# Able Marine Energy Park
# Compensation Site Environmental Monitoring and Management Plan

**March 2013**

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# 1 -INTRODUCTION

1.1 The development of the Able Marine Energy Park (AMEP) east of North Killingholme on the Lincolnshire Coast will partly affect the Humber Estuary Special Area of Conservation (SAC) and the Special Protection Area (SPA) / Ramsar site. Measures to both compensate and mitigate for the effects of AMEP on these European sites have been identified, and will be implemented as part of any future development.

1.2 This document is an Ecological Management and Monitoring Plan for the compensation sites (CEMMP) and it has been drawn up taking account of guidance on management planning produced by the Conservation Management System (CMS) Consortium (www.cmsconsortium.org). It describes the compensation measures that are required and lists specific objectives which are fundamental to their delivery. Further it includes targets and management actions which support the objectives and the monitoring which will be undertaken to confirm progress towards the objectives, and ultimately confirming that they have been achieved. Limits of acceptable change are defined and any necessary remedial actions which will be undertaken should the monitoring show that these limits have not been met.

### *PROCESS OF FINALISING OUTSTANDING TARGETS*

1.3 The compensation proposals for AMEP are complex, and the objectives and targets / management options included in this version of the CEMMP have been subject to extensive discussions with stakeholders. Prior to the DCO being granted, the CEMMP will be further refined through continued regular meetings with key stakeholders about targets / management actions and subsequent monitoring requirements which are yet to be agreed.

1.4 The CEMMP is a live working document which will be in place for as long as it is deemed necessary to achieve the agreed objectives set out in it. Updates to it will be overseen by the Steering Group (see Paragraph 1.7), whose role is explained below and includes undertaking a complete review of the EMMP every five years.

#### *PRINCIPLE FOR REVIEW OF BENTHIC SPA BIRD PREY TARGETS*

1.5 The benthic target protocol set out in this EMMP is based on the current understanding of the benthic communities at NKM foreshore. It is understood that the targets can only be finalised once the baseline benthic surveys at NKM and CCS have been completed. This will occur prior to the start of any work on AMEP that involve the loss of mudflats at the NKM foreshore, or disturbance to SPA birds that use it. The following considerations will need to be taken into account when reviewing the targets:

- The compensation site needs to function like the mudflats on NKM foreshore for black-tailed godwits and other waterfowl, and must support the benthic prey that the birds require. The review of the evidence will assess the presence of patches of high prey density and appropriate size classes associated with the numbers of foraging black-tailed godwits it has to support. The findings of the annual benthic monitoring will be set in context within the agreed target range, taking account of natural changes at the control site(s).

- The ability of univariate and multivariate analysis techniques along with biotope mapping to adequately characterise the necessary functional aspects of Killingholme so they can be replicated within the compensation area will need to be considered; not just peak areas of prey density but also biomass of specific key prey species, only a proportion of which will represent those individuals within a suitable size range to be consumed by specific birds.

- The benthic targets will be set taking account of the energetic requirements of the black-tailed godwits. These will be defined through a combined assessment of the baseline benthic surveys of the mudflats on the NKM foreshore and the identified feeding locations of the birds.

- One of the key concerns is to avoid a situation where benthic targets are met in a single year, but with additional years' survey effort are shown to be consistently at the bottom end of the target range. This could provide sub-optimal habitat for supporting the peak numbers of black-tailed godwits, which are currently using the NKM foreshore in internationally important numbers. The regular review process will focus on benthic distribution, density, size classes and feeding requirements of black-tailed godwits, along with the numbers of birds using the site (see Annex 3 – Target Setting Protocol). This will identify sub-optimal performance early, and allow remedial management actions to be undertaken. Targets will be reviewed and the effectiveness of management actions monitored.

1.6 As the EMMP is a live document it allows the current targets to be re-evaluated and adjusted as and when necessary, including once the baseline benthic surveys have been completed. The Steering Group will oversee the review of the baseline benthic survey findings, and the revision of the benthic targets based on the review findings. The Group may also agree to draw on additional external expertise if required. The cost implications to AHPL of any changes, or additional support, will be subject to reasonable agreement between AHPL and the Steering Group.

### *THE STEERING GROUP*

1.7 Able Humber Ports Limited (AHPL) will have overall responsibility for the implementation and delivery of the CEMMP. However, the involvement of other stakeholders is essential for the effective working of the CEMMP, and hence AHPL will establish a Steering Group whose members and terms of reference are set out in a '*Deed in Relation to the Able Marine Energy Park'*, between Able Humber Ports Limited and Natural England.

1.8 An agenda will be drawn up in advance of each Steering Group meeting by AHPL and minutes will be produced after the meeting by them for agreement.

1.9 Unless otherwise stated, the default duration for the ecological survey work (e.g. saltmarsh intertidal and subtidal benthos and fish communities described within this document is 10 years. Continuance of any of these components beyond that period will be determined through discussion on findings etc by the Steering Group. It is expected that some components of the compensation and the mitigation will require on-going management to ensure that the objectives continue to be met.

## 2 ENVIRONMENTAL BASELINE AND IDENTIFIED IMPACTS

### *INTERTIDAL HABITATS*

### *Baseline North Killingholme Marsh (NKM)*

2.1 The baseline is described in EX28.3 Part 2 in terms of historical trends, mud type, benthic community and bird populations. The shore was eroding but has entered a phase of accretion since 2000 after the construction of the Humber International Terminal. As a result, over the last 10 years the intertidal area that lies between the MHWN and MHWS elevations has increased from 3.27 ha to 18.95 ha, an increase of 15.68 ha. The sediments are composed of a high proportion of fine silts giving soft and sloppy mud. The upper shore is subject to colonisation by *Spartina anglica* dominated saltmarsh. Table 1 summarises the benthic population (details of the methodology are given in Annex 10.1 of the Environmental Statement (ES). Biomass is wet (blotted) weight in grams. Further data is provided in the Marine EMMP (MEMMP).

2.2 Further invertebrate sampling work will be undertaken in Spring and Autumn 2013 to provide a new preconstruction baseline and identify targets for the compensation site.

**Table 1: Intertidal Abundance and Biomass of Principal Species**

| ***abundance*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| species | (12 x 0.01m$^2$ samples) | per m$^2$ | species | (12 x 0.01m$^2$ samples) | per m$^2$ | species | (12 x 0.01m$^2$ samples) | per m$^2$ |
| *Tubificoides benedii* | 268 | 2233 | *Tubificoides benedii* | 271 | 2258 | *Streblospio shubsolii* | 91 | 758 |
| *Hediste diversicolor* | 114 | 950 | *Corophium volutator* | 202 | 1683 | *Corophium volutator* | 88 | 733 |
| *Corophium volutator* | 109 | 908 | Nematoda | 93 | 775 | Nematoda | 21 | 175 |
| *Streblospio shubsolii* | 50 | 417 | *Streblospio shubsolii* | 50 | 417 | *Tubificoides swirencoides* | 16 | 133 |
| Nematoda | 49 | 408 | *Macoma balthica* | 47 | 392 | *Tubificoides benedii* | 15 | 125 |
| ***biomass*** | | | | | | | | |
| | Upper shore | | | Mid shore | | | Lower shore | |
| species | (12 x 0.01m$^2$ samples) | per m$^2$ | species | (12 x 0.01m$^2$ samples) | per m$^2$ | species | (12 x 0.01m$^2$ samples) | per m$^2$ |
| *Hediste diversicolor* | 2.86 | 23.83 | *Macoma balthica* | 1.55 | 12.92 | *Macoma balthica* | 0.21 | 1.75 |
| *Corophium volutator* | 0.42 | 3.50 | *Corophium volutator* | 0.45 | 3.75 | *Corophium volutator* | 0.13 | 1.08 |
| *Macoma balthica* | 0.27 | 2.25 | *Tubificoides benedii* | 0.2 | 1.67 | *Hediste diversicolor* | 0.07 | 0.58 |
| *Tubificioides benedii* | 0.17 | 1.42 | *Hydrobia ulvae* | 0.02 | 0.17 | *Mysella bidentata* | 0.06 | 0.50 |
| *Streblospio shubsolii* | 0.01 | 0.08 | *Streblospio shubsolii* | 0.01 | 0.08 | *Streblospio shubsolii* | 0.03 | 0.25 |
| **Total biomass per m2** | | **31.08** | | | **18.58** | | | **4.17** |

## *Impacts*

2.3 Details of agreed impacts are provided in the Statement of Common Ground (SoCG) on the Shadow Habitat Regulations Assessment (sHRA). Habitat losses are detailed in Annex B and summarised in Table 2.

**Table 2: Long Term Direct (SAC/ SPA) and Indirect (SPA) habitat loss (ha)**

| | HABITAT TYPE | | | |
|---|---|---|---|---|
| | Saltmarsh | Intertidal Mudflat | Sub-tidal (Estuary) | Total |
| SPA | 0 | 88 | 13.5 | 101.5 |
| SAC | 0 | 73.4 | 21.2 | 94.6 |

2.4 A combination of direct and indirect losses associated with the site together with long term losses in the Humber identified by the Environment Agency provide a requirement to replace a long term loss of 101.5 ha of habitat of which 88 ha is intertidal and 13.5 ha is sub-tidal. This total reflects the SPA habitat losses which are higher than those of the SAC (21.2 ha of estuarine and 73.4ha of intertidal) as they include functional loss of use to birds through disturbance. They also reflect the requirement to replace intertidal habitat on 2:1 basis (due to uncertainty) and other habitats on a 1:1 basis. Sub-tidal habitat can be replaced by other estuarine habitats such as saltmarsh.

2.5 Nine species of bird were identified as likely to be displaced by direct habitat loss and functional disturbance to the extent that an impact on site integrity was anticipated. This assessment was based on peak counts. These peaks were all recorded from the Through the Tide Counts (TTTC) reported in Annex 11.9 Marine Energy Park Bird Survey Results April 2010 to April 2011 of the ES. These peaks were all higher than the five year mean peaks reported from WeBs counts for the period 2004/05-2008/09.

**Table 3: Bird Species**

| Species | Humber Qualifying Population | Humber Min & Max Peaks (WeBS 2004/5-2008/09) | NKM Peak & % of Humber population represented by Peak | % Foraging during peak count |
|---|---|---|---|---|
| Avocet (breeding) | 493 | 374-652 | 4 (0.8%) TTTC | 100 |
| Bar-tailed Godwit | 5926 | 1490-5926 | 123 (3.2%) TTTC | 98 |
| Black-tailed Godwit | 3887 | 2435-5323 | 2566 (66%) TTTC | 49 |
| Curlew | 4440 | 3071-5180 | 158 (3.6%) TTTC | 49 |
| Dunlin | 21518 | 14733-26305 | 1029 (4.8%) TTTC | 99 |
| Lapwing | 18756 | 11700-27421 | 325 (1.7%) TTTC | 0 |
| Redshank | 5445 | 3886-8494 | 540 (9.9%) TTTC | 98 |
| Ringed Plover | 2168 | 781-2168 | 210 (9.7%) TTTC | 88 |
| Shelduck | 5314 | 2892-5804 | 109 (2.0%) TTTC | 95 |

2.6 Effects arising from piling on marine mammals and sea lamprey are dealt with in the Marine EMMP (MEMMP).

***Baseline Cherry Cobb Sands Saltmarsh***

2.7 The baseline is recorded in Annex 35.1 of the AMEP Environmental Statement (ES). A description of the saltmarsh that will be affected by the works is included in Annex 34.1 of the ES, and briefly summarised below.

2.8 The upper saltmarsh in the vicinity of Cherry Cobb Sands varies in width from five metres seaward from the base of the existing sea defences at Stone Creek in the south of the site, up to 330 m at the Outstray in the north of the site (2010 data). In a similar manner, the width of the mid saltmarsh zone also varies from 60 m in the south to around 300 m in the north of the site.

2.9 There is dense saltmarsh vegetation cover in the upper and mid saltmarsh zones, with little or no signs of erosion, which indicates that the habitat quality is good. These zones are dominated by sea couch grass *Elytrigia atherica (Elymus pycnanthus)* with other species of note including sea plantain *Plantago maritima*, red fescue *Festuca rubra* and Orache *atriplex sp*. A network of saltmarsh creeks runs through these zones, allowing water to drain off following high tide as well as allowing freshwater from the land to discharge into the estuary.

2.10 The lower saltmarsh zone is extensive, stretching up to 800 m from the edge of the mid saltmarsh zone. It is thought that this zone is gradually accreting. The lower saltmarsh is dominated by 'pioneer' species including annual glasswort *Salicornia europea agg*. and common cord grass *Spartina anglica*.

***Impacts***

2.11 Creation of the compensation site will require the removal of 2ha of saltmarsh for the channel in the immediate term.

2.12 Compensation for saltmarsh losses will be provided in the managed re-alignment (MR) component of the compensation site.

***Baseline for Cherry Cobb Sands Intertidal***

2.13 Bird surveys (EX35.14) that were undertaken between August 2010 and April 2011, in an area which covered both the intertidal habitats at CCS and the farmland which will form the compensation site, , showed that the foreshore was used by important numbers of one or more of the qualifying interest species of the SPA/Ramsar site throughout the period August to April. Species such as shelduck, grey plover, curlew, redshank, knot and dunlin were present in numbers usually well in excess of 1% of the Humber Estuary SPA/Ramsar population at both high and low tides in almost all the months surveyed. Curlew was also present on the compensation site fields in important numbers over the autumn passage period (September – October). Other species such as teal, lapwing and golden plover were present in numbers exceeding 1% in October and December to March, with black tailed godwit present in December and January, and bar-tailed godwit in most months between November and April. Passage interest included ringed plover and greenshank both of which were present on the foreshore in important numbers in August, ruff in September, and little egret on the foreshore in October. WeBS counts (see Section 35.7.9 of the ES) show that important numbers of some species can occur even over the summer months (eg ringed plover in May and dunlin in July).

2.14 EX34.2 provides some information on the temporal and spatial distribution of benthic communities within the Humber estuary, including abundance data for the Cherry Cobb sands area. This is summarised in the Table 4 below;

**Table 4: Prey Abundance at Cherry Cobb Sands**

| **Mean per $m^2$** | **2000** | **2001** | **2002** |
|---|---|---|---|
| *Abra tenuis* | 1367 | 937 | 0 |
| *Corophium volutator* | 51 | 51 | 0 |
| *Crangon crangon* | 0 | 25 | 0 |
| *Cyathura carinata* | 51 | 0 | 0 |
| *Enchytraeidae* | 10937 | 83443 | 8759 |
| *Eteone longa* | 228 | 76 | 152 |
| *Hediste diversicolor* | 582 | 1367 | 1190 |
| *Hydrobia ulvae* | 152 | 0 | 329 |
| *Macoma balthica* | 3165 | 4557 | 6203 |
| *Manayunkia aestuarina* | 3823 | 25 | 0 |
| *Nematoda* | 0 | 39595 | 0 |
| *Nephtys* | 0 | 25 | 0 |
| *Nephtys hombergii* | 0 | 0 | 51 |
| *Paranais litoralis* | 101 | 0 | 0 |

| | | | |
|---|---|---|---|
| *Pygospio elegans* | 0 | 51 | 1975 |
| *Scrobicularia plana* | 0 | 0 | 456 |
| *Streblospio shrubsolii* | 0 | 51 | 0 |
| *Tubificoides benedii* | 14532 | 6582 | 1215 |
| **Total** | **34987** | **136785** | **20329** |

2.15 Key prey species for black-tailed godwit are highlighted in yellow and occur in higher abundance than south shore sites during the same period.

### *Impacts*

2.16 Works to create the compensation site are not predicted to have significant effects on the SPA bird species. This is largely due to the visual and acoustic screening of the works which is expected from the existing sea defence wall, the diversion inland of the coastal footpath which will remove a source of disturbance to birds on intertidal habitats (which may be having effects at present) without increasing the effects on birds on inland fields, and the timing of the works to cover predominantly the summer months. This is a period when the intertidal habitats are typically less well used by waterbirds, the birds have more choice of location in which to forage and roost, and there is more daylight and good benthic invertebrate food availability across the intertidal mudflats. In addition the creation of the new embankment is several hundred metres away from the edge of the intertidal habitat which is very extensive.

2.17 Mitigation to reduce impacts includes timing of the work so that potentially disturbing activities closest to intertidal bird populations occur April to October.

# 3 TERRESTRIAL HABITATS

### *BASELINE FOR THE COMPENSATION SITE*

3.1 The compensation site comprises the Regulated Tidal Exchange (RTE) and Managed Re-alignment (MR), together with the Cherry Cobb Sands Wet Grassland (CCSWG) and is described in EX28.3 Parts 3 & 4. The existing baseline is provided in Chapter 35 of the ES but updated in EX28.3 Part 6 EIA Review, to reflect the movement of the wet grassland and roost site from Old Little Humber Farm to CCSWG. The current use of the area is arable farmland. The landscape was assessed as having low ecological value. No water voles were present but colonisation by transient animals cannot be ruled out.

3.2 A badger survey is reported in Annex 35.8 of the ES and updated by EX35.13. It found two main social groups associated with two mains setts and a number of outlying and subsidiary setts, with some evidence of a decline in use between surveys.

### *Impacts*

3.3 These are described in EX28.3 Part 6 EIA Review and it is concluded that ecological impacts will be largely the same as those predicted in the original ES and be negligible or of minor adverse significance only.

3.4 Badger surveys indicated the proposals would result in the loss of 4 outlying setts associated with the group of badgers based at Sett 28, and 5 outlying setts associated with the group of badgers based at Sett 11. None of the affected setts received high levels of use from badgers in either 2011 or 2012, and none were located close to a key seasonal food source or other resource likely to be crucial to the badgers' survival. Given the availability of alternative setts elsewhere within their range, this loss would be unlikely to have a detrimental impact on badgers. A licence to close outlier setts will be required but overall the increase in foraging habitat will be beneficial.

3.5 Minor construction impacts could occur for reptiles without mitigation.

3.6 The greatest change in impacts related to the Compensation Scheme is apparent during the operation of the scheme, where there will be minor changes to views from a nearby property (Fair View) because of the widened embankment around the RTE scheme, and a minor change to the landscape as a result of the wind pumps at the wet grassland site.

### *Baseline for North Killingholme Haven Pits (NKHP)*

3.7 Operational impacts are dealt with in the Terrestrial EMMP (TEMMP).

3.8 Baseline information on NKHP is in Chapter 11 of the ES and in the sHRA. The site holds significant numbers of the Humber bird population, and those species which are present in numbers of 1% or more of the Humber Estuary SPA populations are summarised in Table 5.

**Table 5: NKHP TTTC & WeBs Peaks**

| Species | Humber population | Peak / Mean of Peak count | Proportion Of Humber Population (%) | Month | Data Source |
|---|---|---|---|---|---|
| Assemblage | 140197 | 4112 | 2.9 | Aug | TTTC |
| | | 3787 | 2.7 | Sep | WeBS |
| Avocet | 493 | 16 | 3 | Mar | TTTC |
| | | 27 | 5.5 | Mar | WeBS |
| Black-tailed godwit* | 3887 | 3 800 | 97.8 | Aug | TTTC |
| | | 3 338 | 85.9 | Sep | WeBS |
| Common sandpiper | (46) | 1 | 2.2 | Jul,Aug | TTTC |
| | | - | - | - | WeBS |
| Dunlin | 21518 | 270 | 1.3 | Oct | TTTC |
| | | 380 | 1.8 | Nov | WeBS |
| Grey heron | 74 | 3 | 4.1 | Oct | TTTC |
| | | 3 | 4.1 | Sep,Oct | WeBS |
| Lapwing* | 18756 | 5 | <0.1 | Oct | TTTC |
| | | 276 | 1.5 | Nov | WeBS |
| Little egret | 38 | 1 | 2.6 | Jun,Jul | TTTC |
| | | - | - | - | WeBS |
| Little ringed plover | 6 | 2 | 34 | Apr | TTTC |
| | | - | - | - | WeBS |
| Mallard | 2096 | 34 | 1.6 | Oct | TTTC |
| | | 71 | 3.4 | Sep | WeBS |
| Moorhen | 146 | 4 | 2.7 | Jul | TTTC |
| | | 2 | 1.6 | Sep | WeBS |
| Redshank | 5445 | 249 | 4.6 | Aug | TTTC |
| | | 215 | 3.9 | Aug | WeBS |
| Shoveler | 145 | 61 | 42.1 | Oct | TTTC |
| | | 29 | 20 | Dec | WeBS |
| Smew | 2 | 1 | 50 | Jan | TTTC |
| | | - | - | - | WeBS |
| Snipe | 118 | 6 | 5.1 | Oct | TTTC |
| | | 4 | 3.4 | Oct | WeBS |
| Teal | 2865 | 46 | 1.6 | Oct | TTTC |
| | | 30 | 1.0 | Nov | WeBS |
| Water rail | 7 | 2 | 28 | Jun | TTTC |
| | | - | - | - | WeBS |

***Impacts***

3.9 No direct impacts are predicted but the loss of intertidal feeding arising from the development may reduce the attractiveness of NKHP as a roost site and lead to displacement resulting in an effect on site integrity.

# 4 OBJECTIVES

## *CONSTRUCTION*

### *Rationale & Objectives*

4.1 Construction impacts at NKM are dealt with in the MEMMP, and those at NKHP in the Terrestrial EMMP (TEMMP).

4.2 Impacts have been identified during the construction of the compensation site (RTE/MR and CCSWG) and objectives to ensure appropriate mitigation and legal compliance during construction are required.

4.3 Impacts requiring mitigation have been identified for intertidal birds, breeding birds, reptiles, badgers (licensing of sett closures will be required), and water voles (probably not present but pre-survey required given records of transient populations in locality).

4.4 The agricultural fields that form the proposed compensation site are only used by curlew in any significant numbers on a regular basis. It has been agreed with Natural England that the birds currently supported on the agricultural fields that comprise the compensation site can be supported in adjacent fields. Much of the work on the inland embankment will have been completed prior to the main period of use during the autumn passage, and construction work will not be ongoing across the whole 3 km of the new embankment all at once. Hence there will be adjacent fields that will not be subject to disturbance from the works that will be available for the birds to use throughout the period they are likely to be present.

4.5 The intertidal area was surveyed as described in EX35.14. However this data represents peak counts only over a single non-breeding season. Targets based on WeBs data are difficult to use as the WeBs count area extends from Paull to Cherry Cobb Sands. One option may be to take the peak counts recorded in EX35.14 and apply a natural variability test derived from the standard deviation of the WeBs count data for Autumn (22% of the 5 year mean peak) and winter (42% of the 5 year mean peak). Further discussions with NE will take place to establish a suitable reference point against which disturbance can be measured.

4.6 The construction of RTE sluices may require piling. If programming of works does not allow piling to be undertaken during April to July then auger piling will be used in conjunction with a method statement agreed with Natural England.

4.7 Good construction practice and adherence to Pollution Prevention Guidance will be embedded into any works undertaken on site.

**Objective C1: Construction will comply with legal requirements and best practice with regard to reptiles and water voles.**

| | | |
|---|---|---|
| **Target** | • | No killing or injuring of protected species |
| **Management** | • | Strim habitat fortnightly to ensure habitat remains unsuitable for colonisation |
| | • | Ecological briefing for workforce (including recognition, contact procedures, action to be taken) |
| **Monitoring** | • | Undertake pre-construction survey of suitable habitat for reptiles and water voles |
| **Who** | • | Survey by suitably experienced surveyor |
| | • | Briefing by Environmental manager/ Ecological Clerk of Works |
| **When** | • | Pre-construction |
| **Limits of Acceptable Change** | • | N/A |
| **Remedial Action** | • | Cease work if animals found in work area and consult with Environmental Manager |
| **Notes** | Likelihood of either reptiles or water voles being present is low given habitat. If habitat has been colonised since the original CCS ES suitable alternative habitat would need to be created. | |

**Objective C2: Prevent harm to breeding birds.**

| | | |
|---|---|---|
| **Target** | • | No damage to nests or eggs, or killing or injuring of chicks of wild birds. |
| **Management** | • | Remove suitable nesting habitat to north of existing sea wall (i.e. protected from disturbance to birds on intertidal area) during September-March. |
| | • | Strim areas fortnightly to reduce suitability. |
| | • | Ecological briefing for workforce (including recognition, contact procedures, action to be taken) |
| | • | Where potential nesting habitat remains (e.g. close to intertidal) and works take place during April-August site to be checked for nesting birds. |
| **Monitoring** | • | Undertake pre-construction survey of suitable habitat for nesting birds |
| **Who** | • | Survey by suitably experienced surveyor |
| | • | Briefing by Environmental manager/ Ecological Clerk of Works |
| **When** | • | Pre-construction |
| **Limits of Acceptable Change** | • | N/A |
| **Remedial Action** | • | Cease work if nesting birds found in work area and consult with Environmental Manager. |
| | • | Any active nests not to be disturbed until young have fledged and capable of sustained flight. |
| **Notes** | | |

## Objective C3: Ensure construction is legally compliant in relation to badgers

| | | |
|---|---|---|
| **Target** | • | Safe and licensed exclusion of badgers from setts. |
| | • | Provision of suitable foraging habitat |
| | • | Provision of 10 earth mounds for sett building at base of RTE northern bund and/or around CCSWG site |
| **Management** | • | Undertake repeat survey to inform licence application. |
| | • | Licence application (licences are usually only issued for period 1st July-30th November). |
| | • | Closure of setts under licence. |
| | • | Adherence to mitigation in licence and EX35.13 |
| **Monitoring** | • | Pre-construction to validate 2012 survey |
| | • | Post construction walkover survey to check colonisation of earth mounds and sett and latrine usage. |
| **Who** | • | Monitoring by suitably experienced consultant |
| | • | Environmental Manager responsible for licensing issues and adherence to conditions. |
| **When** | • | Repeat survey for licence application February-March 2013 |
| | • | Licence application June-July 2013. |
| | • | Creation and planting of mounds, planting of fruit and berry bearing shrubs at wet grassland from winter 2012/13. At RTE this process to take place in winter 2014/15. |
| | • | Sett closure July-November 2013. |
| | • | Post construction surveys annually for five years to cease after 3 years if population stable. |
| **Limits of Acceptable Change** | • | 10% reduction in total number of subsidiary or outlying setts used within three years. |
| | • | 5% reduction in annex setts used within two years |
| | • | Cessation of use of any main sett within one year |
| **Remedial Action** | • | Bait survey to inform analysis |
| | • | If declines associated with foraging resource introduce supplementary feeding during periods of drought or other hardship |
| | • | Increase foraging resource (further planting) |
| **Notes** | Vegetation on mounds, particularly that at CCSWG should be unsuitable for raptors and corvids (i.e. should comprise weak stemmed and low growing cover such as raspberry and bramble). No planting should be undertaken on top of any bunds to avoid providing hunting perches for raptors and corvids.<br>Habitat enhancement for badgers would be on Northern slopes (but below top of bund) of RTE site and North East part of wet grassland. | |

## Objective C4: Minimise construction disturbance to SPA populations

| | | |
|---|---|---|
| **Target** | • | No disturbance to feeding or roosting birds on the intertidal area |
| **Management** | • | Construction work will begin with sea wall area and bunds nearest to proposed CCSWG roost site to provide visual and acoustic screen. This will be carried out during April-October. |
| | • | Piling will be undertaken between April-July (or if this cannot be achieved augur piling will be used). |
| | • | During November-March all work will take place within screen provided by sea wall. |
| **Monitoring** | • | Numbers of birds within the compensation site and intertidal area will be counted on a monthly basis. The reference target will be agreed with NE. |
| **Who** | • | Suitably experienced surveyor for monitoring. |
| | • | Ecological manager/ Ecological Clerk of Works to manage construction. |
| **When** | • | Monitoring during construction |
| **Limits of Acceptable Change** | • | To be agreed with NE (see discussion under rationale) |
| **Remedial Action** | • | Review construction methods |
| **Notes** | See Rationale regarding reference data issues | |

# 5 REGULATED TIDAL EXCHANGE & MANAGED REALIGNMENT

### *RATIONALE & OBJECTIVES*

5.1 It has been agreed with the Regulators that compensation must be put in place to recreate 94.6 ha of habitat (73.4 ha of intertidal mudflat, and 21.2 ha of sub-tidal (estuary)) for the SAC, and 101.5 ha for the SPA.

5.2 The RTE & MR will be constructed to provide initially 88 ha of mudflat and a long term mudflat resource of at least 44 ha. The MR component of the scheme will comprise 30.6 ha of which up to 27 ha is anticipated to revert to saltmarsh. SAC targets for the saltmarsh component are that it recreates typical saltmarsh and mudflat characteristics in terms of topography, zonation and species to that of the middle Humber.

5.3 Targets for the mudflat relate to its sediment quality and benthic communities. In turn these underpin its ability to provide functional feeding habitat for displaced bird species (see objective B1)

5.4 Long term sustainable mudflat will require managing to maintain principal parameters, and the construction of the four cell RTE structure reflects the need to maintain sufficient mudflat habitat even when being managed.

5.5 Benthic targets will be derived from pre-construction surveys and set in agreement with Natural England (NE) as detailed in Annex 3: Target Setting Protocol.

5.6 The managed realignment offers potential for biodiversity gains particularly for estuarine fish. A fish survey that is as far as possible WFD compliant (EA Operational Instruction 328_07) will be implemented and agreed with the EA. Targets are based on delivering monitoring and therefore numerical targets and limits of acceptable change are not required. There are some practical difficulties in complying with WFD guidance in that whilst Fyke nets could be used within the MR, seine nets could not. It may be possible to substitute a small hand hauled epibenthic sledge as a second form of sampling particularly suitable for juvenile fish. This would be dependant on it being safe to do so, and this method is not WFD compliant although it is used on other MR sites. Similarly Fyke nets may be used to sample the RTE components of the site by setting them outside the RTE sluice(s) on the outgoing tide subject to health and safety considerations.

5.7 Management will be targeted to produce suitable sediment types and maintain wetness both to assist feeding birds and reduce saltmarsh encroachment within the RTE. Natural processes will be allowed to develop within the MR part of the site.

5.8 The warping up phase will be used to inform future management and allow the operations manual to be augmented based on experience of the live system.

5.9 A basic manual of operations will be provided prior to the system going live. As part of the ongoing learning process all significant management interventions (e.g. dredging, bed levelling) will be logged (date & time) and photographed from fixed reference points so that they can be referenced against ecological survey data.

## Objective COMP1: Construction of site and sluices

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| **Target** | • Delivery of site to include four RTE fields each of 18ha size, with ponds and channel areas of about 1.5ha per field, operational sluices to enable impoundment of a field at near peak spring tide level and operational sluices to enable drainage of impounded water from one field to another.<br>• Leakage into underlying soils to be less than 200mm over a 10 day period from an initial impounded depth of water of 1,000mm. |
| **Management** | • Construction to be undertaken by appointed contractor, managed by APHL |
| **Monitoring** | • Topographic survey to define extent of site<br>• Engineering analysis to confirm sluice performance and leakage into underlying soils and through bund |
| **Who** | • Survey by suitably qualified surveyor<br>• Analysis by suitably qualified engineer |
| **When** | • Prior to and during the construction period |
| **Limits of Acceptable Change** | • The RTE part of the site must provide a minimum of 66ha of mudflat area. This could be provided in three or more fields. Sluices to be sized accordingly.<br>• Initial level of the RTE fields to be between +1.9m OD and +2.0m OD. |
| **Remedial Action** | • Over consolidation of field surface to reduce leakage. |

## Objective COMP2: Warping up of RTE fields

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| **Target** | • Warping up of RTE fields by an average of 100mm depth of marine muds |
| **Management** | • By site managers:<br>o After construction inlet sluices for the RTE fields are in general to be operated fully open to facilitate rapid accretion of muds across the RTE fields.<br>o After the first winter period following breaching of the realignment site the sluices are to be operated in normal operational mode to avoid extended drying of the mudflat resource over the neap tide period. |
| **Monitoring** | • Levels over the RTE fields are to be monitored using a combination of water level monitoring, marked stakes and LiDAR or other monitoring techniques. Method statement to be prepared for the surveying. |
| **Who** | • Survey by suitably qualified surveyor |
| **When** | • Basic survey of field levels at monthly intervals during warping-up, LiDAR surveys on opportune basis of 1 to 3 year interval |
| **Limits of Acceptable Change** | • If average mud levels in the field achieve 100mm before the end of the first winter period after breaching sluices are to begin to be operated in normal operational mode. |
| **Remedial Action** | • If warping up is seen to be occurring very slowly the three additional outlet sluices could be opened up to increase exchange. |
| **Notes** | • On initial breaching the fields will be operated with the inlet sluices fully open (as per EIA assessment) and the rates of warping up in the fields and scour potential in the breach and Cherry Cobb Sands Creek assessed. If the rate of warping up in one or more of the fields would appear to benefit from increased exchange a trial period of operating the field with the outlet sluices fully open will be instigated. The erosion potential will continue to be examined. A decision will then be made regarding whether to continue exchange with the outlet sluices open.<br>• Changes to the sluice openings from those agreed, would need to be notified to all parties prior to this trial being undertaken. Any longer-term changes to the exchange within the Regulated Tidal Exchange scheme to that currently assessed would need to be discussed with the Environment Agency, due to the potential issues with additional erosion that would occur during this period of time |

## Objective COMP3: Operating Manual for water level management

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| **Target** | • Operating Manual for water level management by site managers |
| **Management** | • By site manager and suitably qualified engineer:<br>o During the initial warping up phase sluice operation, impoundment and flushing are to be trialled<br>o Operating Manual to be developed and used as the basis for operational management of site during remainder of warping up period.<br>o Operational Manual to be reviewed after first year of operations. |
| **Monitoring** | • Water level monitoring<br>• Recording of sluice settings |
| **Who** | • By site managers assisted by suitably qualified surveyor |
| **When** | • Basic Operating Manual to be prepared prior to site being breached.<br>• Revised operating manual to be prepared within 6 months of site being breached taking into account experience of managing live system<br>• Operating Manual to be reviewed within 18-24 months of site being breached.<br>• Operating Manual to be reviewed every 24 months thereafter. |
| **Limits of Acceptable Change** | • Operating Manual provides the basis for adaptive management of water levels within the RTE fields. In combination with the sediment management plan for the RTE fields this provides the means of maintaining the sustainable compensatory mudflat resource. |
| **Remedial Action** | • Review of Operating Manual and modification of operating procedures |

## Objective COMP4: Sediment Management for RTE fields

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| **Target** | • Development and implementation of sediment management plan for RTE fields |
| **Management** | • By site manager and suitably qualified engineer:<br>  ○ To be developed following observation of rates and patterns of mud accretion in the RTE fields.<br>  ○ To be optimised over time to optimise mudflat functionality in the RTE fields based on the results of other monitoring.<br>• Dredging and bed levelling to be undertaken by suitably experienced organisation |
| **Monitoring** | • Bed level monitoring<br>• Photographic records<br>• Particle size and density of accumulating material<br>• Accumulation in channels and pond areas |
| **Who** | • By site managers assisted by suitably qualified surveyor |
| **When** | • Sediment management plan to be developed within 24-36 months of site being breached.<br>• Implementation of plan, possibly involving initial trials, to be undertaken 5-10 years after breaching of site.<br>• Sediment management plan to be reviewed every 24 months thereafter. |
| **Limits of Acceptable Change** | • Sediment management provides the basis for adaptive management of mudflat levels within the RTE fields. In combination with the water level management this provides the means of maintaining the sustainable compensatory mudflat resource. |
| **Remedial Action** | • Trialling and implementation of sediment management measures earlier than expected.<br>• Methods and techniques expected to evolve over time. Could involve floating and/or land based techniques. |

## Objective COMP5: Monitoring of bathymetry outside the RTE fields

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| **Target** | • Topographic monitoring of realignment site, Cherry Cobb Sands Creek, entrance to Stone Creek and wider Foul Holme Sands environment |
| **Management** | • By site manager |
| **Monitoring** | • Survey by LiDAR of local and wider area at 1-3 year intervals<br>• Regular (3 monthly) photographic surveys of realignment site, Cherry Cobb Sands Creek and Stone Creek form fixed points.<br>• Topographic surveys at. four sections across Cherry Cobb Sands and one section in the entrance of Stone Creek |
| **Who** | • Site manager and suitably qualified surveyor |
| **When** | • At regular intervals as outlined above.<br>• Photographic record and topographic surveys to commence at time of consent to establish baseline conditions |
| **Limits of Acceptable Change** | • Changes in Cherry Cobb Sands channel cross section to be within limits assessed in EX28.3 on compensation site or recorded natural variability whichever is the greater.<br>• Siltation in the entrance to Stone Creek that can be attributed to development or operation of the compensation site to be assessed for removal by AHPL. |
| **Remedial Action** | • Modifications to monitoring locations as required and in agreement with Steering Group<br>• Bed levelling or dredging in the entrance to Stone Creek. |

**Objective COMP6: The RTE & MR site will contain similar infaunal communities to those found at NKM as defined by characteristic species in abundance and biomass.**

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| **Target** | • Similar faunal biotope(s) to that found at North Killingholme Marshes based on preconstruction surveys undertaken in Spring and Autumn 2013 and any additional surveys or information provided by EA<br>• This biotope to be provided within 88ha of mudflat of which a minimum of 44ha will always be available.<br>• Quantitative targets are to be defined and agreed following completion of full baseline (pre-construction) surveys. The Survey design for this is set out in Annex 2 and the target setting protocol in Annex 3. |
| **Management** | • Breach of sea defence to be made if possible within the peak benthic larval recruitment phase (March – May)<br>• Bed levelling to be conducted post spawning/recruitment phase of key species; |
| **Monitoring** | • Sampling of the RTE & MR areas is detailed in Annex 2 and replicates the methods used at NKM & CCS<br>• Samples to be taken with hand held corer (0.01 $m^2$), sediment sampled to a depth of c.15 cm. 3 replicate benthic samples should be collected at each station (with one additional core sample collected per station to characterise the sediment).<br>• A topographic survey will be used to inform the stratified systematic design.<br>• Analysis will be as stipulated in Annex 2.<br>• Particle size analysis, organic content and water salinity will also be measured. |
| **Who** | • Environmental Manager and suitably qualified surveyor |
| **When** | • Monitoring to be undertaken annually in August-September (with the optimal time being the last week of August to first week of September) for the first ten years.<br>• Any subsequent change in monitoring to be reviewed and agreed by the Steering Group. |
| **Limits of Acceptable Change** | • Community must be characterised by the biotope and AFDW biomass/ individuals per square metre within the tolerance limits identified from the baseline survey to be undertaken in Spring & Summer 2013 and other relevant data. See target setting protocol in Annex 3<br>• Intertidal mudflats across 60 ha |
| **Remedial Action** | • Alter sluice management to ensure adequate larval transport and suspended sediment transportation into the cells. |

**Objective COMP7: The RTE site post warping up will contain similar sediment distribution patterns to those found at NKM as defined by Particle Size Distribution (PSD)**

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| **Target** | • Sediment distribution to provide **Sandy mud** and **mud** as found at Transect 3 of the characterisation survey.<br>• (79%-95% mud, 4.5%-20% sand) to provide the envelope of Particle Size Distribution |
| **Management** | • Management of warping up and sluice gates to maintain desired sediment and fluidity of sediment |
| **Monitoring** | • Samples taken to support the sediment monitoring programme will be collected by means of hand coring,<br>• When the full distribution has been constructed and the warping up phase is complete the sample should be assigned a description based on the Folk classification system (Folk, 1974) and/or the Wentworth classification system (Wentworth, 1922).<br>• Guidelines to be used in the design and subsequent reporting of benthic monitoring are the Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites (Ware and Kenny, 2011) and the Marine Monitoring Handbook (Davies et al, 2001) unless statutory agency advice indicates an alternative approach. |
| **Who** | • Environmental Manager and suitably qualified surveyor |
| **When** | • Annually in autumn for the first five years<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains materially unchanged.<br>• Any changes in monitoring to be reviewed and agreed by the Steering Group |
| **Limits of Acceptable Change** | • A shift of 2 classifications within the folk system i.e. from mud to sand; OR a shift outside of the desired sediment envelope as defined by the NKM PSD data. |
| **Remedial Action** | • Sluice gate management and dredging of material |

**Objective COMP8 (SAC): Provide 21.2 ha of saltmarsh habitat of similar zonation and species composition to that of the middle Humber.**

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| **Target** | • Deliver a minimum of 21.2 ha of saltmarsh of a composition typical of the middle Humber estuary to replace estuary and sub-tidal habitat loss.<br>• Within 10 years pioneer and lower saltmarsh community to have established over 10 ha with a minimum of 70% of plant species found within similar communities on Humber<br>• Within 15 years zonation to include middle saltmarsh community. Minimum of 70% of the plant species present over similar zonation patterns in Humber.<br>• Within 20 years Saltmarsh extent to be equal to or greater than 21.2 ha |
| **Management** | • Natural processes to occur in MR section of compensation site to allow accretion and establishment of saltmarsh. |
| **Monitoring** | Saltmarsh extent, community, zonation and diversity will be ascertained following EA WFD guidance e.g OI 200_07 or any subsequent relevant revisions.<br>In advance of each annual survey the most recent available aerial images will be requested from the EA (although it is noted that not every year will be updated by the EA), this information providing additional data and informing the survey process. Where the data are current (e.g. the year of image is current to the year of survey, then depending on coverage, it may be unnecessary to undertake an additional survey flight.<br>When such images are unavailable, then a survey flight will be undertaken, with aerial colour images captured. These images will be:<br>• of resolution of at least 25cm<br>• 3 band red green blue (RGB) imagery<br>• taken in daylight at low water around a spring tide<br>• taken under stable lighting conditions (little or no cloud shadow)<br>• taken between June and September each year, with timing to be standardised to a single month per year where possible<br>• taken on an annual basis for a minimum of 10 years, the requirements for subsequent surveys to be determined by the Steering Group<br>In addition to the annual aerial image survey, field survey of the saltmarsh habitat will be undertaken on an annual basis, again following guidelines in the EA's OI 200_07<br>This will include a series of transects of sufficient frequency to adequately describe the communities, their zonation and extent (see OI 200_07 for details). Each transect will cover both the seaward and landward extent of the saltmarsh. Transition points will be mapped and two quadrat samples taken to characterise the major community changes, recording species, cover, sward height etc following OI 200_07 procedures.<br><br>The saltmarsh will then be therefore assessed for the following metrics in accordance with the WFD Saltmarsh Index Tool:<br>• saltmarsh extent as proportion of "historic saltmarsh"<br>• saltmarsh extent as proportion of the intertidal<br>• change in saltmarsh extent over two or more time periods<br>• proportion of saltmarsh zones present (out of five)<br>• proportion of saltmarsh area covered by the dominant saltmarsh zone<br>• proportion of observed taxa to historical reference value **or** proportion of observed taxa to 15 taxa |

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| **Who** | • Environmental Manager and suitably qualified surveyor in consultation with the Environment Agency |
| **When** | • Aerial survey data obtained annually<br>• Annual fixed point photographic surveys of MR site (at same time as vegetation monitoring) for first 10 years<br>• Vegetation monitoring June to September (to aid species identification) for first 10 years.<br>• After 10 years date frequency to reviewed by steering group |
| **Limits of Acceptable Change** | • Less than 10ha of saltmarsh and mudflat formed within first 10 years<br>• Absence of lower saltmarsh within 10 years or middle saltmarsh within 15 years<br>• Species composition of zones is less than 70% that of Humber reference sites (e.g. Cherry Cobb sands saltmarsh) |
| **Remedial Action** | • Beneficial use of sediment from within RTE to aid saltmarsh formation in MR<br>• Planting up of saltmarsh/removal of undesirable species<br>• Creation of artificial creek system within MR to improve dewatering |
| **Notes** | • Natural England have indicated that other estuarine habitat (e.g. mudflat) would be acceptable if the full extent of saltmarsh was not achieved. If the mix of estuarine habitats equalled 21.2 ha no remedial action would be required. |

**Objective COMP9 (SAC): Ensure Compensation site delivers 73.4 ha of SAC intertidal habitat of acceptable depth to ensure no decrease in SAC extent**

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| **Target** | • Deliver a minimum of 73.4 ha of intertidal mudflat in the immediate term and a minimum of 44 ha of sustainable mudflat in the long term<br>• Deliver a minimum average depth of 100 mm marine mud including a minimum of 50 mm within the first year<br>• Ensure that shore profile is developing in line with the established baseline elsewhere in the SAC, ie a shallow profile that allows regular tidal inundation providing 3 -5 hours of tidal movement over the mudflat |
| **Management** | • Inlet sluices for the RTE fields are in general to be operated fully open to facilitate rapid accretion of muds.<br>• After the first winter period following breaching of the realignment site the sluices are to be operated in normal operational mode to avoid extended drying of the mudflat resource over the neap tide period.<br>• Sediment Management Plan to optimise mudflat functionality to be developed within 24-36 months of site being breached |
| **Monitoring** | • Accretion monitoring in RTE fields to identify change in mudflat extent and elevation<br>• LiDAR, bed level monitoring, marked stakes and photographic records to determine extent, elevation and change over time |
| **Who** | • Site managers assisted by suitably qualified surveyor |
| **When** | • bi-annually during first 2-3 years and thereafter at 1-3 year intervals |
| **Limits of Acceptable Change** | • If average mud levels in the field achieve 100 mm before the end of the first winter period after breaching sluices are to begin to be operated in normal operational mode. |
| **Remedial Action** | • Variation in number of sluices operated to control exchange<br>• Implementation of sediment management measures<br>• Sediment management provides the basis for adaptive management of the mudflat levels |
| **Notes** | • It is anticipated that bed levels will normally exceed 100mm due to accretion. Where bed levelling or dredging is required this will retain a minimum average of 100mm over the managed area. |

### Objective COMP10 (SAC): Ensure non-faunal attributes of compensation mudflat habitat are consistent with those of the area of SAC mudflat habitat to be lost

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| **Target** | • PSA of accreted substrate should not differ significantly from that of the SAC area to be lost, ie sediment distribution to provide **sandy mud** and **mud,** with grain size varying between 0.01-0.3mm (79%-95% mud, 4.5%-20% sand) to provide the envelope of Particle Size Distribution<br>• High average organic carbon content of accreted sediment- this should not deviate significantly from the established SAC baseline in the area to be lost<br>• Ensure that excessive nutrient enrichment is not taking place, as indicated by development of macroalgal mat cover in excess of the established baseline found in the SAC area to be lost |
| **Management** | • Management of sluice gates to maintain desired sediment characteristics<br>• Expected that the sediments which settle will have similar organic content to those which have settled elsewhere in the SAC |
| **Monitoring** | • Hand-coring within RTE fields followed by PSA and analysis of organic content<br>• Photographic record and recording of surface conditions- character and composition of surface sediments, evidence of drying, macroalgal cover |
| **Who** | • Environmental Manager and suitably qualified surveyor |
| **When** | • Annually in autumn for the first five years<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains materially unchanged.<br>• Any changes in monitoring to be reviewed and agreed by the Steering Group |
| **Limits of Acceptable Change** | • A shift of 2 classifications within the Folk classification system i.e. from mud to sand<br>• A shift outside of the desired sediment envelope for all parameters listed |
| **Remedial Action** | • Sluice gate management and dredging of material |

### Objective COMP 11: Monitor Fish within Compensation Site

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| **Target** | • To monitor fish using WFD compliant methods as far as possible with reference to Operational Instruction 328_07 *Data requirements for WFD transitional fish surveillance monitoring* |
| **Management** | • NA |
| **Monitoring** | • Use of Fyke nets in main MR channel in May-June (Spring WFD) and September-October (Autumn WFD)<br>• Use of epibenthic sledge (0.9m opening width, dragged for 50m) subject to safe method of work being possible to sample juvenile fish<br>• Fyke nets to be deployed at RTE sluice twices per annum in May-June (Spring WFD) and September-October (Autumn WFD) on outgoing tide.<br>• Results to include following data in line with 328_07<br>▪ fish species present;<br>▪ abundance of each species;<br>▪ length measurements (freshwater and migratory species – fork length, marine species – total length). For large catches only the first 50 lengths for each species during each netting occasion are required, the rest can be counted; |

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| | ▪ for exceptionally large catches sub-sampling techniques will be used ;<br>▪ supporting water quality information: dissolved oxygen (% sat), salinity, temperature<br>▪ GPS position at approximate mid-site location (12 figure NGR);<br>• date, time, trawl duration and tide state. |
| **Who** | • Suitably qualified surveyors in liaison with Environmental Manager and EA |
| **When** | • Every two years in spring & autumn for the first ten years<br>• Any changes in monitoring to be reviewed and agreed by the Steering Group |
| **Limits of Acceptable Change** | • NA |
| **Remedial Action** | • NA |
| **Notes** | • The epibenthic sledge is not WFD compliant but experience at other MR's has shown it to be a useful tool in providing additional sampling of juvenile fish not monitored by Fyke nets. |

# 6 WET GRASSLAND AND OPEN WATER AREA

### *RATIONALE & OBJECTIVES*

6.1 There are no similar sized RTE schemes which have been created, and especially ones designed to support birds.

6.2 Creation of wet grassland is a well-established process, and hence there is greater certainty about the ability to develop it, and also about the biomass that will be available as a result for shorebirds and especially black-tailed godwits.

6.3 Wet grassland is a habitat type which is known to be used by foraging black-tailed godwits, especially as the winter progresses and intertidal food resources can become depleted. There is little grassland around the Humber Estuary at present and its provision will provide a valuable additional food resource, which will also be available to the birds at high tide.

6.4 The provision of the roost site (formed by islands in the open water area at the southern end of the wet grassland site) close to existing mudflats at CCS will mirror the close proximity of NKHP to the mudflats at NKM. The close proximity between a secure roost site and feeding resources is thought to be important in the use of the NKM foreshore by black-tailed godwits, especially during the autumn moulting period. The roost site at CCS is expected to facilitate more extensive use of CCS by black-tailed godwits.

6.5 The wet grassland and open water areas at CCS are therefore included as part of the compensation package to provide additional foraging and roosting habitat in case of any under performance of the RTE.

6.6 Objectives are therefore based around the construction, management and maintenance of both the roost site and wet grassland to deliver suitable functionality for black-tailed godwits in particular.

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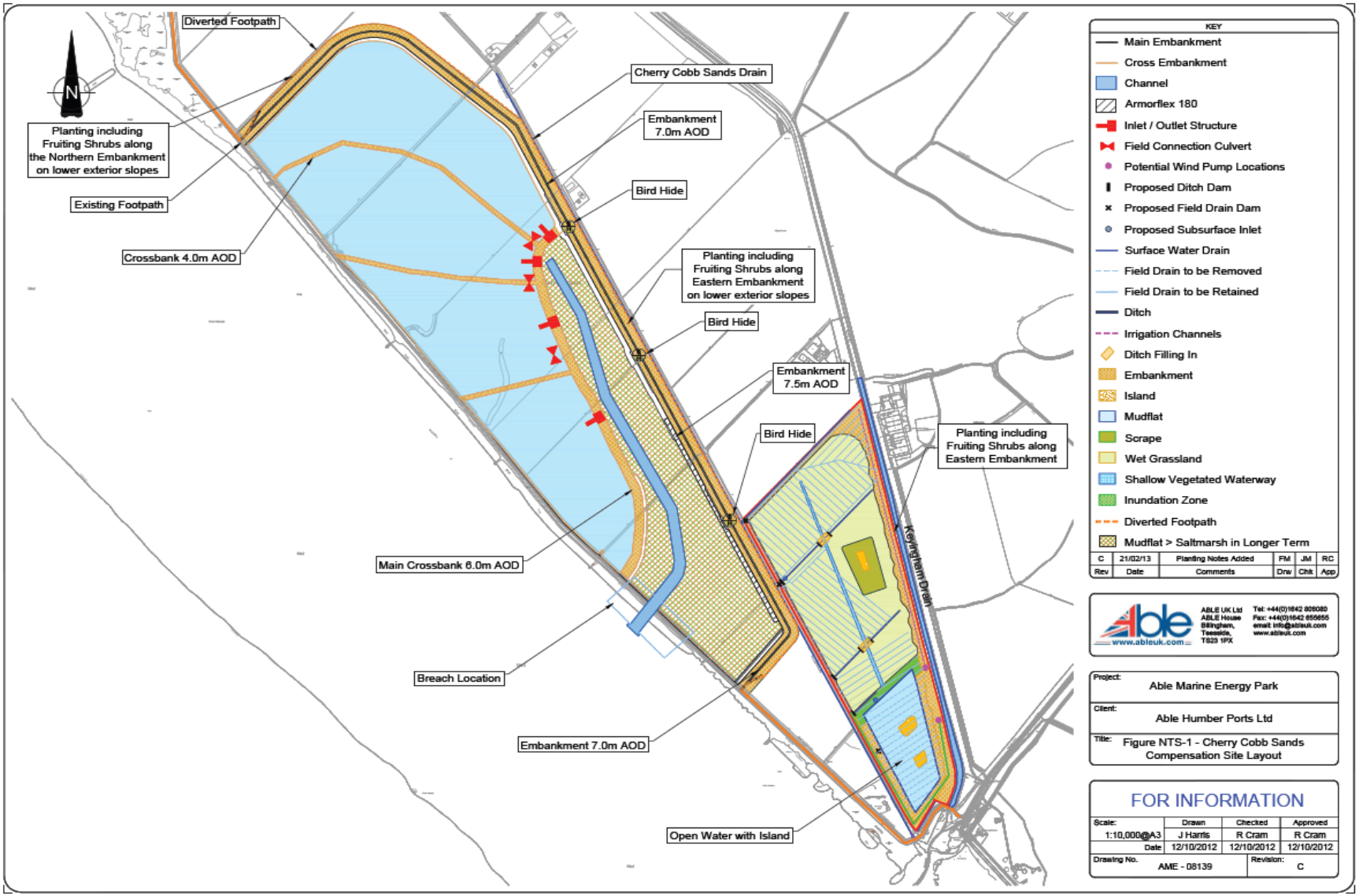
**Figure 1: Indicative Layout of Wet Grassland**



**Objective WG1: The site will contain wide, open expanses of wet grassland habitat with unobscured views of the surrounding area**

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| **Target 1** | • Wet or damp grassland vegetation community across 26ha of the CCSWGS |
| **Management** | • Sowing with an appropriate seed mix (for example EG8 Wet Grassland Mix from Emorsgate Seeds) and leaving uncut and ungrazed for 3 to 6 months, as appropriate<br>• 0.2 livestock units per hectare per year in April to June inclusive in Year 1; AND<br>• 0.3 livestock units per hectare per year in April to June inclusive in all subsequent years; OR<br>• Equivalent management by cutting the grassland<br>• No fertilisers to be used except if needed to boost earthworm biomass<br>• No herbicides to be used except if needed to control problem plant species. These to be applied with a weed wipe or via spot control. |
| **Monitoring** | • 60 permanent quadrats to be established measuring 1m x 1m within the wet grassland area<br>• Plant species and abundance to be recorded for each quadrat |
| **Who** | • Contractors under supervision of Environmental Manager |
| **When** | • Monitoring to undertaken annually in June for the first five years<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains unchanged subject to the agreement of the Steering Group. |
| **Limits of Acceptable Change** | • At least one species characteristic of wet or damp grasslands must be present in 50 permanent quadrats<br>• Wet grassland vegetation community across 20ha of the CCSWGS |
| **Remedial Action** | • Raise sluice heights to increase soil moisture content, providing incidence or extent of flooding does not exceed limits of acceptable change |
| **Notes** | |

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| **Target 2** | • No scrub (including bramble) or trees across the entirety of the CCSWGS |
| **Management** | • 0.2 livestock units per hectare per year in April to June inclusive in Year 1; AND<br>• 0.3 livestock units per hectare per year in April to June inclusive in all subsequent years; OR<br>• Equivalent management by cutting the grassland |
| **Monitoring** | • Visual assessment of scrub |
| **Who** | • Environmental Manager |
| **When** | • Monitoring to undertaken annually in June for the first five years<br>• Monitoring to occur in June once every three years thereafter if limits of acceptable change have not been exceeded in the first five years subject to the agreement of the Steering Group |
| **Limits of Acceptable Change** | • No more than 5% scrub or trees across the entirety of the CCSWGS |
| **Remedial Action** | • Cutting down vegetation and treatment of stumps with herbicide |

**Objective WG2: The site should contain open water with at least one island suitable for roosting black-tailed godwits at high tide**

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| **Target 1** | • An open water area of 4 to 5ha in size and an average depth of 0.35m to 0.7m in depth, according to season |
| **Management** | • Topping up with water from external drains to maintain water level and extent to target levels, as and when required<br>• Adjustment of sluice height to retain water at the appropriate depth, during the winter period<br>• Adjustment or cessation of irrigation rate to keep extent and depth of open water within target levels, during the late summer/autumn period |
| **Monitoring** | • Visual assessment of the extent of the open water area<br>• Recording the depth of the water within the open water area |
| **Who** | • Environmental Manager |
| **When** | • Monitoring of water extent and depth to occur a minimum of twice weekly during the first year; and<br>• Monitoring of water extent and depth to occur a minimum of twice monthly, and more frequently during periods of irrigation, in the next four years;<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains unchanged. |
| **Limits of Acceptable Change** | • No less than 3ha of open water extent<br>• No less than 0.25m average depth |
| **Remedial Action** | • Topping up with water from external drains and cessation of irrigation subject to protocols being agreed with the Environment Agency<br>• Re-instating the integrity of the slowly or impermeable lining of the open water area, if necessary |
| **Notes** | • The Environment Agency carries out periodic maintenance of the Keyingham Drain that requires the maintenance of a head of water for flushing purposes. An abstraction licence will be required and a protocol agreed with the EA |

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| **Target 2** | • No more than 10% dense stands of rushes (*Juncus* spp), tall sedges (*Carex* spp), reeds (*Phragmites australis, Phalaris arundinacea, Glyceria maxima, Typha spp*) within the open water area |
| **Management** | • Cutting dense stands of rushes, sedges and reeds in late summer/Autumn, if present |
| **Monitoring** | • Visual assessment of rushes, tall sedges and reeds within the open water area |
| **Who** | • Environmental Manager |
| **When** | • Monitoring to undertaken annually in June for the first five years<br>• Monitoring to occur in June once every three years thereafter if limits of acceptable change have not been exceeded in the first five years subject to the agreement of the Steering Group |
| **Limits of Acceptable Change** | • No more than 20% dense stands of rushes, tall sedges and reeds within the open water area |
| **Remedial Action** | • Cutting or excavating and removal of stands of rushes, tall sedges and reeds to give a maximum of 5% cover within the open water area |
| **Notes** | • Cutting and removal of swamp vegetation to be undertaken outside the bird breeding season |

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| **Target 3** | • The open water area is to contain freshwater for the purpose of irrigation |
| **Management** | • Only extracting freshwater from the external drains to top up the open water area, which may require adjustments in the extraction point and timing |
| **Monitoring** | • Measuring salinity within the external drains (subject to agreement with EA and Drainage Boards)<br>• Measuring salinity within the open water area |
| **Who** | • Environmental Manager |
| **When** | • Monitoring of salinity to occur continuously using data loggers during the first year within the Keyingham drain.<br>• Monitoring of salinity to occur continuously during the late summer/autumn period for the next four years<br>• Monitoring can cease if the limits of acceptable change have not been exceeded in the first five years, subject to the agreement of the Steering Group |
| **Limits of Acceptable Change** | • Salinity of the open water area less than 1‰ |
| **Remedial Action** | • Adjust extraction regime to return salinity of the open water area to within acceptable limits |

| | |
|---|---|
| **Target 4** | • Two vegetation free islands within the open water area |
| **Management** | • Islands to be capped with butyl rubber and shells/cobbles/gravel to limit vegetation growth<br>• Removal of vegetation annually in June, if limits of acceptable change are exceeded |
| **Monitoring** | • Mapping of the extent of the vegetation on each island |
| **Who** | • Environmental manager |
| **When** | • Monitoring to be undertaken annually in June for the first five years<br>• Monitoring to occur in June once every three years thereafter if limits of acceptable change have not been exceeded in the first five years, subject to the agreement of the Steering Group |
| **Limits of Acceptable Change** | • Up to 25% short perennial or ephemeral vegetation but no shrubs, trees or tall ruderal vegetation in the period July to March |
| **Remedial Action** | • Cut and treat shrubs, trees or tall ruderal vegetation as appropriate; OR<br>• Remove and replace shells/cobbles/gravel cap if islands are repeatedly colonised and management becomes difficult |

**Objective WG3: The soil will be moist throughout the months of August to April to concentrate invertebrates at the surface and to ensure that the soil remains soft enough to be probed by waders**

| | |
|---|---|
| **Target 1** | • Soil penetration resistance less than 6kg on average in each month from July to March using a soil penetrometer. |
| **Management** | • Maintenance of damp but unflooded grassland through appropriate sluice management and irrigation |
| **Monitoring** | • Monitoring to be undertaken at 100 standard sample locations spread across CCSWGS |
| **Who** | • Environmental manager |
| **When** | • Monitoring to occur once per month from July to November annually for 5 years; and<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains unchanged, subject to the agreement of the Steering Group. |
| **Limits of Acceptable Change** | • Soil penetration resistance less than 8kg on average in each month from July to March |
| **Remedial Action** | • Increase irrigation rate in order to increase soil moisture content and reduce soil penetration resistance<br>• Raise sluice heights to increase soil moisture content and reduce soil penetration resistance |
| **Notes** | • Soil resistance is based on data from Ausden et al 2001[1]<br>• Soil resistance to be sampled using a soil penetrometer details of which can be found at http://www.cemml.colostate.edu/assets/pdf/TPS_04-1_Sampling_Compaction.pdf (see Annex 4). |

| | |
|---|---|
| **Target 2** | • Soil moisture content greater than 100% of dry weight on average in each month from July to March |
| **Management** | • Maintenance of damp but unflooded grassland through appropriate sluice management and irrigation |
| **Monitoring** | • Monitoring to be undertaken at 100 standard sample locations spread across CCSWGS |
| **Who** | • Environmental manager |
| **When** | • Monitoring to occur once annually in the month of September for 5 years; and<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains unchanged, subject to the agreement of the Steering Group. |
| **Limits of Acceptable Change** | • Soil moisture content greater than 80% of dry weight on average in each month from July to March |
| **Remedial Action** | • Increase irrigation rate in order to increase soil moisture content<br>• Raise sluice heights to increase soil moisture content |

[1] Ausden, M., Sutherland, W. J. and James, R. (2001), The effects of flooding lowland wet grassland on soil macro-invertebrate prey of breeding wading birds. Journal of Applied Ecology, 38: 320–338.

**Objective WG4: The site should be largely free of winter flooding to prevent floodwaters from killing soil invertebrates.**

| | |
|---|---|
| **Target** | • Less than 10% flooding across the wet grassland area at any time (excluding the scrape and open water area) |
| **Management** | • Appropriate sluice height and irrigation flow rate adjustment |
| **Monitoring** | • Visual assessment of extent of flooding |
| **Who** | • Environmental manager |
| **When** | • Minimum of twice weekly during the first year; and<br>• Minimum of twice monthly, and more frequently during periods of irrigation, in the next four years;<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains unchanged, subject to the agreement of the Steering Group.. |
| **Limits of Acceptable Change** | • Less than 20% flooding across the wet grassland area at any time (excluding the scrape and open water area) |
| **Remedial Action** | • Appropriate sluice height and irrigation flow rate adjustment to enable flood waters to drain away |

**Objective WG5: The site will have a high density of macro-invertebrate fauna to provide food for wading birds.**

| | |
|---|---|
| **Target** | • Average earthworm biomass levels of 65gm$^{-2}$ (wet weight) in less than 5 years and maintained thereafter |
| **Management** | • Maintenance of damp but unflooded grassland through appropriate sluice management and irrigation |
| **Monitoring** | • Annual collection of 100 soil samples measuring 25 x 25 x 10cm at standard sample locations, with subsequent soil biomass calculations |
| **Who** | • Environmental manager |
| **When** | • Annually in September until target is achieved and then for three years thereafter<br>• Monitoring may cease if earthworm biomass levels greater than target levels for more than three consecutive years. Any changes in monitoring to be subject to the agreement of the Steering Group |
| **Limits of Acceptable Change** | • Minimum average earthworm biomass levels of 50gm$^{-2}$ (wet weight) after 3 years |
| **Remedial Action** | • Addition of organic matter as a top dressing to promote biomass increase<br>• Adjustments to soil moisture content or extent of flooding as appropriate |
| **Notes** | • Biomass target is derived from approximate average of natural, unflooded wet grasslands (Ausden et al, 2001)[2] |

[2] Ausden, M., Sutherland, W. J. and James, R. (2001), The effects of flooding lowland wet grassland on soil macroinvertebrate prey of breeding wading birds. Journal of Applied Ecology, 38: 320–338.

**Objective WG6: The wet grassland will be managed to give a suitable sward for wading birds throughout the months of August to March**

| | |
|---|---|
| **Target 1** | • Average sward height of 10cm across the CCSWGS each month from July to March |
| **Management** | • 0.2 livestock units per hectare per year in April to June inclusive in Year 1; AND<br>• 0.3 livestock units per hectare per year in April to June inclusive in all subsequent years; OR<br>• Equivalent management by cutting the grassland |
| **Monitoring** | • Measurement of sward height at 100 sampling points |
| **Who** | • Environmental manager |
| **When** | • Monitoring to occur once per month from July to November annually for 5 years; and<br>• Monitoring can cease if the target is achieved for three consecutive years after the first five years of monitoring provided that the management regime remains unchanged, subject to the agreement of the Steering Group. |
| **Limits of Acceptable Change** | • Average sward height of 15cm across the CCSWGS each month from July to March |
| **Remedial Action** | • Increase livestock density to achieve shorter swards at the end of June; OR<br>• Increase length of time livestock are present on CCSWGS to end July; OR<br>• Introduce rotational grazing/cutting from July to September across the CCSWGS; OR<br>• Cut grass once in August/early September. |

| | |
|---|---|
| **Target 2** | • No more than 10% dense stands of rushes (*Juncus* spp), tall sedges (*Carex* spp), reeds (*Phragmites australis, Phalaris arundinacea, Glyceria maxima*) or tall ruderal vegetation (thistles, docks etc) in the North and Middle Fields (including the scrape) |
| **Management** | • 0.2 livestock units per hectare per year in April to June inclusive in Year 1; AND<br>• 0.3 livestock units per hectare per year in April to June inclusive in all subsequent years; OR<br>• Equivalent management by cutting the grassland |
| **Monitoring** | • Visual assessment of the extent of the species listed above |
| **Who** | • Environmental manager |
| **When** | • Monitoring to undertaken annually in June for the first five years<br>• Monitoring to occur in June once every three years thereafter if limits of acceptable change have not been exceeded in the first five years<br>• Return to annual monitoring for three years following exceeding the limits of acceptable change<br>• Any changes in monitoring to be reviewed and agreed by the Steering Group. |
| **Limits of Acceptable Change** | • No more than 15% cover of dense stands of rushes, tall sedges, reeds or tall ruderal vegetation in the North and Middle Fields (including the scrape) |
| **Remedial Action** | • Flailing the areas dominated by unwanted vegetation twice in the year that the limit of acceptable change is exceeded; OR<br>• Herbicide application for severe infestations of rushes |

# 7 BIRDS

## *RATIONALE & OBJECTIVES*

7.1 The objective is to maintain populations of displaced birds. Previous sections describe objectives, management actions, and monitoring of the compensation package required to achieve this.

7.2 The compensation package is centred on a secure wet roost that will allow birds to exploit existing mudflat resources on the north shore immediately as well as the new wet grassland and RTE/MR as these develop functionality.

7.3 The development of the full package will be incremental and how birds respond to it will require monitoring of all potential resources available to them.

7.4 These resources include the mudflat remaining at NKM. The total mudflat area is 77ha of which 31.5ha will be directly lost to AMEP and 11.6ha predicted to be functionally lost to disturbance. Use of the remaining area will need to be part of the monitoring programme.

7.5 Early provision of the roost at CCS will require monitoring of the existing mudflat between Paull and Cherry Cobb for evidence of increased use and potential competition effects.

7.6 The area monitored for bird numbers will therefore include not only the developing RTE/MR and wet grassland but also the remaining mudflat at NKM, the existing intertidal area between Paull and Cherry Cobb Sands, and NKHP.

7.7 As the compensation site develops functionality it will be required to support the peak count (see Table 3) of the birds displaced from NKM within the range of national trends. Functionality from construction for the CCSWG will be reached within 2-4 years and up to 6 years for the RTE.

7.8 As there is a danger that rapid declines could be masked by natural variability as expressed by the national population trend then a review would be required after any one year where declines exceeded any negative change in the national trend, or after two years of consecutive decline even where this was within the range of changes in the national trend.

**Objective B1: The Compensation site supports peak counts of displaced species (see Table 3) with the same levels of foraging activity.**

| | |
|---|---|
| **Target** | • When RTE/MR & CCSWG reach full functionality (i.e. when biomass and physical targets are met) they support peak counts of each species as identified in Table 3. It is anticipated the RTE will reach full functionality within 4-6 years and the CCSWG within 2-4 years.<br>• Foraging use reflects that recorded in Table 3 (an exception is allowed for avocet as numbers are small). |
| **Management** | • Provide secure roost in first instance at CCS<br>• Develop RTE/MR and CCSWG |
| **Monitoring** | • Through the Tide Counts at NKM, CCS, CCSWG and RTE/MR and NKHP |
| **Who** | • Suitably experienced surveyors |
| **When** | • Twice monthly on a spring and a neap tide |
| **Limits of Acceptable Change** | • Any one year where declines exceeded negative changes in the national trend<br>• Two years of consecutive decline even where this was within the range of negative changes in the national trend |
| **Remedial Action** | • Review data to ascertain if population is being maintained within Humber<br>• Review data on national population to ascertain if population maintained within UK<br>• If evidence of range decline provide additional compensation where this is achievable |
| **Notes** | • If the area of functional disturbance is less than predicted and birds continue to use areas of NKM these may be counted toward the peak bird target identified for the compensation site |

# ANNEX 1: DECISION MATRIX FOR ASSESSMENT OF SUCCESS OR FAILURE OF COMPENSATION SITE FOR BLACK-TAILED GODWIT

| Bird Targets | Invertebrate Targets (Benthic and Wet Grassland) | Outcome | Management Required |
|---|---|---|---|
| Met | Both met<br>Roost Provided | **Fully Met** | Maintain |
| | | | |
| Met | Not met<br>Roost Provided | **Partially Met** | Improve RTE/MR & WG management to meet invertebrate targets. |
| | | | |
| Met | Benthic met<br>WG not met<br>Roost Provided | **Partially Met** | Improve WG management to meet invertebrate targets. |
| | | | |
| Met | Benthic not met<br>WG met<br>Roost Provided | **Partially Met** | Improve RTE/MR management to meet invertebrate targets. |
| | | | |
| Not met | Benthos met<br>WG met<br>Roost Provided | **Partially Met** | Determine if other reasons for birds not being present, and if numbers in SPA maintained. Identify management requirements. |
| | | | |
| Not met | Benthos met<br>WG not met<br>Roost Provided | **Partially Met** | Determine if other reasons for birds not being present, and if numbers in SPA maintained. Identify management requirements. Improve WG management. |
| | | | |
| Not met | Benthos not met<br>WG met<br>Roost Provided | **Partially Met if overall biomass acceptable** | Determine if other reasons for birds not being present, and if numbers in SPA maintained. Identify any additional management requirements.<br><br>and<br><br>Improve RTE/MR management to meet benthic invertebrate targets. |
| | | | |

| Bird Targets | Invertebrate Targets (Benthic and Wet Grassland) | Outcome | Management Required |
|---|---|---|---|
| Not met | Benthos not met<br>WG met<br>Roost Provided | **Not Met if overall biomass not acceptable.** | Determine if other reasons for birds not being present, and if numbers in SPA maintained<br><br>and<br><br>Improve RTE/MR management to meet benthic invertebrate targets. Identify any additional management requirements.<br><br>If the compensation continues to fail then this will be reported through the Steering Group to the Secretary of State. |
| | | | |
| Not met | Both sub-optimal but close to target value<br>Roost Provided | **Partially Met if combined sub-optimal biomass is acceptable.** | Determine if other reasons for birds not being present, and if numbers in SPA maintained. Identify any additional management requirements.<br><br>and<br><br>Improve RTE/MR and WG management to meet invertebrate targets. |
| | | | |
| Not Met | Not met<br>Roost Provided | **Not Met** | Determine if other reasons for birds not being present, and if numbers in SPA maintained. Identify any additional management requirements.<br><br>and<br><br>Management of RTE/MR and wet grassland to improve invertebrate biomass.<br><br>If the compensation continues to fail then this will be reported through the Steering Group to the Secretary of State. |

Notes:

The outcome column describes targets as fully met if they meet both bird and invertebrate targets; partially met if they achieve some but not all of the target but do so in such a way that either bird targets are met or sufficient mix of the invertebrate targets are met. Where targets have failed they are recorded as not met.

The management column is colour coded. Green indicates management is correct and should be maintained. Amber indicates a partial failure of one or more targets and indicates that action is required to address this and should be implemented for all the failing components. Red indicates a failure of the compensation site and that if remedial action is unable to reverse this failure this will be reported through the Steering Group to the Secretary of State.

Bird targets would be based on the peak numbers presented during the Appropriate Assessment and Panel process. Higher counts of birds using NKM could occur subsequent to that process and it is acknowledged that the compensation design is based on the Appropriate Assessment figures only.

The only circumstances in which bird targets can be lowered is where there has been a significant (>1%) decline in the relevant biogeographical populations.

Where the benthic target is a mixture of RTE (including the MR component) and WG it is acknowledged that WG is a buffer against failure rather than the principle feeding resource. Therefore in assessing success or failure based on any mix of sites greater weight will be given to RTE/MR populations. Therefore any combined invertebrate target must represent a combined minimum of 150% of the theoretical 200% (based on 100% of RTE/MR & WG invertebrate targets) subject to the RTE/MR component of that mix never falling below 75%. If the RTE/MR invertebrate population falls below 75% of the target value then the whole invertebrate target fails even where this exceeds a combined value of 150% (e.g. 75% RTE/MR & 75% WG= 150% would be compliant whereas 65% RTE/MR & 100% WG= 165% would not).

# ANNEX 2: SURVEY DESIGN FOR BENTHIC INVERTEBRATES

Survey rationale: the survey is designed to monitor the status of the intertidal benthic component at the compensation site (RTE and managed realignment) to be assessed against established targets as the site develops overtime. In particular, two aims have been identified for the survey:

1) to provide a good estimate of the community and target species densities in order to be assessed against the target defined at NKM;

2) to assess the development of the compensation site over time and its ability to provide intertidal habitat that is comparable to the natural mudflats in the area.

Effort has been put into devising a survey design that fulfil both aims, although it should be noted that there is not a single survey design that can be optimal for both aims. In addition, it is noted that the target assessment (aim 1) is a priority over the site development assessment (aim 2), in agreement with the importance placed by Natural England on the ability of the compensation site to meet the feeding requirements for Black-tailed Godwit. Therefore any modification of the survey design (e.g., following the revision of methods as described in Appendix 3) will be towards an improvement of the design to fulfil the target assessment, even if these modifications might involve a decrease in the power of the analysis for the site development assessment.

The survey design and methods have been devised based on existing guidelines (Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites - Ware and Kenny 2011; the Marine Monitoring Handbook, Davies et al 2001).

Sampling method: hand held corer (0.01 $m^2$), sediment sampled to a depth of c.15 cm.

Sampling period: monitoring to be carried out annually, in late summer-early autumn (preferably between the last week of August and first week of September, to allow direct assessment against the target defined for this season).

Sampling design: the distribution of the intertidal stations in the compensation site is dependant on the extent and distribution of the inundated habitat within the site, a factor that is expected to change over the years during the sites development. It is not possible to identify *a priori* the number of stations and their location without knowledge of the habitat distribution within the site. In order to allow a detailed survey design a topographic survey will be undertaken soon after breaching and the resulting map will be used to guide the location of the stations within the RTE and MR site.

Although the details of the survey design cannot be defined yet, some general criteria can be identified to guide the choice of the survey stations.

As at NKM, a stratified systematic design is devised as the best way to estimate population size of clustered (patchy) populations (Mier & Picquelle 2008[3] and references therein). Strata would be defined in order to cover the different sections of the compensation site (four RTE fields and MR site) as well as the different intertidal habitats (e.g., with different degree of inundation). In addition, the even coverage of the available intertidal habitat within the site will provide data for spatial analysis, which will allow biotope mapping as well an assessment of performance against benthic targets (see appendix 3).

Sampling stations will be positioned at regular intervals on the available intertidal habitat, their location being chosen on a pre-defined criterion that will be followed whenever new stations need to be added.

It is of note that the ability of the sampling design to provide good estimates of the benthic species populations (considering the variability in their spatial distribution) will depend on the spatial resolution of the sampling grid (i.e. on the number of stations) rather than on the replication of sampling at each station, as indicated by Ware and Kenny (2011 - Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites). It is suggested that a similar spatial resolution to that one used in the target setting survey at NKM is used in the compensation site (1 station every 0.7 ha ca.).

As a control for the benthic community development within the site, natural mudflats outside the site should also be sampled. It is suggested that 9 stations are located in correspondence of each of the 6 transects identified within the two control sites for the impact monitoring at CCS (north and south of the breach; see Marine EMMP for details), with a total of 54 faunal samples collected. This will allow monitoring of temporal (seasonal and inter-annual) variability in natural mudflats adjacent to the compensation site, thus allowing temporal revision of the targets if required (see Annex 3 on setting and assessing targets).

One sediment sample will be taken at each station for faunal analysis and an additional sample will be collected for PSA and organic matter analysis. Sample locations will be recorded using DGPS..

Sample processing: Samples from different replicates should be kept separate. Benthic samples are to be sieved through a 0.5mm sieve. Laboratory analyses will include species (identified to highest taxonomic detail), abundance, size class and biomass (WWTB), with standard AFDW conversion factors applied (using, for example, Rumohr et al., 1987; Ricciardi and Bourget, 1998; and Eleftheriou and Basford, 1989) for comparison with targets.

Supporting parameters: Sediment particle size analysis (PSA) and organic content will also be measured in the additional sediment sample. Also sediment water content is a relevant parameter that should be measured in the sediment samples. Additional supporting

[3] Mier KL and Picquelle SJ, 2008. Estimating abundance of spatially aggregated populations: comparing adaptive sampling with other survey designs. Can. J. Fish. Aquat. Sci. 65, 176-197.

parameters recorded on site will include the recording of the character and composition of surface sediments (type, colour, smell), depth of RPD layer, texture and presence of surface features. A photographic record of the sampling station and of the sediment will be also collected. It is recommended also that, during the benthic sampling, a visual estimate of the vegetation coverage and its height is derived within a 10x10 m square area around each benthic station, in order to allow a better characterisation of the wider habitat the benthic station falls within.

Supporting parameters derived from other surveys: As highlighted before, the initial topographic (LIDAR) survey, as well as regular surveys over the years will be important, not only to inform the setting and modification of the stations' location, but also to allow the characterisation of the different benthic stations based on their elevation and derived parameters (e.g., accretion, inundation frequency).

Water salinity measured within the compensation site will be relevant, particularly within RTE fields, as the water retention combined with particular conditions may lead to changes in salinity (e.g. the potential for hypersaline conditions during dry periods with high temperatures) that may affect the benthic community.

Data analysis: With the purpose of characterising the benthic community at the compensation site towards the assessment of the targets derived for NKM (see Appendix 3 for details on these targets setting and assessment), multivariate analysis will be carried out using cluster analysis (combined with similarity profile routine, SIMPROF) and ordination techniques (e.g., MDS, PCO) in order to identify different community types and gradients in the assemblage distribution/variation, as well as applying the SIMPER routine to identify the species which contribute most to the differentiations between groups. Multivariate statistical analysis (e.g., ANOSIM, PERMANOVA) will be applied to detect changes in community structure and composition. Bio-Env routine and linkage trees (BEST) in Primer will be used to explore the relationship between biotic (community) patterns and substrate characteristics.

Benthic fauna in the compensation site will be characterised also based on the main community descriptors (e.g., abundance, richness, biomass, evenness, diversity and biomass-to-abundance ratio) as well as abundance and biomass distribution of target species. Based on these analyses, the main biotope(s) present in the site will be identified and their distribution over the compensation site will be presented in a biotope map to highlight the broad scale homogeneity in terms of MNCR biotopes. Also GIS methods will be used to present maps of the distribution of biomass/abundance/species diversity (e.g., using kernel density interpolation) in order to provide information on the spatial extent of what may be the hotspots of each parameter (biomass etc). Analysis will also be integrated with the findings of the intertidal LiDAR surveys as elevation change can influence benthic community structure hence food availability to bird species.

With the purpose of addressing the compensation site development over time towards conditions reflecting adjacent natural mudflats (aim 2), an analysis of variance will be carried out similarly to that described for the MEMMP (on a BACI-type approach, but there will be

no “before” in this case). It is of note that stations within the strata defined by the different intertidal habitats present in the site (e.g. based on shore level) as well as by the distinction between the compensation site and the control areas outside will be will be considered as replicates of the strata for the purpose of the analysis.

The null hypotheses that will be tested during site development is that the mudflat community in the compensation site is developing over time, becoming more and more similar to the community in the control areas outside the site. Therefore an interaction between time (years) and treatment (compensation site/controls) will be expected, with the difference between the compensation site and the controls reducing year after year. The trajectory of change can be visualised also for the community structure through multivariate ordination techniques (e.g., MDS, PCO, in Primer), showing a decreasing dissimilarity between the compensation site and the control areas over the time during development. In turn, when the mudflat community will become established inside the compensation site, then the null hypothesis would be that its changes over the years are in line with the variability observed in the natural mudflat (control sites), hence in this case, the interaction term between time and treatment is expected to be non significant.

# ANNEX 3: TARGET SETTING PROTOCOL

Target

Targets will be set for metrics measured for the whole benthic community (community target) as well as for specific elements of the community that characterise the observed prey resource for Black-tailed Godwit (BW) at NKM (species targets, e.g., *Macoma balthica*, *Hediste diversicolor*).

The community target will be set as the average benthic community recorded at NKM.
Species targets will be set as the average abundance and biomass density (ind/$m^2$, g/$m^2$ the latter then being converted to AFDW g/$m^2$ using standard conversion factors) recorded at NKM.

Target assessment criteria

The values recorded at the compensation site will be compared with the target under the management objective set for the compensation site (i.e., they should be equal or higher than the target range). However, in order to take into account the inherent natural variability of estuarine mudflat benthic fauna, an acceptable level of change (ALC) will be identified.
The ALC will be defined taking into consideration the natural levels of temporal variability associated to the specific metric. These can be quantified in different ways (or a combination of them), depending of on the data availability:

- Based on the inter-annual variability observed at NKM, assuming that more than one pre-construction monitoring (in autumn) is allowed (e.g., Aug/Sept 2013 and Aug/Sept 2014);
- Based on the intra-annual variation between the Spring 2013 and Autumn 2013, and Spring 2014 and Autumn 2014 surveys with additional context provided by the 2010 characterisation survey.
- Based on the inter-annual variability observed in control areas in mudflats at NKM and CCS; it is of note that, as this information will be only available over the years of monitoring of the sites, it will be useful for periodical revisions of the ALC;
- Based on existing data (e.g., EA data) on mudflat benthic communities in the middle estuary in the last decade;

Data from autumn observations will be the primary source of data for the purpose of target setting, and will be under-pinned by the long term data for NKM provided by EA.. Intra-annual/seasonal variations will enable the identification of prey depletion during the winter period and provide valuable analysis of the intra-annual increase in biomass at NKM when compared to other sites, and the compensation site.

The data will be reviewed after each annual monitoring survey and as outlined within the *Target assessment review* section below.

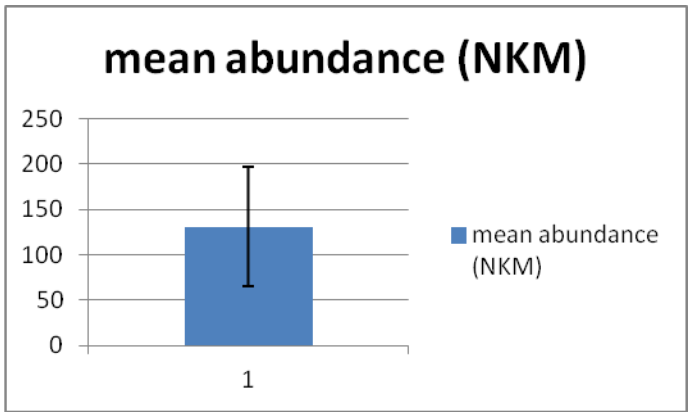
Hotspot analysis:

A suggested method for the presentation of the baseline results is to interpolate the biomass/abundance utilising a GIS method such as kernel density thus allowing the illustration of the spatial extent of what may be the hotspots of each parameter (biomass etc) using an objective approach. As described below the target standard deviation would then be adjusted based on all data points which fall within these areas of high density infauna (hotspots).

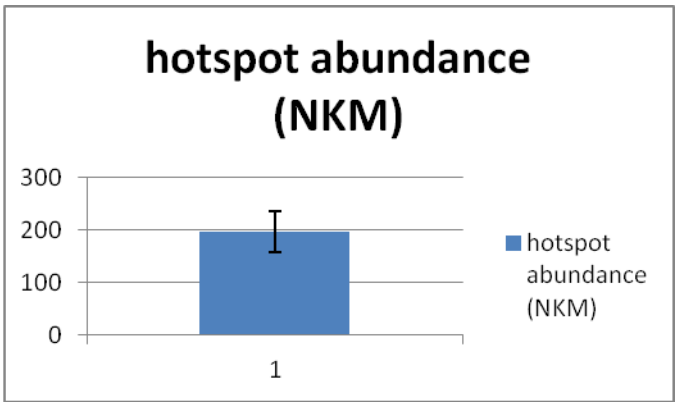
Species targets on NKM:

The target will be set using the mean value (e.g., abundance, biomass) obtained during the NKM baseline survey(s), within a range defined by the standard deviation from the mean abundance of the preferred BW foraging area.

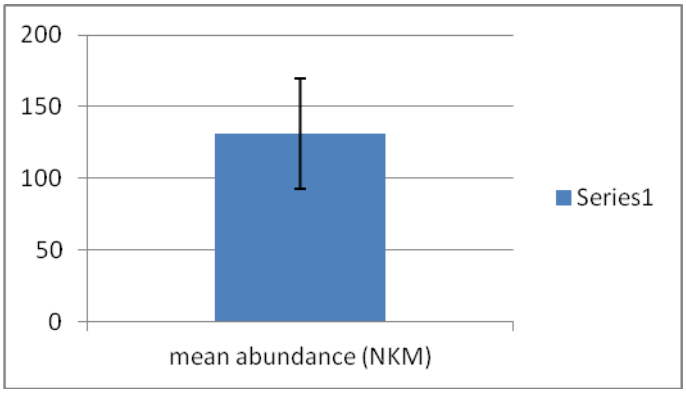
The following numbers are randomly generated for the purpose of illustration, and should not be taken as indicative of proposed targets, or target ranges. In an example dataset of 144 samples of random numbers (within a range of 20-250 individuals per metre square) the mean is 131.0, with a standard deviation of 65.7 giving a potential target of 131 individuals within a range of 65.3-196.7; displayed graphically below.



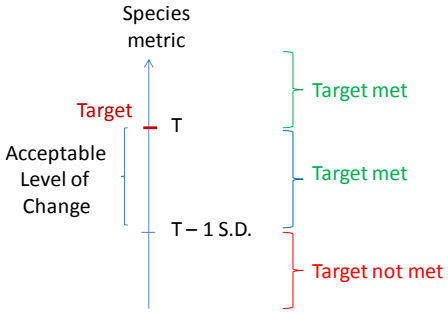

Within the preferred foraging area for BW (hotspots), assuming a number of samples (44) with a generally less variable, higher mean abundance (randomly generated numbers within a range of 120-250) the mean is 197 individuals with a standard deviation of 38.7; displayed graphically below.




In compensating for the loss of intertidal habitat by providing comparable intertidal habitat the appropriate target is the mean abundance (or alternative metric such as biomass) across the site. However in order to provide for a level of precaution, and to reduce the risk associated with the use of the wider variability at NKM which may mask the higher density prey requirements of BWs, the range of variability is to be reduced to reflect the standard deviation from the mean biomass found within the preferred foraging area "hotspots".
Using the random generated numbers above this then provides for a mean of 131 with a standard deviation of 38.7, resulting in a target range of 92.3-169.7, again presented graphically below.




The target will be considered as met if the value measured at the compensation site is equal or higher than the target, or, if lower, it is within the ALC, i.e. higher or equal to the target minus 1 SD (calculated as described above). The initial target in the above scenario for abundance would therefore be 131 individuals per metre square at the RTE/MR with an ALC of 92.3 individuals per metre square.



**Schematic representation of assessment for species targets.**

Inter-annual Development targets:

It is recognised that over the longer term there may be a risk of the target being met in terms of comparable habitat but in the lower end of the range, thereby risking failure of providing bird prey. To monitor this risk it is considered that after the community has reached the point of proposed stabilisation (i.e. 5 years post breach) the long term mean biomass/abundance should be equal or greater than the target mean within a range that is linked to the inter-annual variation (measured by Standard Deviation) at the NKM control site.
A simplified representation of this would be that over 5 years from stabilisation (i.e. years 5 onwards) the annual Parameter X (e.g. abundance) may fluctuate within the target range, the target mean being 5 individuals. The data for these years are:

Year 5 =4 individuals, year 6 =5, year 7 =3, year 8 =5, year 9 =7, with a mean of 4.8. During the same period of time the Parameter X at the control site is 5, 5, 6, 4, 4.8, with a standard deviation/variation between years of 0.71.

The long term target mean is therefore 5 individuals +/- 0.7 which means the long term mean of 4.8 indicates a success of the compensation site.

Community target on NKM:

The MNCR biotopes present at NKM will be identified based on the community analysis at the study sites; allowing for ready comparison in terms of the target of providing comparable intertidal habitat (currently considered to be LS.LMu.MEst.HedMac (*Hediste diversicolor* and *Macoma balthica* in littoral sandy mud) in the upper and mid shore at NKM, and LS.LMu.MEst.NhomMacStr (*Nephtys hombergii, Macoma balthica* and *Streblospio shrubsolii* in littoral sandy mud) in the lower shore at NKM. Similarly, community data at the compensation site will inform a biotope analysis, and the results will be compared to those at NKM in order to ensure that the dominant biotopes occur in both sites. The biotopes will be mapped both at the NKM and compensation site.

The target would be that the main biotopes in NKM are to be present at the compensation site and the dominant biotope at NKM has to be also dominant at the compensation site.

Target assessment review

The targets will be set according to the methodology defined previously and agreed with the relevant authorities with recognition that the target must be validated against not only the primary objective of providing compensatory estuarine habitat, but also the provision of prey resource for the BW.

With this in mind the initial target will undergo a sensitivity analysis after the pre-construction survey data has been collated for year 1 pre-construction (PC-1) and if available year 2 pre-construction (PC-2). The PC-1 and PC-2 data will be analysed for inter-annual variation with the longer term data provided by the EA to ensure that both the target (i.e. mean biomass) and the range within which the mean target will sit (i.e. standard deviation around the mean set according to standard deviation found within preferred foraging habitat for BW) is representative of NKM as observed within the long term dataset and appropriate. This will provide the first tier of confidence in the target itself, and will be subject to review by the steering group and where appropriate the SNCBs in a special meeting held as soon as possible after the survey and data analysis has been conducted.

A second tier of confidence will also be applied whereby the understanding of the foraging behaviour in terms of preferred sediment type and giving up density of key prey species of the BWs will be used as a benchmark against which the target and range is assessed for suitability. Again this will be subject to review by the steering group and where appropriate the SNCBs in a special meeting held as soon as possible after the survey and data analysis has been conducted.

Additional methods of analysis may also be employed which may include an analysis of taxonomic distinctness within a funnel plot as has been suggested by Natural England. The use of this method is that it has the potential to identify areas which are in greater fluctuation than others – habitats under greater levels of perturbation are considered to have lower taxonomic distinctness than stable, established habitats. Whilst an advantage of using taxonomic distinctness is that it is independent of sampling effort, which can strongly influence the values of other commonly used diversity indices owing to the influence of sampling effort on species richness, given the objective to provide comparable habitat and key prey species it is not considered appropriate to use the TD analysis as a specific target setting measure. Rather these forms of analysis may be applied as an ongoing form of validation within the review periods to enable discussion of progression of the community present within the compensation site from settlement to a stable community.

The assessment of targets will be carried out initially during the 10-years post-construction monitoring, at years 0 as highlighted above, year 5 and year 10. The end of the first 5 years is considered to be a key review period as it is at this point that the initial settlement should be reaching the proposed target and the collected data allow*s* for the monitoring design to be adjusted, in order to ensure that sufficient data are collected at the compensation site to capture the site variability and patchiness. Within the 5 year review relevant information will be incorporated to ensure that not only the objective is on target to be met in terms of providing comparable habitat to that observed at NKM, but also that it is suitable to supporting BWs. Again the relevant information that could be included might be *inter alia* the giving up density of key prey items such as *Macoma balthica* and *Hediste diversicolor.*

# ANNEX 4: GUIDE TO USING PENETROMETER

THE CENTER
for Environmental Management of Military Lands

# Guide to Sampling Soil Compaction Using Hand-Held Soil Penetrometers

CEMML TPS 04-1

CENTER FOR ENVIRONMENTAL MANAGEMENT OF MILITARY LANDS
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# Guide to Sampling Soil Compaction Using Hand-Held Soil Penetrometers[1]

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## Introduction

Vehicle traffic and foot trampling in military training areas can result in varying levels of soil compaction, depending on uses, climate, soil properties, and soil moisture at time of impact. Increased soil compaction results in higher soil bulk density (mass/unit volume), which can reduce water infiltration, reduce soil surface strength, increase runoff and erosion potential, and reduce site productivity (Braunack 1986, Thurow et al. 1995). The loss of macro-pore space via compaction has the greatest impact on water and air movement. Shrink-swell and freeze-thaw action typical of soils high in certain clays can significantly reduce surface soil compaction, but the most common remedy applied to highly compacted soils in relatively small areas is soil ripping using a chisel plow pulled by a tractor or bulldozer. Renewed root growth can also reduce soil compaction. Minimization of compaction is best achieved by confining traffic to specific areas, avoiding sensitive soils, and avoiding driving off-road when soils are excessively wet.

Soil compaction is most often characterized by changes in soil bulk density, typically expressed in $Mg/m^3$ or g/cc. Soil density is also related to soil resistance, which can be measured using a penetrometer much more rapidly that bulk density samples can be obtained (Miller et al. 2001). Some soils such as stony, light-textured, or highly friable soils are difficult to sample consistently

[1] Funding for this report was provided under the Land Condition-Trend Analysis (LCTA) Technical Support Contract administered by the Army Environmental Centre, Aberdeen, MD.

using hammer type bulk density samplers using corers or rings. Cone penetrometers are thus commonly used to measure soil compaction because of their easy, rapid, and economical operation (Perumpral, 1987). The purpose of this guide is to briefly discuss the advantages/disadvantages of hand operated static, dynamic, and drop cone penetrometers. Specifications and vendor information for selected penetrometers are also presented.

## Compaction Issues

The level of compaction and the thickness of compacted layers can vary with soil depth and across the area of interest. Military training areas affected by compaction include assembly/administrative areas, bivouac areas, heavy equipment training areas, and off-road maneuver areas. Understanding the effects of compaction within the soil profile is essential for developing land repair and mitigation efforts. The follow key issues influence both the measurement and treatment of compaction (adapted from Rooney et al. (undated)):

- Intensity – How compacted is the soil relative to unimpacted soils? Slight compaction may not cause management problems and may heal over time.
- Extent – Is the compaction across the entire training/disturbed area or concentrated in specific areas?
- Depth – At what depth does the highest compaction occur?
- Thickness – How thick is the compacted layer, and does the thickness vary considerably across the site?
- Seasonality – How, if at all, does compaction change over the course of a year?

In general, an increase in compaction, as indicated in increased resistance to penetration, indicates reduced air and water movement within the soil, less favourable conditions for plant growth, and increased erosion potential.

## Types of Cone Penetrometers

There are two general types of hand-held cone penetrometers: static penetrometers and dynamic penetrometers. Both measure soil resistance to vertical penetration of a probe or cone. The distinction between the two penetrometers lies in how force is applied to the cone. Static penetrometers subject to a constant hydraulic, mechanical, or electric power (via truck, tractor, or other motorized source) record data deep into the soil profile using digital data acquisition. These mechanical penetrometers work well to document compaction profiles due to the constant penetration rate, but are expensive and often limited to road-accessible sites. The drop cone penetrometer is considered a type of dynamic penetrometer, and will also be briefly discussed.

### Static Cone Penetrometers

Static cone penetrometers measure the force required to push a metal cone through the soil at a constant velocity (Figure 1). The force is usually measured by a load cell or strain gauge (e.g., proving ring) coupled with an analog dial or pressure transducer for readout (Herrick and Jones, 2002). The force is commonly expressed in kilopascals (kPa), an index of soil strength referred to as the cone index (ASAEa, 1999), or as $Kg/cm^2$ or PSI. As the operator pushes down on the penetrometer, the note keeper records cone index values for each depth increment to evaluate the degree, depth, and thickness of compacted layers. Cone indices depend on cone properties (angle and size) and soil properties (e.g., bulk density, texture, and soil moisture) (ASAEb,

1999; Herrick and Jones, 2002). A static cone penetrometer with a 30° cone has been recommended by the American Society of Agricultural Engineers (ASAE) as the standard measuring device for characterizing the penetration resistance of soils (ASAEa, 1999). While this configuration may work in a wide variety of soils, it is not critical that all instruments adhere to these standards, since results are generally relative to one another at a particular time and place.

Figure 1. Example of hand held static cone penetrometer. Photo courtesy Durham Geo Corp.

Although the methods for static cone penetrometer operation have been standardized, there are several limitations which may limit their use for monitoring (Herrick and Jones, 2002). Static penetrometers can be relatively expensive (≥$600), particularly for models with digital recording capability (Table 1). More importantly, since static penetrometers must be moved through the soil at a constant velocity (i.e., pressure), different rates of insertion by different observers can yield variable results and affect repeatability (Herrick and Jones, 2002). Even the pressure exerted by a single operator can be difficult to apply at a constant and repeatable rate. Operator strength may also limit the use of static penetrometers in dry soils. Recalibration to the operator is recommended to optimize repeatability. Repeatability and difficulties sampling hard or dry soils are the primary drawbacks of this type of penetrometer. Advantages of static cone penetrometers over dynamic cone penetrometers include well-documented and standardized methods and ease of use.

## Dynamic Cone Penetrometers

Dynamic cone penetrometers (DCPs) apply a known amount of kinetic energy to the cone, which causes the penetrometer to move a distance through the soil (Herrick and Jones, 2002). Dynamic penetrometers do not rely on constant penetration velocity, as most dynamic penetrometers use a slide hammer of fixed mass and drop height to apply consistent energy with each blow (Figure 2). Either the number of blows required to penetrate a specified depth, or the depth of penetration per blow are measured, and results can be calculated as a cone index described above. The weight of the hammer, slide distance, and cone angle influence the energy delivered and can be adjusted to local conditions (e.g., soft vs. hard soils).

Figure 2. Example of dynamic cone penetrometer showing slide hammer (left), extension rods (centre) and cone attachment (upper right). Photo courtesy Durham Geo Corp.

Measurements are taken by placing the cone on the soil surface with the shaft upright. To minimize variability in starting depth, the cone is pressed into the soil until the soil is level with the base of the cone. The slide hammer is raised until it touches the collar and is released. The depth of penetration is recorded for each blow until a maximum or desired depth is reached. Penetrometers driven to depths greater than approximately 30 cm may be difficult to remove from the soil (Herrick and Jones 2002). Soil resistance for each soil depth interval is

calculated using standard equations that account for differences in hammer drop distance, weight, and cone size.

DCPs tend to yield much more consistent results and have a greater range of repeatability because they are not subject to operator variability (Herrick and Jones, 2002). Dynamic penetrometers have fewer limitations in dry soils and tend to be less expensive than static penetrometers (Table 1). Because of these reasons, the DCP is well suited for soil compaction monitoring on military lands. The design and application of a low-cost ($150-$200) DCP is described by Herrick and Jones (2002).

### Drop Cone Penetrometers

A drop-cone penetrometer is used to estimate surface soil strength (Figure 3). It has been used to estimate compaction effects associated with cattle grazing (Paul Ayers, unpublished data) and military vehicles (Jones 2000). The drop cone used in the aforementioned studies was constructed based on design information provided by Godwin et al. (1991) and advice from Dr. Paul Ayers[2]. The drop-cone technique is rapid and precise, allowing many samples to be obtained in a short period of time. The device consists of a 30 degree metal cone and lifting rod with a combined weight of 2.0 kg, a 1 m long PVC or acrylic guide tube, and an aluminum millimeter ruler inlaid in the holding rod. The cone is machined with a collar to ensure that it falls perpendicularly through the guide tube. To take a measurement, the base of the guide tube is placed on the ground surface and the cone is lifted until its top is flush with the top of the tube. The cone is released and penetrates the ground surface. Penetration depth is recorded at the top of the guide tube by reading the ruler inlaid in the holding rod.

This apparatus is inexpensive, easy to use, rapid, and highly repeatable. The disadvantage of this penetrometer is that only surface soil resistance is measured and nothing can be inferred about the underlying soil profile.

Figure 3. Drop cone penetrometer held in release position.

[2] Former professor of Chemical and Bioresources Engineering, Colorado State University, Fort Collins, Colorado; currently at the University of Tennessee at Knoxville.

Table 1. Specifications and vendor information for hand-held cone penetrometers for measuring soil compaction. Listing of a vendor does not constitute promotion of their products.

| Penetrometer Type | Manufacturer/ Vendor | Model# | Digital | Specifications | Cost[1] | Vendor Contact | Notes |
|---|---|---|---|---|---|---|---|
| dynamic | "local machine shop" | "Jornada Impact Penetrometer" | No | choice of cone angle (generally 30°, 45°, or 60°), rod length, slide hammer weight, and material (iron vs. stainless) | $150-$250 | machined and constructed locally | Described in detail in Herrick and Jones (2002) |
| dynamic | Durham Geo | S-205 | No | 45° cone w/ diameter of 3.8cm; (4) 30" drill rods; 15 lb (6.8 kg) steel hammer | $425 | www.durhamgeo.com solutions@durhamgeo.com 800-837-0864 | Model S-200 is similar but includes auger head and (4) 36" auger extensions; cost is $550 |
| dynamic | Triggs Technologies, Inc. | Wildcat | No | Uses polymer/water slurry injection to prevent soil from caving onto rods; 35lb hammer; uses lost points (cones-90° apex, 10cm$^2$) | $2,145 | www.triggstechnologies.com; info@www.triggstechnologies.com.com 800-383-2624 | Several optional accessories also available, including the Stork hammer-lifter ($1975). Designed to be used in augered holes at specified depths. Cones detach in holes so a new cone tip must be used each time. |
| dynamic | Vertek/Applied Research Associates, Inc. | Hand-Held DCP Kit | No* (see Notes) | Includes 10 disposable cones and receiver for disposable cones, Pelican case, vertical scale, 8 kg sliding weight | $1,475 | www.verteck.ara.com; verteck@ara.com 800-639-6315. | Electronic data acquisition system also available ($4995) |
| dynamic (drop) | "local machine shop" | | No | choice of cone angle (generally 30°, 45°, or 60°), rod length, slide hammer weight, and material (iron vs. stainless) | $150-$250 | machined and constructed locally | Drop cone penetrometer data provides an index of surface soil strength and typically is only dropped once per sample. Apparatus described in Godwin et al. and has been used by D. Jones (CEMML). |
| static | Durham Geo | S-212 | No | 60° cone w/ area of 1.5cm$^2$; 2.5' rod; pressure gauge (kg/cm$^2$) | $642 | www.durhamgeo.com; solutions@durhamgeo.com 800-837-0864 | |
| static | Eijkelkamp | Hand Penetrometer | No | Probes to a depth of 1m; Includes (4) sizes of 60° cones; probing and extension rods; carrying case; tool set; cone check; pressure gauge (kPa) | $1,232 | Soil Moisture Equipment Corp. www.soilmoisture.com 805-964-3525 | Similar model can probe to 3m depth ($2062); The 1m model is also available from Ben Meadows (benmeadows.com); cost is $1373 |
| static | Eijkelkamp | Penetrologger | Yes, with datalogger & PC software | Probes to a depth of 0.8m; Records soil depth in 1cm increments; Penetration resolution of 0.1 kPa; Includes various sizes of cones; carrying case; tool set; cone check; battery charger | $5,207 | Soil Moisture Equipment Corp. www.soilmoisture.com 805-964-3525 | |

| Penetrometer Type | Manufacturer/ Vendor | Model# | Digital | Specifications | Cost[1] | Vendor Contact | Notes |
|---|---|---|---|---|---|---|---|
| static | Geneq, Inc. | H-4210 | No | 60° cone w/ area of 1.5cm$^2$; 2.5' rod; pressure gauge (kg/cm$^2$) | $823 | info@geneq.com<br>800-463-4363 | |
| static | Spectrum Technologies, Inc. | Field Scout (SC-900) | Yes, with datalogger & PC software | Weighs 2.75 lbs; Records soil depth in 1" increments; Penetration resistance in PSI or kPa; GPS port | $1,495 | www.specmeters.com<br>info@specmeters.com<br>800-248-8873 | Identical to Investigator below |
| static | Forestry Suppliers, Inc. | The Investigator Soil Compaction Meter | Yes, with datalogger & PC software | Weighs 2.75 lbs; Records soil depth in 1" increments; Penetration resistance in PSI or kPa; GPS port | $1,395 | www.forestry-suppliers.com<br>sales@forestry-suppliers.com<br>800-647-5368 | Identical to Spectrum's Field Scout |

1 - Prices as of January 2004

## Compaction Sampling Guidelines

The following guidelines are provided to assist in the development of compaction sampling protocols and optimize data analysis opportunities:

- Develop written sampling objectives to direct data collection and evaluate success of the monitoring and management efforts. Include specific attributes such as intensity, depth, extent, etc. For example, “Estimate the mean penetrometer resistance of 0-10cm, 10-20cm, and 20-30cm soil depths with 90% confidence that the estimate is within 10% of the mean. These assessments will be performed every two years in high-use areas where soil compaction is a management concern”.
- Develop a standardized sampling design and methodology for use in areas of interest.
- Because soil strength is highly influenced by soil moisture, sampling of a site should take place over a short period of time to minimize potential effects of changing soil moisture. If comparison of different sites or analysis over time is desired, it is recommended to sample when soils are at or near field capacity (Miller et al. 2001).
- Sample adjacent “control” or reference areas to provide a benchmark for comparison with impacted sites. Reference areas should be relatively close to damaged areas and have a similar soil type.
- Due to the effects of soil moisture on penetration resistance, measurements should be analyzed as relative values at a particular time and place. Differences in soil texture, rainfall patterns, and sunlight exposure can affect soil moisture across the landscape.
- Sample size necessary to meet desired precision should be determined using pilot sampling. Approximately 15-25 samples are often adequate but results will depend on site heterogeneity.
- Sampling designs should be stratified if appropriate. Bias in selection of sampling locations must be minimized through the a priori selection of locations or the use of additional sampling rules of thumb. Navigation to random or systematic grid points (with a random start point) or navigation using pacing and compass are both acceptable approaches to minimize subjectivity.
- Soil moisture content and soil texture classification could be collected and recorded as corollaries to compaction.
- Repeated attempts may be necessary where stones are encountered, indicated by a distinct sound and or penetrometer vibration. In stony soils, penetrometer resistance may be poorly correlated with bulk density (Miller et al. 2001).
- Additional vegetation, disturbance, groundcover/biological crust, erosion, or other data can be collected at compaction sample points and the data can be analyzed to infer the causes of compaction, its effect on natural resources, and the effectiveness of compaction mitigation efforts.

## Conclusions

A variety of types and models of hand held penetrometers are available, and present a relatively low cost and expedient alternative to collecting bulk density samples for measuring soil compaction. Following the lead of Herrick and Jones (2002), the slide hammer type DCP is recommended for sampling compacted soil areas on military installations. While DCP results are not necessarily comparable across sites and over time due to differences in soil moisture

and other factors, the procedure is highly repeatable and rapid, and addresses the key issues of compaction intensity, extent, depth, and thickness. The penetrometer can be purchased commercially from several vendors or constructed to ASAE standards using a local machine shop.

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