prism is an important metric to include in the conceptual model for several reasons. For any cross-section in an estuary, an increase in the tidal prism will lead to an increase in tidal discharge resulting in increased current velocities. The tidal prism therefore has implications for the geometry of a range of different scale features including estuarine channels and saltmarsh creeks (height, width and cross-sectional area). In estuaries, there are empirical relationships between estuary properties that reflect their size and shape. The most widely used of these regime relationships is between channel cross-sectional area and upstream tidal prism (or discharge), known as hydraulic geometry. This relationship, first proposed by O’Brien (1931), is between the spring tidal prism (the volume of water that enters and leaves the estuary during a spring tide) and the cross-sectional area at mean sea (tide) level at the mouth. This equation takes the form:

- $CSA = a.P^b$

Where:

- CSA = cross-sectional area (mean sea level);
- P = upstream spring tidal prism;
- a = constant coefficient; and
- b = constant exponent.

The tidal prism of a habitat creation scheme is the volume of water that would inundate it following scheme implementation. This is important for the calculation of velocities through a breach or changes in velocity across the existing intertidal zone due to the discharge of tidal waters from the scheme. If these velocities are too high then they could lead to significant widening of a breach or erosion of the intertidal area.

Empirical hydraulic geometry relationships can be used for a variety of purposes, including sizing tidal channel excavations in habitat creation schemes and predicting channel sedimentation or erosion responses to changes in upstream tidal prism. For tidal channels in mature saltmarshes, the channel-forming flow is largely a function of the saltmarsh area drained (i.e. watershed area) and the tidal range.

An estimate of the spring tidal prism of a habitat creation scheme prior to inundation can be made from the hypsometry by superimposing the MHWS and MLWS datums on to the hypsometric curve (Figure 10). The tidal prism is then calculated by multiplying the height difference between the two datums by the difference in area inundated between the two datums. A similar calculation could be made for the whole estuary using the bathymetry as the baseline elevation data.

### 3.2.5. Tidal Current Velocities

Tidal currents are the primary driving force in importing sediment into estuaries on the flood tide and exporting sediment on the ebb tide. They are an important factor in suspended and bedload sediment transport, accretion and erosion, both within habitat creation schemes and further afield, and should be considered in the conceptual model. Tidal currents vary through the water column, with near-bed currents being most critical to bedload sediment transport processes. Suspended sediment transport is influenced by the balance between current velocities and sediment settling characteristics (which in turn are dependent on sediment particle size and composition). Habitat creation schemes can influence the general flow directions by re-directing flows onto the scheme due to the creation of an additional floodable zone.

General information on tidal currents in estuaries or nearshore open coast areas can be obtained from UKHO collected data, including tidal diamonds on Admiralty Charts and Admiralty Tidal Stream Atlases. These data are sufficient for use in the conceptual model, but they are not accurate enough or detailed enough to use as calibration for numerical models (see Section 4.2.1). Tidal diamonds are symbols on Admiralty Charts that indicate the direction and speed of tidal streams. There is an accompanying table that quantifies the direction of the tidal stream and its speed in knots at both spring tide and neap tide. Admiralty Tidal Stream Atlases display, in diagrammatic form, the major tidal streams for selected waters of northwest Europe, including direction and rate at hourly intervals. The key atlases for Wales are NP256 (Irish Sea) and NP258 (Bristol Channel). More detailed information on tidal currents may be obtained from the published results of numerical hydrodynamic models (if available) in the vicinity of the scheme.

### 3.2.6. Wave Climate

A significant factor inhibiting the evolution of a scheme is wave energy, which slows sediment deposition rates and induces re-suspension of deposited sediment. Propagating waves create turbulence in the water column that prevents deposition, and breaking waves create high bed shear stresses that re-suspend deposited muds, allowing sediment to be exported on the ebb tide. Conceptually, this results in a retarded evolutionary trajectory or, for high wave energy sites, one that will be a permanent mudflat that is too low to be colonised by emergent vegetation (Figure 11) (Williams and Orr, 2002).

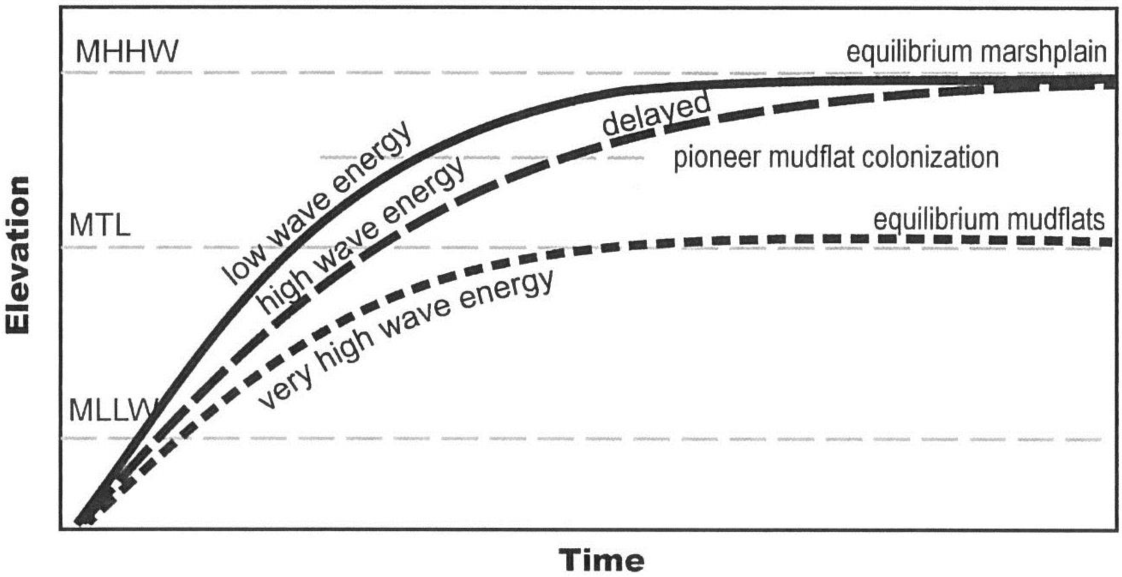

Figure 11: Conceptual effect of wind-waves on tidal wetland evolution (Williams and Orr, 2002). Note that MHHW (mean higher high water) and MLLW (mean lower low water) are approximately equivalent to MHWS (mean high water spring) and MLWS (mean low water spring), respectively.

Within a scheme, the size of the waves that might be generated is dependent on the wind climate and the fetch length. Fetch is the distance travelled by wind or waves over open water, and the longer the fetch, the greater the chance of higher and more energetic waves. Where habitat creation schemes are small or are oriented so that the shortest fetch coincides with the prevailing winds, saltmarsh development will be faster than in those schemes that are larger or where their orientation allows the generation of higher wind-driven waves.

Outside a habitat creation scheme the wave climate is a combination of wind-waves generated locally and swells moving into the area (having been generated remotely). Swell waves are more relevant to schemes in exposed open coast environments, whilst wind-waves are relevant to schemes in estuarine environments.

Wave data to support the conceptual model can be obtained from a variety of sources. Nearshore wave data is available from buoys set up and administered by Cefas as part of the WaveNet monitoring network for England and Wales (https://www.cefas.co.uk/publications-data/wavenet/). Wave data is also available from the Weston Bay directional wave rider buoy in the Severn Estuary deployed by the Channel Coastal Observatory. Around the Welsh coast the currently deployed buoys are described in Table 13. Available data includes wave height and direction, peak and mean period and the directional spread at the peak period.

Table 13: Waveriders buoys around the coast of Wales deployed as part of the WaveNet monitoring network and the Channel Coastal Observatory.

| Name | Provider | Latitude | Longitude | Water Depth (m) | Start | Due End |
|---|---|---|---|---|---|---|
| Liverpool Bay | Cefas | 53°32'.01N | 3°21'.31W | 24 | 13.11.2002 | 01.04.2018 |
| SEACAMS (Anglesey) | 'SEACAMS' | 53°13'.00N | 4°43'.44W | 45 | 13.08.2014 | |
| Aberporth | Met Office | 52°22'.30N | 4°41'.51W | 30 | 27.01.2003 | |
| West Pembrokeshire | Cefas | 51°50'.25N | 5°50'.42W | 115 | 11.09.2014 | 01.04.2018 |
| Pembroke | Met Office | 51°36'.00N | 5°06'.00W | 45 | 27.01.2003 | |
| LCRI Marine | LCRI Marine | 51°33'.51N | 4°51'.63W | 40 | 23.09.2014 | |
| Scarweather | Cefas | 51°25'.99N | 3°55'.98W | 35 | 11.05.2005 | 01.04.2018 |
| Hinkley Point | Cefas | 51°13'.96N | 3°09'.54W | 10 | 16.12.2008 | 01.01.2019 |
| Weston Bay | CCO | 51°21'.20N | 3°01'.11W | 13 | 10.09.2009 | |

Wave data can also be obtained from the UK Meteorological Office European Wave Model at a point(s) located near to the scheme. Wind and wave hind cast values are archived initially at six-hour intervals and subsequently (from June 1988) at three-hour intervals. Data can be requested at specified grid points as time series and include wind strength and direction, wave direction, wave height and period. In the nearshore zone, there is the potential for introduction of inaccuracies in the data due to computational complications in shallow water. More detailed information on modelled waves may be obtained from the published results of numerical models (if available) specifically close to the scheme.

### 3.2.7. Sediment Dynamics and Sediment Budget

The tidal regime and wave climate described in Sections 3.4.3 to 3.4.7 control the erosion, transportation and deposition of sediment (collectively called sediment dynamics). The availability of sediment is a strong control on the morphology of a habitat creation scheme. If there is a lack of available sediment, then deposition within the scheme is unlikely, even if the physical conditions are otherwise suitable. Sediment therefore provides a critical link between form and function, and most physical changes within a scheme are associated with its movement. For this reason the nature of contemporary sediments and the response of these sediments to changing physical forcing are factors of fundamental importance and should be included in the conceptual model.

For a typical habitat creation scheme, the required elevations are achieved by taking advantage of the natural deposition of suspended sediments brought into the scheme on flood tides. The rate of accretion will depend on the suspended sediment concentrations carried into the scheme, the amount that is deposited from suspension and the amount of sediment that is eroded and carried out of the scheme on ebb tides. The expected rate of sedimentation at a scheme can be predicted from previous observations of nearby suspended sediment concentrations, rates of sedimentation at similar schemes and/or local established saltmarsh areas.

Large-scale habitat creation itself can affect the sediment budget of the estuary. Restoring tidal action to a scheme may create a sediment sink that is large enough to affect the sediment budget. Suspended sediment concentrations in the estuary could be decreased by the capture of sediment suspended in the water column in flood tide flows entering the scheme. This in turn could lower the rate of saltmarsh evolution within the estuary and potentially accelerate the rate of mudflat erosion outside the scheme (Brew and Williams, 2010). Hence, an appreciation of the sediment budget of the estuary provides useful background information to predict potential changes that might be induced by a scheme and should be included in the conceptual model.

A sediment budget is an accounting or tabulation of the inflows and outflows of sediment together with the change in sediment volume through a fixed boundary in space and time to estimate the net accumulation or loss of sediment within the boundary. A sediment budget can be expressed as:

sediment inputs (sources) – sediment outputs (sinks) = change in storage

Sediment budgets can be applied to whole estuaries, specific habitat creation schemes or a combination of both. Considering both together, the following inputs, outputs and storage components should be considered in the conceptual model:

- Inputs: e.g. sediment delivered down-river and from the watershed during floods, sediment carried into the estuary during flood tides and sediment eroded from the saltmarsh edge.
- Outputs: e.g. loss of sediment from the estuary on ebb tides and losses due to dredging. In addition, the capture of sediment in the habitat creation scheme should be treated as an output or sediment demand.
- Change in storage: net accumulation or erosion of sediment within each of the intertidal and subtidal geomorphological units. Stores can be considered as features where sediment is stored for a certain period of time, but may be mobilised again to take part in the transport process.

Typically, the more reliable data should form the foundation of the budget, and lesser-known or more uncertain parameters should be treated as an unknown and estimated by the residual in the budget. A balanced sediment budget is a valuable tool for investigating observed coastal change and for forecasting the consequences of implementing a habitat creation scheme.

### 3.2.8. Sediment Transport Processes along Open Coasts

Waves have the potential to transport large volumes of sediment along the coast and in onshore and offshore directions. Most important to the alongshore transport of sediments is waves approaching and breaking obliquely to the coast, causing a zig-zag movement of sediment particles in the swash zone (Figure 12). During this process, the swash moves up the beach in the direction of wave propagation, but the backwash will move down the steepest slope under the influence of gravity, usually perpendicular to the shore. This causes sediment particles to move alongshore in the direction of the front of the breaking waves.

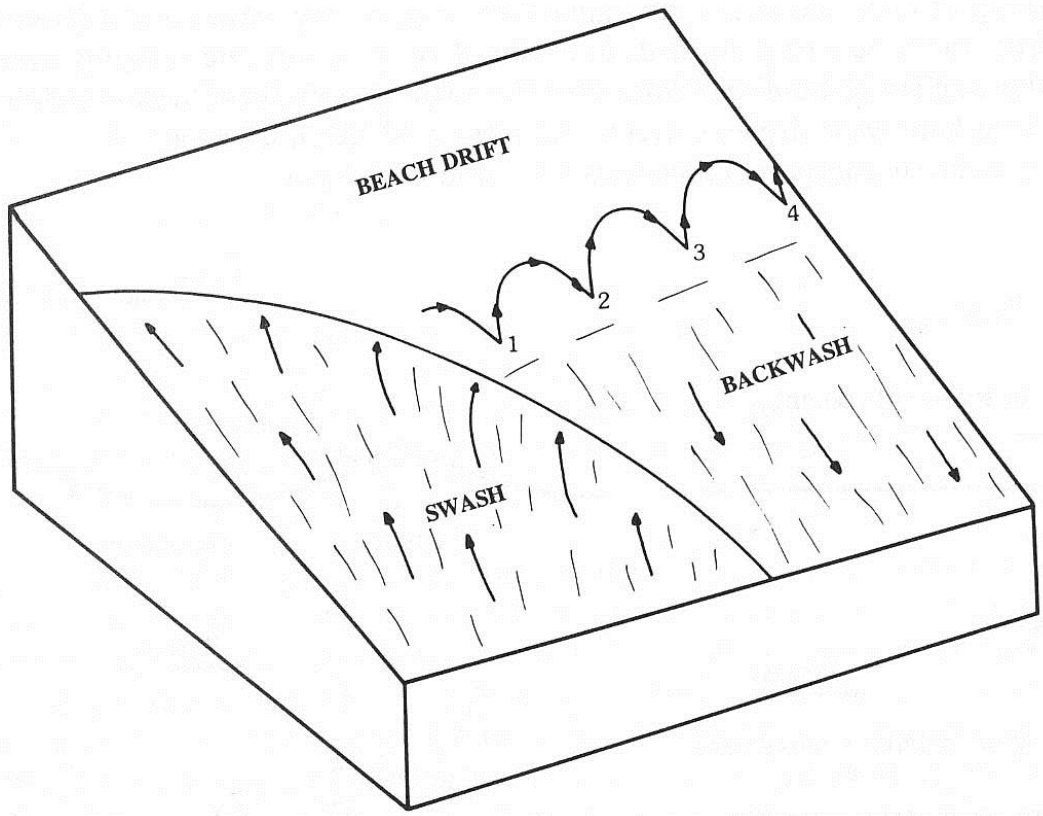

Figure 12: Processes responsible for the longshore transport of sediment particles (Van Rijn, 1998)

Longshore sediment transport processes are important when considering habitat creation schemes with an entrance at the open coast. In order to naturally maintain the entrance would require that the tidal flows (tidal prism, see Section 3.4.4) entering and leaving the scheme be powerful enough to scour longshore transported sediment that fills in the entrance. Infilling of the scheme entrance with sediment transported longshore could lead to unwanted restriction of tidal exchange and a less than fully functioning system, and at worst total blockage of the scheme from inundation. Hence, understanding the potential relationship between longshore sediment transport rate and scheme tidal prism (discharge) is an important part of the conceptual model for open coast schemes (see Section 2.4.1, Inlet Stability Analysis).

Longshore sediment transport can be qualitatively measured by examining the impoundment of sediment on the ‘updrift’ sides of shore-normal structures such as jetties, groynes or breakwaters. Quantitative measurements are much more involved, including interpretation of sediment transport model results.

Cross-shore sediment transport is more difficult to quantify and understand. It is generally manifest in the cross-shore profile. There is typically a seasonal difference in the cross-shore profile as sediment is transferred either onshore or offshore. In summer, the coast is approached by shallower swell-dominated waves whereas in winter, steep storm waves are prevalent. The summer waves drive sediment up the foreshore to build berms and winter waves move sediment seaward to build a longshore bar. The winter profile exhibits a longshore bar above the mean bed profile and a trough below the mean profile (Figure 13). The bar acts as a submerged breakwater dissipating wave energy and further erosion of the foreshore is reduced. In the summer the sediments are transported onshore and a berm-type profile is gradually formed and the beach will eventually be restored.

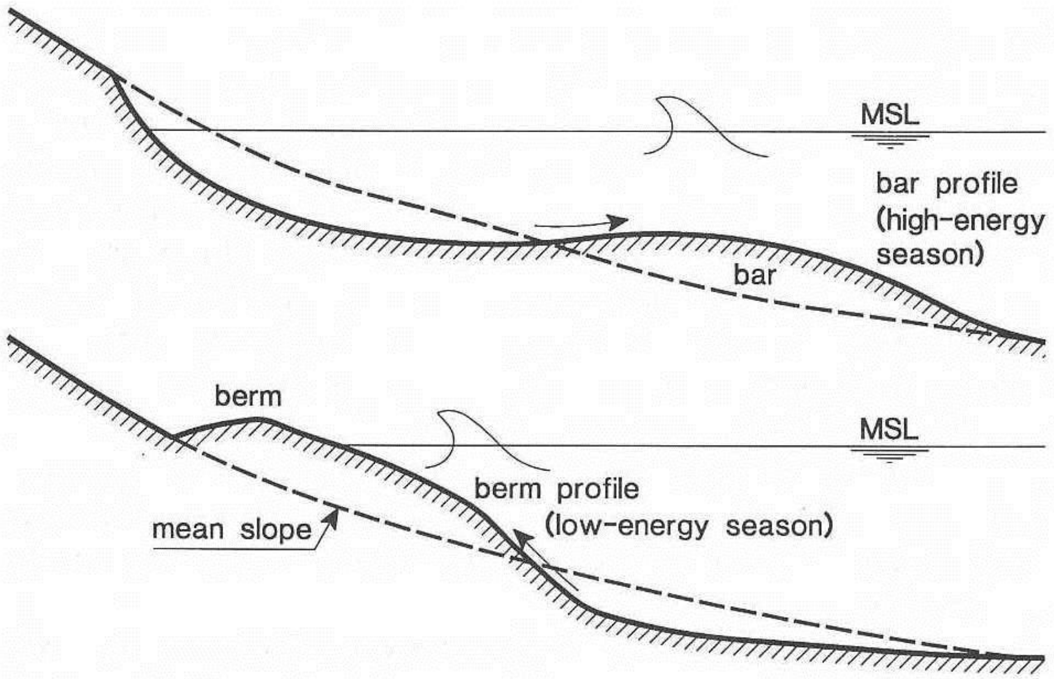


Figure 13: Comparison of a steep beach profile characterised by a berm and a shallow beach profile characterised by a longshore bar (from Van Rijn, 1998).

### 3.2.9. Climate Change and Sea-level Rise

Historical data shows that the global temperature has risen since the beginning of the 20th century, and predictions are for an accelerated rise, the magnitude of which is dependent on the magnitude of future emissions of greenhouse gases and aerosols. As a result of future global warming, sea level is predicted to rise at accelerated rates. At a local scale, the position and height of the sea relative to the land is known as relative sea level (Figure 14). Local changes can take the form of either isostatic effects (changes in land elevations due to the redistribution of weight on the land surface, e.g. due to glacier ice) or tectonic effects (changes in land elevations due to tectonic adjustments). With respect to intertidal habitat creation it is important to determine if the rate of accretion across the scheme is able to keep pace with the future rate of relative sea-level rise, and a summary should be included in the conceptual model.

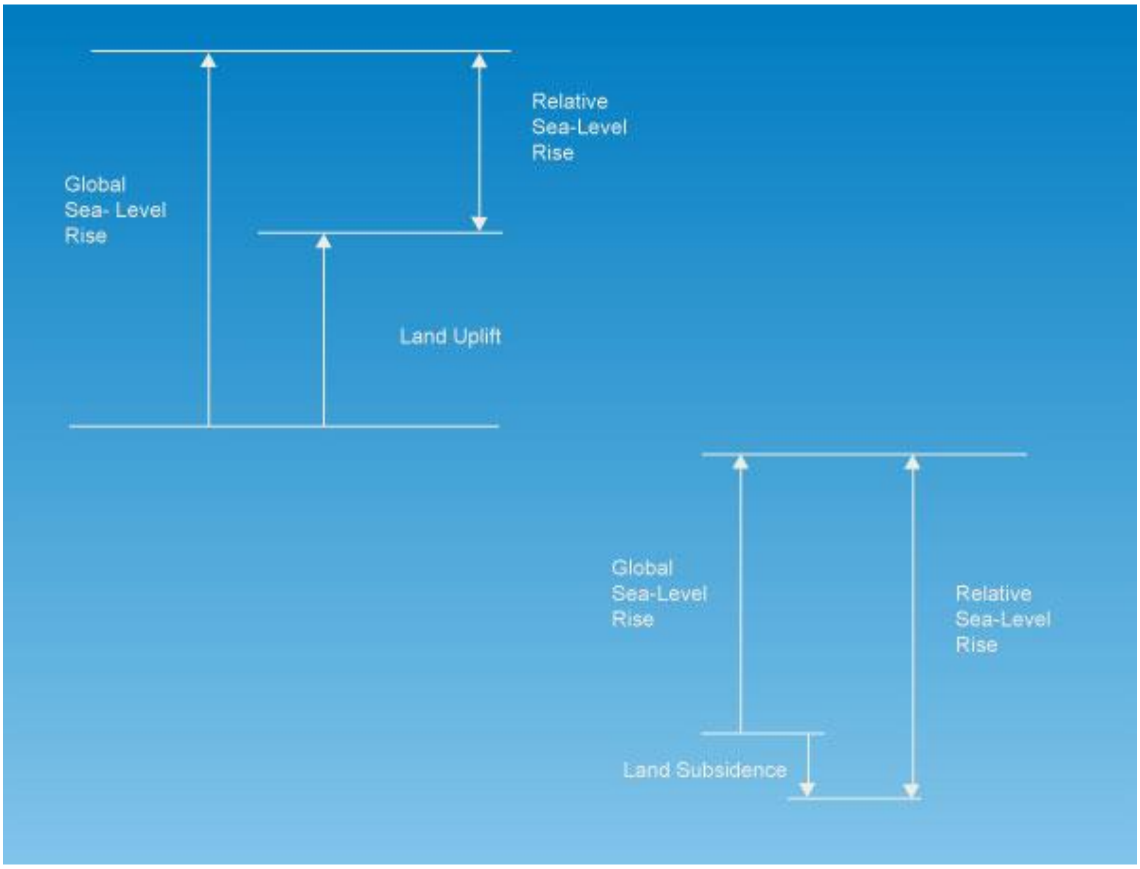

Figure 14: Schematic explaining the meaning of relative sea-level rise.

Sea-level rise is a familiar concept and for many years work has been carried out using the latest policy and views on the subject. Predictions of future sea-level rise are continually being refined, as the understanding of the science evolves and improves. In this respect, the information on sea-level rise that should be included in the conceptual model should be based on the latest guidance, particularly that provided by the Intergovernmental Panel on Climate Change (IPCC) and the United Kingdom Climate Impacts Programme (UKCP).

The IPCC was established by the World Meteorological Organisation and United Nations Environment Programme to assess scientific, technical and socio-economic information relevant to the understanding of climate change, its potential impacts and options for adaptation and mitigation. The latest guidance on global sea-level rise is contained in the IPCCs 5th Assessment Report (2014) (https://www.ipcc.ch/report/ar5/). The UKCP was established by the United Kingdom Government in 1997 to provide a framework for a national assessment of climate impacts. The latest guidance on sea-level rise projections across the land and marine regions of the United Kingdom is contained in UKCP 2009 (UKCP09) (http://ukclimateprojections.metoffice.gov.uk/) and is based on the IPCC 4th Assessment Report. It is possible that future UKCP guidance (UKCP18) may be produced based on the latest (5th) IPCC assessment.

For the NHCP the strategic approach to habitat creation uses the UKCP09 medium emissions 95th percentile scenario for sea-level rise. For large-scale habitat creation schemes it may also be appropriate to undertake a sensitivity analysis of sea-level rise based on best (low emissions 50th percentile) and worst (H++) scenarios (Environment Agency, 2011).

### 3.2.10. Synthesis of the Conceptual Model

Sections 3.2.1 to 3.2.9 provide advice on developing a conceptual understanding of the estuary or open coast system in which the habitat creation scheme is located, which will be largely descriptive text with supporting illustrations. This structured description of the system should comprise the bulk of the conceptual model report. However, the report should conclude with several summary diagrams that provide a representation of the overall dynamics of the estuary or open coast in question. The style of the summary diagrams is subjective, but a commonly used form is for the background to illustrate the geomorphology and landforms (and possibly habitats) upon which the key process information is superimposed. These are:

- hydrodynamic processes (related to water movement, waves and tidal currents); and
- sedimentary processes (sources, transport and sinks of suspended and bedload sediment)

The movement or transport of sediments and the physical drivers can be depicted using arrows with a legend provided where required (Figures 15 and 16).

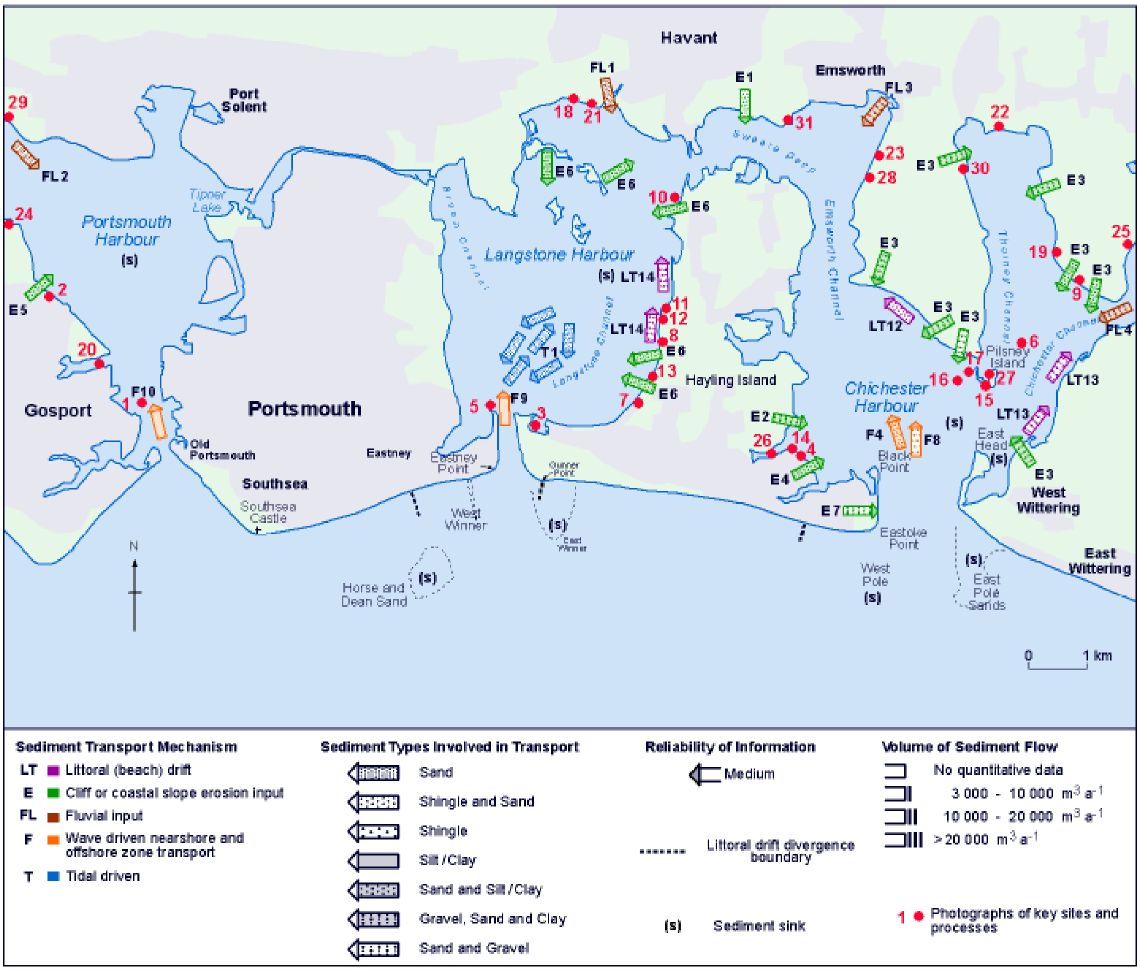

Figure 15: Synthesis of sediment transport processes for the embayments of Portsmouth, Langstone and Chichester Harbours (SCOPAC, 2004).

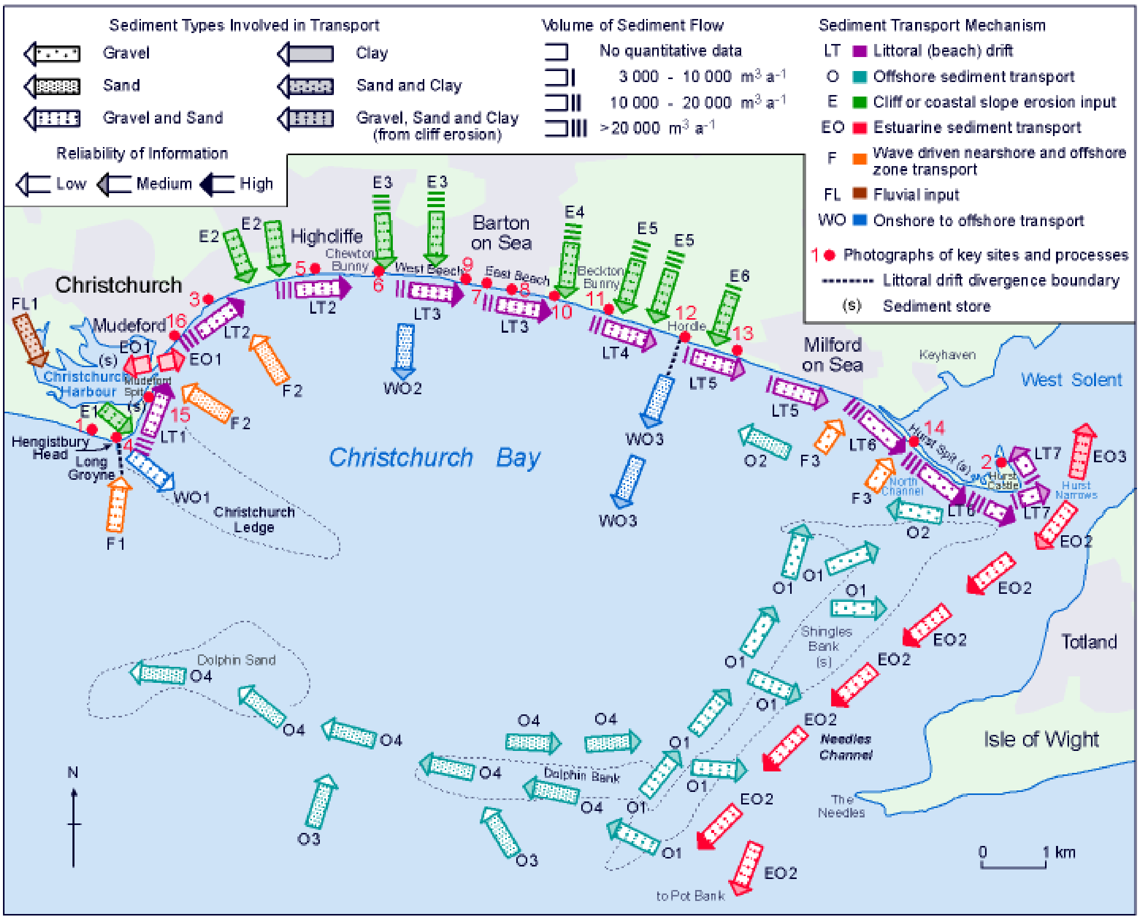

Figure 16: Synthesis of sediment transport processes for the open coasts of Christchurch Bay (bottom) (SCOPAC, 2004).

# 4. Physical Assessments

This section focuses on the range of physical assessments that are available to support the understanding of a habitat creation scheme. The physical assessments described are not exhaustive, but considered to be the key ones which could be applied, and does not preclude use of other available assessment techniques. Further information on physical assessment techniques is available on the 'The Estuary Guide' website (http://www.estuary-guide.net/).

## 4.1. Top-down Assessments

Top-down (long-term) predictive methods are highly varied, meaning different things to different people. The majority of methods are able to measure the long-term response of an estuary to natural changes in forcing, such as sea-level rise, and also account, to a varying degree, for changes in morphology following human interference such as habitat creation. Leggett *et al*. (2004a) defined two types of top-down assessment; expert analysis of data or consideration of regime type concepts. Expert analysis synthesises all the available data from various techniques and extrapolates these trends to form a prediction. Two of the most commonly used methods are Historical Trend Analysis and Expert Geomorphological Assessment (usually combined). Regime Theory/Rollover (estuary only) develop relationships between the estuary geometrical shape and tidal flows. The main advantages and disadvantages of long-term predictive methods are shown in Table 14.

Table 14: Advantages and disadvantages of long-term (top-down) predictive methods.

| Advantages | Disadvantages |
|---|---|
| they provide an integrated approach making predictions for whole estuary over long periods | they are not suited to predict local or short-term changes |
| they are computationally cheap, allowing various options and scenarios to be explored | they generally omit detailed physics and rely on the quality of the data available |
| whole estuary calibration takes account of other processes such as biological and sedimentological processes | they cannot predict responses to extreme events |

### 4.1.1. Historical Trend Analysis and Expert Geomorphological Assessment

The Historical Trend Analysis method essentially involves the interrogation of time series data to identify directional trends and rates of processes and morphological change, over varying time periods. The most common dataset is historic bathymetric charts. The Expert Geomorphological Assessment method incorporates output from Historical Trend Analysis, but also takes account information about current physical processes, geological constraints and sediment properties, general relationships between processes and morphological responses, and the potential use of analogue sites. These methods could be supported by comparison with analogue sites which have similar characteristics to that of the scheme being assessed (if data is readily available).

As long as due regard is taken of data origins and accuracy, predictions based on extrapolation of trends can provide a reliable estimate of the most probable evolution of an estuary or open coast. However, a simple linear extrapolation into the future will not take into consideration the complex nature of natural systems where future conditions may differ from the past. There are many reasons for this type of departure including climatic or human-induced change, or the presence of geological controls.

### 4.1.2. Regime Theory and the Rollover Method

Regime Theory uses an empirical relationship between estuary gross morphology and tidal prism, through simple power-law equations. Predictions of the effect of a habitat creation scheme are made in terms of the resulting changes in estuary cross-section. The rollover method is based on Regime Theory and investigates the landward transgression of the estuary with sea-level rise. The change in shape, elevation or position of the estuary may be predicted, but caution must be exercised to account for anthropogenic effects.

Crucial to the whole philosophy of prediction using Regime Theory is that the morphology will evolve to achieve equilibrium between the forcing of the waves and currents moving sediment and the resulting form of the estuary created by that movement. At present there is no evidence that any estuary system is in long-term equilibrium. It is also difficult to quantify how close, or how far, an estuary is from equilibrium morphology. Understanding sediment budgets in the medium- to long-term, and whether enough sediment will be available to allow morphologies to reach equilibrium, is a further constraint and uncertainty in this type of analysis.

## 4.2. Bottom-up Assessments

Leggett *et al*. (2004a) defined bottom-up assessments as numerical models that simulate physical processes in an estuary or along an open coast by solving equations for water movement (hydrodynamics) and sediment transport. Numerical models are based on formulations of the component processes reduced down, as far as possible, to the first principles of physics. This assumes that the physical principles are known and correct. Simplifications are often made and this may eliminate crucial or significant components. The main advantages and disadvantages of short-term predictive methods are shown in Table 15.

Table 15: Advantages and disadvantages of short-term (bottom-up) predictive methods.

| Advantages | Disadvantages |
|---|---|
| they provide local, short-term predictions of morphological change | they require a complete understanding of the physics of processes |
| they give additional information on changing current patterns and other physical processes | they are not suited to large-scale or long-term prediction |
| they allow the effects of short-term events to be quantified | they cannot predict major changes in flow or form |
| they can quickly evaluate many different scenarios | they are computationally expensive |

Numerical models can be broken down into 1D, 2D and 3D models, each with a different level of complexity, which are defined as follows:

- 1D - One-dimensional models only simulate situations in one dimension (e.g. river models) and assume that the other dimensions do not vary. This is an inexpensive method of modelling in homogenous areas and can also be used to provide a quick and simple solution to determine whether additional modelling may be required.
- 2D - Two-dimensional models can be horizontally 2D or vertically 2D along one profile. Horizontal 2D models assume that there is little or no variation through the profile. The most common type of 2D models are either depth-integrated or depth-averaged models. Vertical 2D models take one profile and consider variations with depth.
- 3D - Three-dimensional models use the equations of motion in all three spatial dimensions to represent the behaviour of a system. These models are very complex and are usually used for looking at small areas only, due to excessive computer time demands. 3D coastal models are of most use when studying regions of complex behaviour, such as wave breaking.

Decisions about how the results of a model should be interpreted need to be made at the start of the assessment, and should relate to a clear understanding of the type of information needed from the model. These decisions are reflected in the choice of model and its mode of use. It is important to understand what the assumptions in the model are, and the results should be interpreted in this context.

It may not be necessary to understand the details of the internal code or hardware of the different models available, but rather to concentrate on considering how the confidence in the model can be maximised. This is achieved through calibration and validation, which consider the resolution and accuracy of the results. The aim of calibration and validation is to compare model predictions with data of sufficient quality and quantity, so that reliable conclusions can be made about the models performance as a predictive tool. Although the results of 1D, 2D and 3D methods offer increasing realism with the number of dimensions modelled, they also are increasingly difficult to calibrate and validate.

Several factors need to be considered to ensure confidence in the interpretation of the model outputs. These are:

- do not assume either the model or data are accurate, both may contain a degree of uncertainty;
- use relevant data to calibrate and validate methods against observed patterns;
- ensure that the predicted changes are plausible;
- are the results consistent with those from other similarly classified estuaries?;
- are the results consistent with accepted geomorphological development?; and
- evaluate the results using sensitivity testing.

### 4.2.1. Hydrodynamic Modelling

Hydrodynamic modelling is the simulation of water movements including water levels, tidal current velocity and waves. Depending on the particular location of the scheme, it may also be necessary to consider river modelling as the river catchment may be significant in the evolution of the scheme.

*Tidal Current Models (including Water Levels)*
Tidal current models simulate water movement driven by the up and down movement of tidal level or storm surge, or quite often by a combination of two forces. A tidal current model may also consider wind- or wave-driven currents. The results of a model are validated using tidal elevation records within the model domain.

A tidal current model is fundamental to a coastal modelling system, upon which a sediment transport model can be built. Typically, the 2D modelling technique is adopted for both spatial accuracy and computational efficiency. The use of a 1D model is generally limited to estuaries where tidal currents are linear. The 3D model is required where flow stratification is significant due vertical density differences caused by salinity or temperature. Tidal current models can provide bed shear stress which is useful information from which to assess potential erosion or accretion, before applying a sediment transport model.

*Wave Models*
There are several types of wave models, which can be applied depending on the purpose or the environment to be modelled:

- wave hind cast models - for wave generation by wind, usually in the open sea;
- wave transformation models - for simulating wave propagation from deeper water into shallower water; and
- wave disturbance models - to simulate wave propagation into a harbour or semi-enclosed water body through a relatively narrow entrance and then wave disturbance due to reflection from waters' edge.

Wave transformation models may be grouped into either wave ray models or spectral models. Ray models track an individual wave from offshore to inshore (in simulation, it is calculated reversely from inshore to offshore by iteration). Spectral models transform a whole wave spectrum (describing a group of waves with different heights and periods), and then wave parameters (statistical wave height and period) are extracted from the transformed spectrum. Wave propagation can be simulated either as phase average or phase resolving (i.e. in time series). The phase resolving model is required in an area where non-linear process is dominant (i.e. in shallow water).

### 4.2.2. Sediment Transport Modelling

Sediment transport modelling is the simulation of sediment movement due to hydrodynamic influences and the corresponding changes in morphology. Typical time scales for the models are one day to one month, with spatial scales between 100m and 1000m. In practice, sediment transport models are classified into two groups depending on whether the dominant force is currents or waves. For nearshore areas, waves often play the dominant role in moving sediment. Using a 1D model is typically the method to predict near-sediment transport, and models are grouped into longshore sediment transport and cross-shore sediment transport. A coastline evolution model is often built onto a longshore sediment transport model (coastline evolution models do not consider cross-shore transport).

Sediment transport by currents is often built on tidal current models and the two models are coupled. The 2D sediment transport model has been widely used in practice for understanding coastal and estuarine morphological change and for quantifying that change. The 1D sediment transport model is used for morphological change in rivers or navigational channels although the use of width-averaged currents is questioned.

At present, sediment transport models are largely based on the theory of suspended sediment load and bedload sediment transport. Most of the transport equations were originally developed for sand although they can be modified for finer or coarser sediment. In general, sediment transport models are less accurate than tidal current and wave models due to the limited understanding in the sediment transport mechanism and subsequently limitations in its mathematical description. Also, a good understanding of the overall sediment budget of the region is valuable (see Section

3.2.7) against which the results of the model can be compared and tested. Therefore, care is needed in using sediment transport models particularly for medium or long term predictions.

# 5. Physical and Ecological Monitoring

This section provides advice on physical and ecological monitoring that could be used to inform scheme success and verify environmental impact assessment. A wide range of monitoring techniques of varying sophistication is described, including how they can be used and what their range, frequency and timescales should be. The spatial distribution of the monitoring outside the scheme will depend on the potential geomorphological and ecological zones of influence. These will be scheme specific and should be assessed as part of the initial geomorphological conceptual model.

## 5.1. Hydrological Monitoring

Hydrological monitoring focuses on tides and tidal currents, and wave climates, ideally derived by direct measurement using tide gauges, current meters and wave recorders. The measurements are generally designed for a specific purpose and involve instrumentation of varying degrees of sophistication.

The main difficulty with any equipment is how representative the deployment site is of the surrounding area, but gaining a sufficient spatial spread of measurements to characterise key interactions is both difficult and cost-prohibitive. This is not a problem if the results are not extrapolated or applied beyond the set of conditions that the site represents. Also, there are limitations with respect to the period of monitoring. Often intensive measurements can only be carried out over a limited time period and only a limited range of conditions are represented within a highly variable natural system. The measurements will only be characteristic of that time period and cannot be directly applied to other time periods. Consequently, the hydrological monitoring should be undertaken at specific locations over specific time periods that have been identified using the initial conceptual model (see Section 3) to address the relevant issues and uncertainties. General advice on location and length of measurement are provided in Sections 5.1.1 to 5.1.3, but each scheme will require a bespoke hydrological monitoring plan depending on how it fits within the range of hypothetical scenarios (see Section 2.6).

### 5.1.1. Water Levels

Measurements of the water levels within a habitat creation scheme are undertaken to assess if the scheme is receiving the full range of tidal action. If tides are unimpeded, the tidal stage and tidal range will be nearly identical inside and outside the scheme. If tides are constricted, then the tidal heights inside the scheme will provide a simple indicator of this problem.

Recording tide gauges are typically installed at several locations within and outside the scheme depending on its size. One gauge is located outside to capture the tidal signal in the adjacent estuary. One gauge is placed just inside the breach to capture the tidal signal at the downstream end of the main tidal creek. Another gauge is located near the furthest point from the breach within the scheme. This gauge will capture the tidal signal reaching the areas of the scheme that are most distant from the tidal source. The exact location of the gauges should be selected in the field (with help from the conceptual model), primarily on the basis of acquiring the necessary tidal datums, but with considerations given to access.

There are a number of automatic tide gauges suitable for mounting on the bed, such as submersible pressure transducers and acoustic gauges. These types of instruments can also be mounted on stable objects underwater, such as pilings, or constructed stilling wells. The gauges can be connected by cable to a data logger, typically programmed to record one sample every ten minutes, and downloaded at intervals throughout, or at the end of, the monitoring campaign. Alternatively, tide gauges can be installed which have a telemetry capability; wireless transmission of the water level data to receiving equipment remote from the measurement location.

Typically, water levels are recorded over complete two-week spring-neap tidal cycles, at six month intervals until it is certain that full tidal action is in operation or the regulated tidal exchange system is working. Given the importance of tidal action to sedimentation and habitat development, full exchange should be attained within three years after breach. However, if an adequate tidal range is established before year three, further monitoring may not be required.

### 5.1.2. Tidal Currents

Tidal current velocities are measured to provide data on bed shear stress and tidal current asymmetry. Bed shear stress is important as an indicator of when sediment particles will be eroded from the bed or allowed to deposit once they are in suspension. For bedload, particles of a certain size will be deposited once the bed shear stress falls below the critical shear stress that was needed to start them moving. Tidal current asymmetry is important in terms of sediment movement into and out of the scheme (or estuary). If the flood velocities are higher means a greater quantity of sediment will be driven into the scheme/estuary on the flood than is driven back out on the weaker ebb tide. Therefore, the scheme/estuary is likely to be accretionary. Ebb dominance will mean more sediment is transported out of the scheme/estuary on the ebb than is driven back in on the relatively weaker flood tides. As a result an ebb dominant scheme/estuary is likely to be erosional. This is a simplified view of tidal dominance and how it affects the transfer of sediment into and out of the scheme/estuary. In reality many other factors will complicate this balance; however, it is an important concept within the overall dynamics.

Current meters (Figure 17) deployed across the scheme are typically arranged with one in the main channel and others (the number depending on the size of the scheme) elsewhere on the mudflat (or saltmarsh) areas, to record over a full tidal cycle. Within the estuary, flow velocity data should be collected at several locations on transects spanning the estuary. The timing of the monitoring should allow tidal currents to be measured over both spring and neap tides. Typically (and if required), tidal current data is collected every year for the first three years and then at a lower frequency after that (for up to a maximum of 15 years) following review of the first three years data.


Figure 17: Example of a current meter.

The types of current meter to be used and their exact locations should be determined within the context of the geomorphology of the scheme (locations of main channel and mudflat/saltmarsh, water depths). Within the scheme, two commonly used types of fixed position current meter could be used; electromagnetic which operate on the basis of measuring changes in an induced magnetic field, and acoustic which operate on the basis of apparent variation in the speed of sound due to water movements. In the estuary, Acoustic Doppler Current Profiler's (ADCPs) are increasingly being used to obtain details of currents through the water column. An ADCP uses transducers to emit an acoustic signal and measures the 'Doppler Shift' in a series of depth strata (or 'bins'), providing a profile of currents vertically through the water column.

### 5.1.3. Waves

Measurements of waves within a scheme (generally larger schemes where fetches are long enough to generate waves and re-suspend sediment) are made to establish any relationship between wave energy and areas of erosion. Remobilised sediment in highly energetic waters within a scheme will not settle and as the tide ebbs, fine sediment is drawn out of the scheme and delivered into the adjacent environment. Deployment of several wave recorders inside the scheme will provide information on wave heights. They should be deployed in the winter and summer of the first year, for periods of approximately one month, to capture seasonal and tidal cycle variations. Two potential types of wave recorder could be installed:

- Surface-mounted systems (Figure 18): surface buoys use accelerometers to record wave dynamics and do not require a fixed structure for support, simply a mooring system. Pitch, roll and heave buoys can be used to provide directional wave data and an estimate of directional wave spectrum.
- Sub-surface systems: these devices use pressure sensors to record pressure variations in shallow water. They can provide real time output of wave height and period, together with full spectral analysis. As well as the standard non-directional data, some instruments can also collect real time directional information.

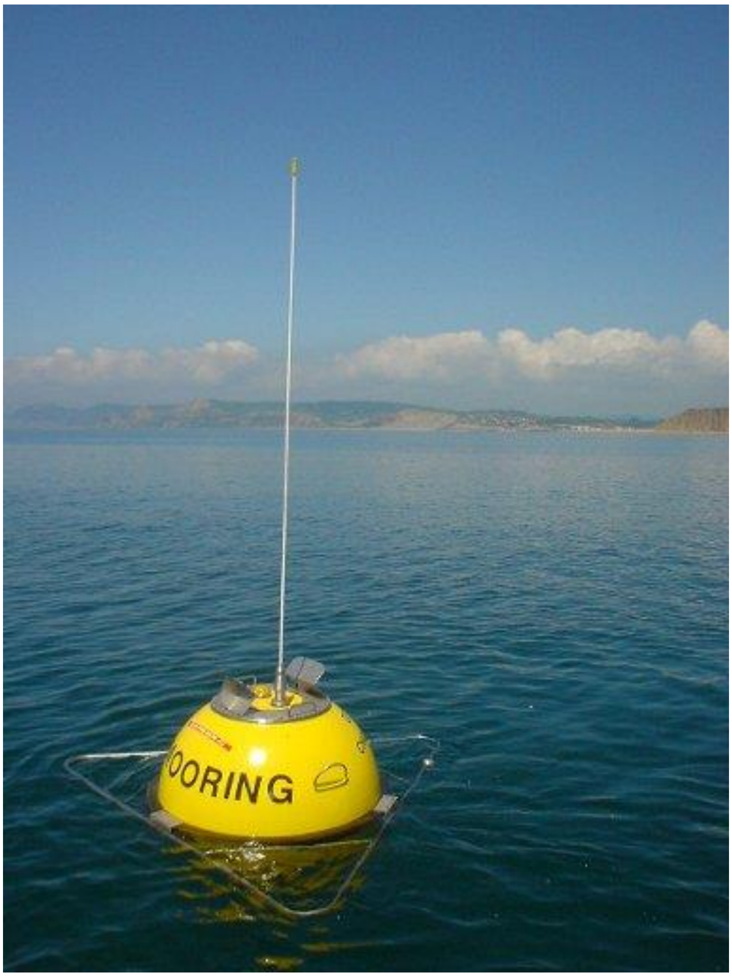


Figure 18: Directional waverider buoy in West Bay (Regional Coastal Monitoring Programme).

The types of wave recorder to be used and their most appropriate locations should be determined after a visual observation of the wave climate inside and outside the scheme has been carried out.

## 5.2. Geomorphological Monitoring

Geomorphological monitoring is typically designed to understand how the form of the habitat creation scheme and its creek channels are evolving in response to the physical processes of sedimentation and erosion. Monitoring includes topographic surveys of the tidal channels and the mudflat/saltmarsh surface, and measurement of accretion and erosion rates. These types of monitoring may also be required in relation to verify impacts on the wider estuary/coastal environment.

### 5.2.1. Planform Development

Monitoring of the planform of the scheme using a time series of aerial photography is important to define development of channel networks and the distribution of mudflat and saltmarsh. Aerial photographs should be taken of the scheme at a scale that can distinguish the development of the channel networks, and the distribution of mudflat and saltmarsh areas (Figure 19). Photographs are taken in the late summer and during a tide no greater than low spring tide so that channels are clearly visible and mudflat/saltmarsh areas can be viewed.

The frequency of aerial photograph collection depends on the stages of scheme development and associated risk. During a schemes early development there are likely to be rapid changes as the first order channel system develops, and potentially to the wider environment where issues might arise to other assets/infrastructure or sensitive features that require immediate remedial action. Hence, the initial period of scheme development may present a high risk as a consequence of rapid changes and so aerial photographs should be collected every year for the first five years. As the scheme starts to evolve towards equilibrium, the changes may be less severe and lower risk. Hence, the monitoring frequency should be reviewed following the start of the second order channel system.

Typically, the scheme will require aerial photograph monitoring for up to 15 years after breach, and changes in habitat layout compared to previous aerial photographs. Newly-formed channels and significant changes to the channel layout should be noted in each monitoring year. It is expected that a first order channel system will form and stabilize within the first five years and a second order system within the first ten years.


Figure 19: Aerial photograph showing saltmarsh edge at Saltfleet, Lincolnshire.

The boundaries of the mudflat/saltmarsh interface can be digitised as enclosed polygons with sufficient detail to be accurately represented at an appropriate viewing scale. The images should be obtained in a digital fully rectified format with a resolution less than 25cm, to allow use in a GIS system. However, there are some limitations to mapping this boundary. Using aerial photography as a tool for mapping saltmarsh is effective for large dense saltmarshes. However, saltmarsh often develops in patches and the edges may not be that distinct. Small isolated clumps that often define the edge of the saltmarsh extent can be hard to define and some ground-truthing may be needed, especially for those saltmarshes in their establishment phase which may not be dense enough to be clearly identified from aerial imagery.

The levee breach and channel through any outboard saltmarsh is expected to erode in response to tidal scour, until equilibrium conditions are achieved. Breach monitoring documents the response of breach width to either tidal scour or sedimentation to aid management decisions regarding breach maintenance. The width of the breach, measured from one bank to the other at the centre line of the remaining defence structure, and the area of the outboard tidal channel, delineated along the saltmarsh edge, should be measured using aerial photographs.

### 5.2.2. Cross-Sectional Development (Accretion/Erosion)

Measurement of elevation changes across the scheme is important to assess development towards target habitat; to determine if sediments transported by the tide into the scheme are accumulating at a rate necessary to achieve the desired site maturity and/or vegetation colonization elevations. Measurements outside the scheme can be used to verify impacts on the surrounding environment. The cross-sectional geometry of the mudflat, saltmarsh and channel system are typically monitored using remote techniques such as LiDAR (Figure 10), drones/UAV or laser scanning, or ground-surveyed transects located at key locations.

The use of LiDAR, drones and laser scanning and their advantages are described in Section 3.2.1 and further benefits and uses as a monitoring tool are outlined below:

- accretion of the saltmarsh within a scheme is fundamental to achieve successional development and therefore a full topographic coverage of the scheme would enable quantification of rates of change which can then be linked to the ecological evolution of the scheme;
- use of remote techniques is particularly important for estuarine sites or habitat creation schemes where access and health and safety risks make it may be difficult to collect data on the ground;
- issues such as extent of channel erosion may be difficult to determine on the ground and the extent only becomes visible from interpretation of remote datasets (see also Section 5.2.1); and
- large amounts of data can be collected; with regard to cross-sectional development of a scheme a number of transects could be extrapolated at desired locations.

The mudflat/saltmarsh transects will provide information on changes in elevation and creek channel dimensions (Figure 20). Transect data will indicate whether or not mudflat/saltmarsh areas are receiving sedimentation at the expected rates. It is also important that transects are established and surveyed in conjunction with the ecological monitoring (Section 5.3). The establishment and colonization of saltmarsh vegetation is directly related to elevation changes.

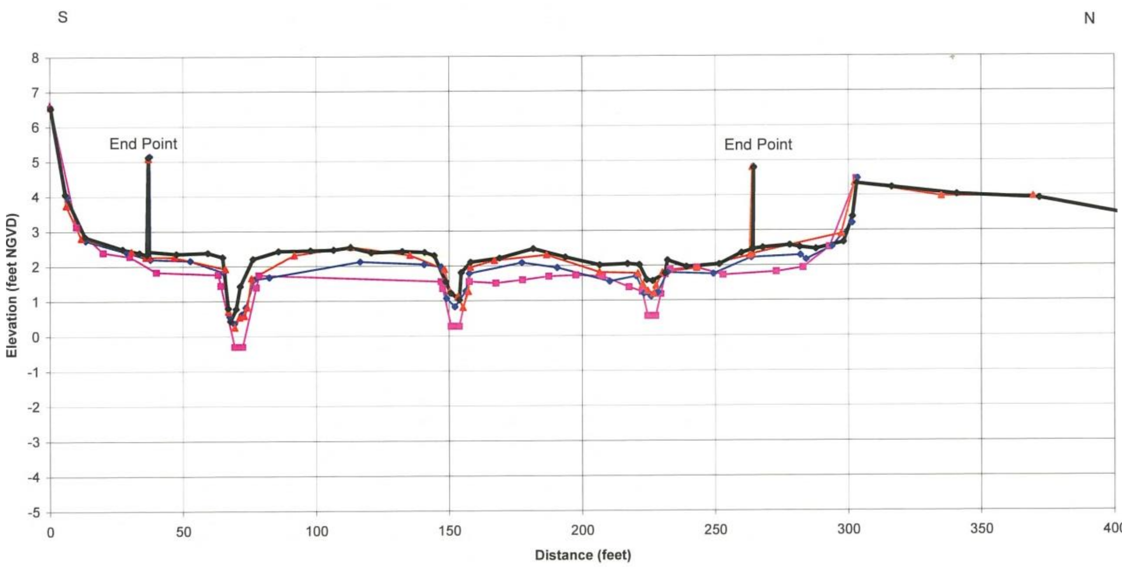


Figure 20: Time series of elevation along a transect at Martinez Regional Shoreline in San Francisco Bay. Pink = 2001, Blue + 2003, Orange = 2005 and Black = 2006. Note both scales are in feet.

Transect elevations should be surveyed during high tides by boat using RTK GPS until it is possible to accomplish the surveys on foot. However, the use of a boat does have inherent uncertainty with respect to positional accuracy. Transect starting and ending points should be permanently marked in the field to facilitate reoccupation in subsequent monitoring years.

Topographic data should be collected annually for the first five years, and then once every two years until design expectations are met (up to 15 years after breach). The use of drones, aerial photographs and ground surveys could be completed simultaneously, representing potential efficiencies (cost/time) and consistency of interpretation as the timing of the collection of the different data sets would be the same.

Surveys of the geometry of the tidal channel outside the scheme should also be conducted annually following breach in order to determine if the channel is providing unrestricted tidal exchange with the scheme. The surveys should continue until there is no significant increase in the channel dimensions and full tidal action has been attained. The ground surveys should be supported by analysis of aerial photographs (Section 5.2.1).

## 5.3. Summary Table of Hydrological and Geomorphological Monitoring

Table 16 summarises the key hydrological and geomorphological monitoring to determine progression of a habitat creation scheme towards its objectives and for verification of scheme impacts on the surrounding environment.

Table 16: Summary of hydrological and geomorphological monitoring techniques

| Measured parameter | Technique | Frequency | Duration after breach |
|---|---|---|---|
| Water levels | Tide gauge | Over a spring-neap tidal cycle every six months | Three years (maximum) |
| Tidal currents | Current meter and ADCP | Over a spring-neap tidal cycle every one year for first three years and then a lower frequency after that (following review) | 15 years (maximum) |
| Waves | Surface wave rider buoy and sea bed mounted pressure sensor | For one month in summer and one month in winter | One year |
| Planform development | Aerial photographs | Once a year for the first five years and then a lower frequency after that (following review) | 15 years |
| Cross-sectional development | LiDAR, drones, laser scanning and ground survey | Simultaneously once a year for the first five years and then a lower frequency after that (following review) | 15 years |

## 5.4. Ecological Monitoring

There are two key drivers for ecological monitoring at a habitat creation scheme; compliance monitoring and verification of impact assessment monitoring. Compliance monitoring enables an appraisal of whether the scheme is achieving a required objective, generally related to the compensation needs for the scheme. The mitigation/compensation requirements will have been determined based on a number of factors and are likely to include the following:

- type of habitat to be created or proportions of diverse habitat types;
- area of habitat(s) to be created;
- time scale for creation of the habitat(s) and potentially the duration required for the habitat(s); and/or
- associated communities that are expected to colonise/use the scheme (can include benthic species and birds).

The monitoring should therefore be specifically designed to ensure that compliance with the objectives (which may be linked to license and/or planning conditions) can be determined.

Impact assessment monitoring may also be required if a scheme is likely to have a significant effect on the surrounding environment. The degree of monitoring required will therefore depend on the overall objective(s) for the scheme and the sensitivity and vulnerability of the surrounding environment.

There are several general guidance documents that provide information for monitoring coastal and intertidal habitats. These should be used for providing further details for the survey methodologies.

### 5.4.1. Successional Development of a Scheme

Prediction of the successional development of the scheme through monitoring of the intertidal habitat types including transitional vegetation, vegetation establishment and benthic fauna over time can provide important information to enable an estimation of site compliance and to estimate whether the scheme will reach its objective(s). Monitoring of transitional habitats can also provide useful information and may be required to ensure no adverse effect occurs as a result of the habitat creation scheme. The objective of the habitat creation scheme will determine the degree of intervention of the succession of a scheme. If there is a short-term objective for the scheme development then more intervention can be undertaken including planting of vegetation or introduction of key species. However, if the objective is for the longer term it can be preferable to allow a scheme to develop naturally as the sediment will have had more time to consolidate and the natural succession of vegetation and infauna will have occurred at a slower rate giving time for the build-up of organic matter for later stages of colonisation. Intervention may also be necessary to stabilise the site in the short term to prevent erosion or to ensure that succession occurs in a particular way.

As a habitat creation scheme develops there should be a succession of flora and fauna species colonising the scheme. The location, physical conditions and surrounding environment at the scheme will influence what colonises and the rate at which species arrive. Colonisation of flora is likely to include an initial coverage of diatoms (microscopic phytoplankton) that secrete mucus which then binds the sediments together. The diatoms stabilise the sediment and provide organic enrichment which provides a more suitable surface for attachment of pioneer vegetation. Pioneer saltmarsh plants colonise the mudflats or sandy mud habitat and can enhance accretion in the area by reducing the flow of water across the scheme causing the settlement of fine sediment. This then provides a more stable habitat for more mature saltmarsh growth. To create a diverse saltmarsh community would require several years of successional growth. Wolters *et al*. (2008) monitored the development of saltmarsh on previously reclaimed land and found that it took approximately five years for species diversity in the scheme to become similar to a local reference saltmarsh. The duration for development to a target objective will be dependent on the type of community required as higher marsh, for example, will take a lot longer to develop than pioneer and mid-marsh. The duration will also be site specific and depend on the location of sources of seeds or larvae for colonisation or level of intervention.

Successional development of fauna also occurs within a newly formed or disturbed scheme. The initial colonisers are the opportunistic species which can take advantage of a disturbed scheme. These species exhibit certain characteristics including a short life-cycle, rapid growth, high fecundity and larval recruitment, which enable them to quickly colonise at high abundance and exploit the resources available. Following this stage the slower-growing, longer-lasting species arrive and out-compete the initial colonisers. These species are likely to remain on the scheme and make up the basis of the community, unless there is a high level of disturbance at the scheme.

The importance of monitoring throughout the successional stages of a habitat creation scheme is to enable intervention if needed to ensure compliance with the conditions for a scheme (i.e. to adjust elevation levels if necessary to ensure the appropriate balance of mudflat and saltmarsh to develop). To monitor the phases of succession, it is necessary to undertake survey work to investigate the overall habitat types within the scheme and the abundance and diversity of species (vegetation and benthic fauna) within a community. The methods used for these surveys are outlined below and those selected will depend on the objectives of the habitat creation initiative.

### 5.4.2. Habitat Type and Extent

Repeat habitat survey of the site would enable a series of habitat maps to be produced showing the distribution of broad scale habitats. This would allow the quantification of change in extent of target habitats over time and for habitat maps to be produced to illustrate this. This could be achieved in a number of ways depending on the size of the scheme. For small schemes it would be feasible to undertake a phase one habitat survey for the entire scheme mapping the overall distribution of habitats distinguishing between saltmarsh, sandflats, mudflats saltmarsh and sand dune, etc., whereas for large schemes a broad-scale map using remote sensing techniques may be more applicable.

A phase one habitat survey involves a walkover to map boundaries of habitats onto a map base. Target notes are also used to describe key features that are observed during the survey that may have some influence on the future development of the scheme (i.e. evidence of erosion of a saltmarsh edge or disturbance due to people walking on the site). Mapping is generally completed following a desk-based exercise to determine the likely habitats and their distribution. This data is then taken into the field for verification and boundary definition based on ground truthing. A walkover survey can also involve sediment sampling with in situ analysis undertaken to determine sediment types and any vegetation, infauna (animals living in the sediment) and/or epifauna (animals living on the sediment surface or on the surface of other animals/plants) that is visible and identifiable.

Remote sensing is a method for mapping overall habitat distribution and change over time for a large area and can include use of satellite images and aerial photography from aircraft, drones or remote controlled aerial devices. These methods have the benefit of showing areas that may be otherwise inaccessible on the ground due to large creek systems or other hazardous conditions. LiDAR (see Section 3.2.1) can also be used to map the distribution of habitats by measuring the elevation of the scheme relative to adjacent areas. This method is often used for saltmarsh mapping and can be used in combination with bathymetric surveys that cover the intertidal and shallow subtidal zones.

### 5.4.3. Vegetation Monitoring

The vegetation monitoring method to be used will be dependent on the objective of the habitat creation scheme. Initially it will be necessary to monitor the development of the habitat (i.e. saltmarsh or sand dune) over time and once the habitat has developed monitoring will be required to determine if it meets the objectives and conforms to the description and quality of the Annex I features or other agreed objectives. Monitoring of key species should be considered to enable rapid assessment of compliance against objectives. Vegetation monitoring needs to be undertaken during the late spring or summer months, particularly for annual ephemeral species which die off during the winter months. Perennial species may be identifiable to genus level at other times of year although identification is much more reliable during flowering periods. For ephemeral species there may be no evidence remaining during the winter months.

*Saltmarsh*
The level of saltmarsh monitoring required will vary, depending on the objective. Widely used methods include:

- transects and fixed quadrats at successive stages to enable an assessment of change over time which would enable the development of the site from pioneer marsh to mixed marsh communities to be established. Data from transects and fixed quadrats should be used to ground truth aerial surveys or aid mapping for walkover surveys;
- aerial survey or walkover survey to map the distribution and abundance of annual and perennial species;
- more detailed survey to map the communities according to zones; and
- detailed survey using the National Vegetation Classification (NVC) (Rodwell, 2000) to map all vegetation communities present.

If the scheme objective is to generally create areas of saltmarsh (Figure 21) and mudflat then a review of any aerial survey data followed by a walkover survey to ground truth the extent of each habitat with differentiation between zones where annuals and perennials dominate may be sufficient. Annuals such as Salicornia spp. are often present not only in the pioneer stages but up to the upper marsh in low levels along creeks and where there has been disturbance but the abundance is likely to decrease with the successional stage. Monitoring of these zones could provide a generalised distinction between the stability of different areas. However, if the objective is to create a particular type of saltmarsh with specific community types then a more detailed survey would be required with mapping of zones (pioneer, low-mid saltmarsh, mid-upper saltmarsh and transitions to terrestrial habitats) and species presence and abundance. A review of existing data on saltmarsh extent, species and historical development within the surrounding area is recommended to guide any survey work undertaken.

Where the scheme objective is to create compensation habitat relating to the Habitats Directive it is recommended that a NVC is carried out once other monitoring indicates that the objectives relating to saltmarsh vegetation have been achieved, this would enable confirmation of the presence and quality of the Annex I habitat types. In some cases an NVC survey may be used for baseline information for the site where the site supports habitats of interest. Regular, short term (e.g. annual) repetition of an NVC survey is not suitable to monitor incremental changes in community extent because of the subjectivity inherent in mapping these complex community types.

Figure 21: Saltmarsh

A walkover survey would involve mapping of key features (preferably mapped in advance using aerial techniques) with notes taken at regular intervals within a habitat type and GPS to locate boundaries between habitats. This type of survey would be required to inform the baseline. To ensure that all possible attributes are covered during the walkover survey, monitoring of the following parameters is recommended (Connor *et al*., 2004):

- habitat extent;
- physical structure of the saltmarsh (i.e. presence and approximate size of creeks and pans);
- vegetation structure - zonation of the saltmarsh and sward structure (grazing regime and effect);
- vegetation composition - characteristic species and indicators of negative trend (*Spartina anglica*, invasive species); and
- other negative indicators.

If more information on species or community types is required a more detailed survey could be undertaken involving overall distribution mapping together with species identification and abundance (estimated as percentage cover) recorded within agreed areas of survey (quadrats, generally 1-4m2 in area depending on the required coverage and the density of plants). Quadrats are generally recorded along transects from the transitional habitats down to pioneer vegetation to establish patterns of zonation within the saltmarsh. Photographs should also be taken together with notes of any influential factors observed during the survey, such as substantial erosion within creeks. Fixed point photography is also a useful technique to monitor the development of a particular area, often along transects, as it can be used to show how the communities change throughout the zones.

Following creation of a saltmarsh habitat it is recommended to monitor annually until a short-term objective is achieved (i.e. five years) with longer monitoring as required. Ongoing monitoring will then be guided by the objectives and the findings of previous years' monitoring.

*Eelgrass Beds*

Creation of eelgrass beds requires specific habitat requirements. *Zostera noltii* is the main intertidal eelgrass species (Figure 22) and occurs at low water in shallow muddy to sandy mud habitats. Monitoring of habitat suitability for eelgrass beds therefore requires monitoring of elevation (and therefore inundation levels) and sediment type. The narrower the habitat niche for a species the more critical is the habitat characterisation and the need for monitoring. Adequate planning, in relation to physical processes, such as monitoring tidal elevation, to ensure the long-term stability of the scheme will also be critical, because species within narrow habitat niches can easily be outcompeted by other species if conditions change, for example if the tidal elevation changes due to accretion of sediment and other eelgrass species can outcompete other species.

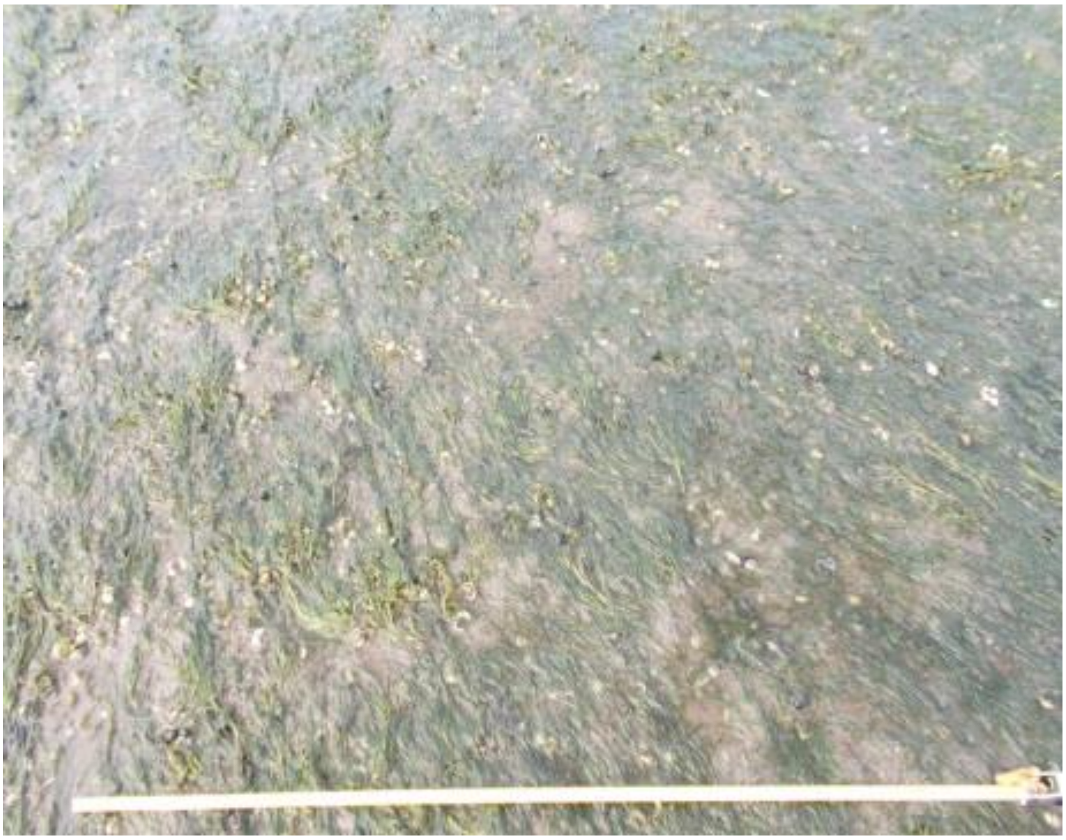
Figure 22: Eelgrass bed

To monitor the development of an eelgrass bed, broad scale mapping of the bed would provide a good indication of its size and its change in distribution over time. Walking around the edge of the bed with a GPS would delineate its boundary. It is recommended that a distinction is drawn between patchy areas (<5% coverage) and the main dense bed (>5% cover) as the patchy areas are more likely to be subject to greater levels of natural (or other anthropogenic) disturbance. Quadrat sampling (0.25m2 or 1m2 quadrats) within the habitat (with at least twelve or three quadrats respectively taken at each location with more smaller quadrats in patchier areas of eelgrass) can also be used to determine coverage of eelgrass. Statistical analysis of percentage cover over time from the same quadrats would provide a good indication of development of the bed and any localised changes.

### 5.4.4. Benthic Fauna

Benthic monitoring is generally undertaken to assess the development of a scheme in terms of its species distribution, abundance and diversity. The aim of monitoring is often to determine whether the predicted communities do actually colonise the scheme but it may also be specifically targeted at certain species (i.e. cockles or polychaetes which are required to provide specific feeding resources for birds). Surveys of benthic fauna are generally undertaken between February and July to ensure a good distribution of characteristic species and avoid a potentially high number of recruits likely to occur later in the summer. The timing of surveys should always be consistent, so if existing information exists for sampling outside of these months then it may be beneficial to continue the sampling during the same time of year to compare similar data.

Monitoring can include a number of methods including broad-scale survey to map the distribution of biotopes and/or grab sampling at high tide and/or core sampling along transects down the shore to determine zonation patterns. The level of survey will depend on the size and sensitivity of the scheme and the objectives for the habitat creation.

Biotope mapping involves classification of the area into the characterising biotopes based on the habitat type and dominant species (Wyn *et al*., 2006). A walkover survey is undertaken with a map derived from aerial photography, OS maps or previous mapping undertaken of the survey area. Each biotope, or area mapped for analysis, is observed and then sampled by extracting the sediment and sieving the sample to identify the species present and the number of individuals and/or their abundance (Figure 23). From the resulting information the biotope can be assigned to each zone within the survey area. Boundaries of the biotope should be estimated based on the walkover survey.

Figure 23: Benthic fauna sample.

A widely used method to collect more detailed quantitative intertidal monitoring data involves the use of grab or core samples at specific locations, using a grab sampler (type of grab is dependent on the sediment type) or more commonly a 10cm diameter core. One sample is used for particle size analysis to enable an assessment of the sediment type, to determine any association between particle size and species present. Further cores are analysed for species presence and abundance. The number of cores taken will be site specific and depend on the objectives of the survey, the size of the scheme and the variability within the scheme. From the sample analysis it is then possible to determine a number of characteristics including species richness and abundance, species diversity, and biomass. Statistical analysis can then be undertaken to determine any associations between the parameters measured (e.g. whether sediment size is influencing the community present and any similarities between schemes, either temporal or spatial).

# 6. Estimated Monitoring Costs

This section provides a preliminary estimate of the costs for each element of the monitoring specified in Section 5. The estimates are divided into three main categories: hydrological monitoring, geomorphological monitoring and ecological monitoring, further divided into specific methods of monitoring under each category.

These estimates will be subject to refinement and revision as any particular habitat creation design is developed over time. Estimated costs are presented in 2016 pounds sterling, and would need to be adjusted to account for price escalation for implementation of monitoring in future years. This opinion of probable monitoring costs is based on available published cost estimates and Royal HaskoningDHV past experience and professional judgement. There are no estimated costs for permitting, design construction or ongoing maintenance. Note that in providing opinions of probable monitoring costs, Royal HaskoningDHV has no control over the actual costs at the time of implementation. The actual cost of monitoring may be impacted by the availability of equipment and staff and fluctuation of supply prices at the time the work is bid. Royal HaskoningDHV makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bids or actual costs.

For each of the monitoring methods, the quantities used to estimate costs are described. The quantities used vary between each type of monitoring. All the hydrological monitoring elements are based on both one monitoring time segment and the full monitoring period including equipment rental, mobilisation (installation) / demobilisation, and data processing and reporting. For geomorphological elements (both remote sensing and ground survey), the costs are provided as ranges for a single survey which relate to the size of the scheme to be monitored. For ecological monitoring, the overall cost per type of survey or pre type of analysis is provided.

## 6.1. Hydrological Monitoring Costs

Tables 17 and 18 break down the approximate costs of hydrological monitoring, for one deployment (Table 17) and for deployments for each of the recommended monitoring periods (Table 18). The costs for the entire monitoring periods are three years for water levels and tidal currents, and one year for waves. After each full monitoring period, the data should be reviewed to determine if further longer-term monitoring is required. Estimated costs after three years are not presented here.

Table 17: Hydrological monitoring costs for a single deployment

| Monitoring Technique | Assumptions | Estimated Cost* |
|---|---|---|
| Water levels | 3 gauges for 2 weeks @ £35/day<br>2 days each for two FTE @ £500/FTE/day<br>2 days FTE @ £500/FTE/day | £4,500 |
| Tidal currents (site) | 3 current meters for 2 weeks@ £35/day<br>2 days each for two FTE @ £500/FTE/day<br>2 days FTE @ £500/FTE/day | £4,500 |
| Tidal currents (estuary) | 2 ADCPs for 2 weeks @ £70/day<br>2 days each for two FTE @ £500/FTE/day<br>2 days FTE @ £500/FTE/day | £5,000 |
| Waves | 2 wave riders for 1 month @ £135/day<br>2 days each for two FTE @ £500/FTE/day<br>2 days FTE @ £500/FTE/day | £11,000 |

*estimated cost includes equipment rental, mobilisation and demobilisation, and data processing and reporting

Table 18: Hydrological monitoring costs for the entire monitoring period (up to three years for water levels and tidal currents and one year for waves).

| Monitoring Technique | Assumptions | Total Cost* |
|---|---|---|
| Water levels | 3 gauges for 2 weeks, 7 times (over 3 years) @ £35/day<br>2 days each for two FTE, 7 times (over 3 years) @ £500/FTE/day<br>14 days FTE @ £500/FTE/day | £31,500 |
| Tidal currents (site) | 3 current meters for 2 weeks, 4 times (over 3 years) @ £35/day<br>2 days each for two FTE, 4 times (over 3 years) @ £500/FTE/day<br>8 days FTE @ £500/FTE/day | £18,000 |
| Tidal currents (estuary) | 2 ADCPs for 2 weeks, 4 times (over 3 years) @ £70/day<br>2 days each for two FTE, 4 times (over 3 years) @ £500/FTE/day<br>8 days FTE @ £500/FTE/day | £20,000 |
| Waves | 2 wave riders for 1 month, 2 times (over 1 year) @ £135/day<br>2 days each for two FTE, 2 times (over 1 year) @ £500/FTE/day<br>4 days FTE @ £500/FTE/day | £22,000 |

*estimated cost includes equipment rental, mobilisation and demobilisation, and data processing and reporting

## 6.2. Geomorphological Monitoring Costs

Table 19 provides estimated costs of single geomorphological monitoring surveys. In general, for remote sensing the acquisition price per square kilometre decreases as the surveyed area increases (although the cost to process would increase for larger areas). For ground surveys, the cost increases as the surveyed area increases.

Table 19: Geomorphological monitoring costs for a single survey.

| Monitoring Technique | Item | Unit | Unit Price |
|---|---|---|---|
| Planform development | Aerial photograph flight | Per square kilometre | £200-400 |
| | Data processing and reporting | Lump | £3,000-6,000 |
| Cross-sectional development | LiDAR flight | Per square kilometre | £150-300 |
| | Topographic ground survey | Per hectare | £400 |
| | Data processing and reporting | Lump | £1,500-3,000 |

## 6.3. Ecological Monitoring Costs

Table 20 provides an example for costs of an ecological monitoring survey and different types of analyses required to support the survey. The overall cost will be highly dependent on the objectives of the survey and the location, extent and complexity of the site and type of analysis required.

Table 20: Ecological monitoring costs for surveys and associated analyses.

| Monitoring Technique | Item | Unit | Unit Price |
|---|---|---|---|
| Habitat type | Particle size analysis | Per sample | £70-150 |
| Vegetation | Saltmarsh and/or eelgrass survey | Quadrat survey along transects within saltmarsh/eelgrass area | £1,500 for survey<br>£2,000 for analysis of data<br>£2,000 for reporting |
| Benthic Fauna | Benthic sampling (mudflat) | 12 locations. Coring with 3 replicates at each site | £1,500 for taking samples<br>£8,000-12,000 for analysis*<br>£4,000 for reporting |
| | Benthic fauna to species level within a mud habitat | Per analysis | £150-220 |
| | Benthic fauna to species level within a sand habitat | Per analysis | £100-150 |

*depending on parameters analysed

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## Data Archive Appendix

No data outputs were produced as part of this project.

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