Wightlink Ltd

Wightlink - Replacement Lymington to Yarmouth Ferries: Information for Appropriate Assessment

Date: May 2008

Project Ref: R/3772/1

Report No: R.1427

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Project Manager:	J A Richards	[signature]	29/05/08
Quality Manager:	M J Smedley	[signature]	29/05/08
Project Director:	C R Scott	[signature]	29/05/08

ABP Marine Environmental Research Ltd
Suite B, Waterside House
Town Quay
SOUTHAMPTON
Hampshire
SO14 2AQ

Tel: +44(0)23 8071 1840
Fax: +44(0)23 8071 1841
Web: www.abpmer.co.uk
Email: enquiries@abpmer.co.uk

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Acronyms and Abbreviations

μPa	μ Pascal
AA	Appropriate Assessment
ABPmer	ABP Marine Environmental Research Ltd
AIS	Automatic Identification System
CCO	Channel Coast Observatory
CD	Chart Datum
CFD	Computational Fluid Dynamics
dB	Decibel
DETR	Department of the Environment Transport and the Regions
DGM	Digital Ground Model
EA	Environment Agency
EC	European Commission
EEC	European Economic Community,
EIA	Environmental Impact Assessment
ELP	Eagle, Lyon, Pope
EN	English Nature
ES	Environmental Statement
FEPA	Food and Environment Protection Act
ha	Hectare
HT	Hearing Thresholds
HW	High Water
INTERREG	European Union funded programme that helps Europe's regions form partnerships to work together on common projects
LHC	Lymington Harbour Commissioners
LIDAR	Light Detection And Ranging
LSE	Likely Significant Effect
LW	Low Water
MCEU	Marine Consents and Environment Unit
MFA	Marine and Fisheries Agency
MHW	Mean High Water
MLW	Mean Low Water
MLWS	Mean Low Water Springs

NE	Natural England
NFDC	New Forest District Council
OS	Ordnance Survey
ppm	Parts per million
PSA	Particle size analysis
Ramsar	International treaty for the conservation and sustainable utilisation of wetlands
RT	Response Thresholds
SAC	Special Area of Conservation
SCI	Site of Community Importance
SCOPAC	Standing Conference on Problems Associated with the Coastline
SL	Source Level
SMB	Sverdrup-Munk-Bretschneider
SPA	Special Protection Area
SSSI	Sites of Special Scientific Interest
TL	Transmission Loss
VSP	Voith Schneider Propeller

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1. Introduction

This report has been prepared to bring together the information that is needed to produce an Appropriate Assessment (as required under the under the UK Conservation (Natural Habitats &c.) Regulations 1994 that are hereafter referred to as the 'Habitats Regulations') for proposed revisions to the Wightlink Ltd. ferry service that operates between Lymington to Yarmouth. This Wightlink Ltd proposal involves the following elements:

- The introduction of a new class ('W' Class) of vessel to operate Wightlink's Lymington to Yarmouth service.
- 'Shoreside' works at Yarmouth involving the berth modification to the existing fenders, ramps and link-span.
- 'Shoreside' works at Lymington involving the dismantling of the main berth timbers and piles followed by the installation of new steel piles and modifications to link-span bridges using a barge mounted crane.

The Marine and Fisheries Agency (MFA) has advised that new shoreside works at the harbours of Yarmouth and Lymington, and the introduction of new ferries between them, should be considered as a plan or project under the Habitat Regulations. Natural England (NE) have confirmed (in their letter to the Marine Consents and Environment Unit (MCEU now the MFA) dated 24 September 2007) that the project is 'likely to have a significant effect' (according to the "coarse filter" definition of significance that they apply for such judgements under Regulation 48 of the Habitats Regulations) on the adjacent Solent Maritime European Marine Site and as such an Appropriate Assessment (AA) needs to be produced for this proposal.

However, it was agreed that the works at Yarmouth works are not likely to have a significant effect on European marine site features and that impacts here can be considered *'de minimis'*. Therefore, this part of the proposed scheme was separately consented and does not form part of this AA document. The consent for the Yarmouth work was issued on 21 February 2008 (MFA Ref 33959/08/0). Consequently, this AA has focused only on the potential impacts at Lymington end of the services from the introduction of the new ferries and the shoreside works.

The aim of this study is to bring together available information and undertake relevant technical analyses such that the MFA, as the Competent Authority in this case, can determine whether these two elements of the project will affect the integrity of the Solent Maritime European Marine Site. This decision will need to be made by the MFA in consultation with the statutory conservation authorities NE and the Environment Agency (EA) and it is a judgement that needs to be taken with reference to the Conservation Objectives of this European Marine Site.

The scope and structure of this 'Information to support Appropriate Assessment' report have been defined in consultation with NE and with reference to available guidance on AA content (English Nature, 1997). In particular it was agreed that this report did not need to repeat all the findings from the many previous studies that have been undertaken as part of this proposal but should concentrate on highlighting the key sources of information and presenting the relevant details and findings that are needed for the MFA and their consultees to make a decision about the effects on site integrity. Therefore, where non-critical contextual information is required and is presented in these preceding studies, the location of this information is simply referred to here. In so doing the intention has been to produce a relatively brief and clear document that focuses on the following aspects:

- **Designated sites, need for AA and scheme description (Section 2)**: Identification of the designated sites that may be directly or indirectly affected and confirmation of the reasons why this assessment is required along with an overview of the proposed project (for the Lymington Section) with details of the shoreside works and summary details of the proposed vessel size changes.
- **Impact pathways and conservation objectives (Section 3):** Identification of the interest features of the designated sites that may be affected via relevant impact pathways and a review of the relevant Conservation Objectives (as prepared under Reg. 33 of the Habitat Regulations).
- **Potential impacts of the shoreside works (Section 4):** A review focussing on the effects of noise on fish species in response to potential concerns expressed by NE (the EA were also consulted on this issue but no formal view was received).
- **Potential impacts from introduction of the new ferries (Section 5):** The focus of this assessment including a collation of the best available evidence to determine whether, and to what extent, the new ferry operation will have an adverse effect on the channel or the adjacent intertidal habitats (this includes a review of the information relating to the effects of the existing vessel operations and an assessment of the potential indirect effects the replacement ferries on the intertidal area operating at the same speed and frequency as the existing ferries).
- **In-combination effects with other plans or projects (Section 6):** A review of the effects that the proposal will have 'in-combination' with other projects that are in the planning domain.
- **Mitigation and monitoring measures (Section 7):** Identification of the most appropriate impact reduction and/or mitigation measures along with a statement about the confidence that can be had in these and a review of possible monitoring options.
- **Conclusion (Section 8):** A final summary statement about the potential effects of the scheme that is designed to inform the MFA decision on the effects on integrity.

2. Designated Sites, Need for AA and Scheme Description

2.1 Designated Sites

The ferry route lies within the Lymington River Estuary, in the Solent and the Isle of Wight (Yarmouth), and the international nature conservation importance of the habitats within and adjacent to the Lymington River are recognised through their inclusion within the Solent and Southampton Water SPA and Ramsar site; and the Solent Maritime SAC. SACs and SPAs are defined as European Sites in the Habitats Regulations and, where a European Site lies below highest astronomical tide i.e. land covered (continuously or intermittently) by tidal waters, it is described as a European Marine Site.

Figure 1 shows the boundaries of these sites in relation to the ferry navigation route. Further information about the relevant qualifying criteria and interest features for each of the international designations is given in Section 2.3. The navigation channel is within the SPA and Ramsar sites, but not within the SAC. Although the mudflats on the eastern shore within the Harbour are Ramsar, SPA and SAC Horn Reach itself is not designated. Further outline details of the interest features of the designated sites are presented in Section 2.1.1 to 2.1.3.

2.1.1 Solent and Southampton Water SPA

The Solent and Southampton Water SPA, covering 5506ha, was designated in October 1998. The SPA comprises 48% tidal rivers, estuaries, mudflats, sandflats and lagoons (including saltwork basins), 18% saltmarshes, salt pastures and salt steppes, 17% humid and mesophile grassland, 10% shingle, sea cliffs and islets, 3% bogs, marshes, water fringed vegetation and fens, 3% coastal sand dunes, sand beaches and machair, and 1% broad-leaved deciduous woodland.

The Solent and Southampton Water SPA qualifies under the EC Birds Directive (79/409/EEC) given that it achieves the following:

- Article 4.1: Regularly supports an internationally important population of breeding Annex I species, comprising Mediterranean gull, little tern, roseate tern, common tern, sandwich tern; and
- Article 4.2: Supports an internationally important assemblage of overwintering birds, and internationally important populations of regularly occurring migratory species, including Eurasian teal, dark-bellied Brent goose, ringed plover, and black-tailed godwit.

2.1.2 Solent and Southampton Water Ramsar Site

The Solent and Southampton Water Ramsar Site, covering 5346ha, was designated in October 1998. The site comprises estuaries and adjacent coastal habitats, including intertidal flats, saline lagoons, shingle beaches, saltmarsh, reedbeds, damp woodland, and grazing marsh. The different habitats support internationally important numbers of wintering waterfowl, important breeding gull and tern populations and an important assemblage of rare invertebrates and plants.

The Solent and Southampton Water was designated a Ramsar site by meeting the qualifying criteria outlined below:

- Criterion 1: The site is one of the few major sheltered channels between a substantial island and mainland in European waters, exhibiting an unusual strong double tidal flow with long periods of slack water at high and low tide. It comprises many wetland habitats characteristic of the biogeographic region: saline lagoons, saltmarshes, estuaries, intertidal flats, shallow coastal waters, grazing marshes, reedbeds, coastal woodland and rocky boulder reefs;
- Criterion 2: The site supports an important assemblage of rare plants and invertebrates. At least 33 British Red Data Book invertebrates and at least eight British Red Data Book plants are represented on site;
- Criterion 5: Supports internationally important assemblages of overwintering waterfowl; and
- Criterion 6: Used regularly by species/populations occurring at levels of international importance. Qualifying species/populations (as identified at designation) that have peak counts in spring/autumn are ringed plover. Those having peak counts in winter are, dark-bellied Brent goose, Eurasian teal and black-tailed godwit.

2.1.3 Solent Maritime SAC

The Solent Maritime SAC, covering 11,325ha, was proposed as eligible as a Site of Community Importance (SCI) in October 1998, and designated as SAC in April 2005. The SAC comprises 59% tidal rivers, estuaries, mudflats, sandflats and lagoons (including saltwork basins), 23% salt marshes, salt pastures and salt steppes, 14% marine areas and sea inlets, 3% shingle, sea cliffs and islets, and 1% coastal sand dunes, sand beaches, machair, and broad-leaved deciduous woodland.

Annex I habitats that are a primary reason for selection of this site are:

- Spartina swards (*Spartinion maritimae*);
- Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*); and
- Estuaries.

Annex I habitats present as a qualifying feature for selection of this site are:

- Sandbanks which are slightly covered by seawater all the time;
- Mudflats and sandflats not covered by seawater at low tide;
- Coastal lagoons;
- Annual vegetation of drift lines;
- Perennial vegetation of stony banks;
- Salicornia and other annuals colonising mud and sand; and
- Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes").

Annex II species present as a qualifying feature for site selection is: Desmoulin`s whorl snail, *Vertigo moulinsiana.*

2.2 Need for an Appropriate Assessment

As the scheme is located within, and has the potential to affect, the above European Marine Site, the Marine and Fisheries Agency (MFA), as the lead Competent Authority in this case, needs to take account of the Habitats Regulations, taking appropriate advice from Natural England. Natural England has confirmed in their scoping response (Scoping Opinion received from the MFA on 10 January 2008) that an Appropriate Assessment is required for this scheme, under Regulation 48 (1) of the Habitats Regulations, which states that:

> *"A competent authority, before deciding to undertake, or give any consent, permission, or other authorisation for a plan or project which:*
>
> *(a) is likely to have significant effect on a European site in Great Britain (either alone or in combination with other plans or projects); and*
> *(b) is not directly connected or necessary to the management of the site*
>
> *shall make an appropriate assessment of the implications for the site in view of that site's conservation objectives".*

The decision as to whether an Appropriate Assessment is required or not is the assessment of 'Likely Significant Effect', or LSE, is recognised within Natural England as being a 'coarse filter' or statement that the anticipated effects of the proposal will be more than trivial, i.e. that the anticipated change(s) resulting from the proposal has the potential to impact on a receptor. It does not automatically follow that an impact will occur, or that the impact would be significant, with a decision of LSE being purely an indication of the need for an Appropriate Assessment. The interpretation of the term significant under the Habitats Directive in England is therefore different to its use under the EIA Directive, with LSE in the Habitats Directive effectively analogous to a Screening Decision under EIA. Early consultation with the appropriate conservation agency as regards to LSE and the basis for the assessment is recommended, to ensure that the issues that are required to be addressed in the AA are highlighted at an early stage. However, when considering the undertaking of such consultation, it should be noted that if insufficient information is available on the project, the advice given may be stricter than if more information were available (ABPmer, 2007).

For this proposal, the issue about whether the introduction of new ferries can be considered a plan or project under the Habitats Regulations has been the subject of legal debate and written discussions between Wightlink Ltd., NE and MFA. This debate is not re-opened here except to note that Wightlink Ltd have accepted the need for an AA to be undertaken and that the vessel change is one element of a wider proposal for shoreline work and berth redevelopment rather than an individual initiative in its own right. Therefore it is considered that it is not the vessel change per se that has prompted the need to an AA but the whole development of which this change is an element that brings with it relevant impact pathways that need further consideration.

2.3 Scheme Description

As noted above, this AA relates to the application for "Licensing of Deposits at sea for the purposes of construction to modify existing fenders, ramps and linkspan bridges on the Lymington to Yarmouth Route". It addresses the shoreside works at Lymington and the change of vessels. At Lymington the critical issue is the piling and the noise created (see next section) and these piling works at Lymington will consist of the following:

- New fender piles within the main berth. It is anticipated that a total of fifteen piles will be installed over a period of about two weeks.
- Two standby berths are to be constructed, each comprising approximately twelve piles. The total period estimated for pile installation is likely to be three weeks.

The works are to be carried out within working hours from Monday to Friday, unless the works overrun, in which case works may be carried out on a Saturday.

In terms of the vessel changes, Wightlink are planning to replace the existing 'C' class ferries with new ferries ('W' class), during 2008, partially in order to comply with new health and safely legislation. The specifications of the new 'W' class ferries, the existing 'C' class ferries and the differences to the existing ferries can be found in Table 1. The information provided is considered to be the most up to date and is as provided by BMT SeaTech (2008).

Table 1. Details of the existing and proposed ferries, with percentage differences

Detail	Existing Ferries	Proposed Ferries	Difference
Length overall	55.5 m	62.4 m	12.4 %
Length at waterline (2.3m draught)	55.3 m	61.0 m	10.3 %
Beam	15.2 m	16.0 m	5.3 %
Beam at waterline (2.3m draught)	12.4 m	16.0 m	28.7 %
Length / beam ratio at waterline	4.5	3.8	-15.3 %
Draught	2.3 m	2.1 m (max laden draught)	-8.6 %
Load displacement	868 tonnes	1489 tonnes	71.5 %
Displacement / length ratio	0.0051	0.0085	66.3 %
Block coefficient	0.54	0.65	20.5 %
Combined horsepower of Voith Schneider units (approx)	800 h.p.	2360 h.p.	
Power / weight ratio (h.p. / displacement)	0.94	1.57	67.0 %
Above water lateral area (windage area – laden)	365.3 m²	665.7 m²	82.2 %
Below water lateral area	125 m²	129 m²	3.2 %
Above / below water ratio	2.36	4.22	78.8 %
Maximum (operational) speed	10.0 knots	12.0 knots	20.0 %

(Source: BMT SeaTech Ltd, 2008)

3. Impact Pathways and Conservation Objectives

For this study it was agreed that the relevant SAC interest features for this assessment are the intertidal mudflats and saltmarsh that could be indirectly affected by the change to ship vessels sizes and any associated physical/hydrodynamic changes occurring (e.g. to shipwash, propulsion thrust, channel morphology etc,). Also of relevance are the overwintering waterbird populations that are SPA/Ramsar interest features. These populations may be impacted by disturbance caused by piling noise during the shoreside works at Lymington. This latter issue was not considered to be a cause for concern by NE if Wightlink Ltd took appropriate mitigation measures in the form of vibro-piling for any work that is to be done during the winter months (when migratory bird populations are present). Wightlink have agreed to undertake a vibro-piling approach but this is not a formally stated element of the works, within the FEPA licence application to MFA, and therefore the impacts and mitigation measures warrant further reaffirmation here.

The potential impacts of piling noise on migratory fish species has also been raised by NE (in their letter dated 24 September 2007) as these are an interest features of the New Forest and Lymington River Sites of Special Scientific Interest (SSSIs). Fish species are not however an interest feature of any international designated sites and thus do not specifically need to be considered here (as part of this assessment, a formal EA view on this aspect was sought but was not obtained). However, to guarantee completeness a review of noise impacts on fish has been presented for this study.

The conservation objectives for the Solent Maritime European Marine Site are contained with Natural England's (formerly as English Nature) advice under Regulation 33(2) Habitats Regulations for the Solent European Marine Site (English Nature, 2001). These conservation objectives are intended to define the desired condition of an attribute, taking into account fluctuations due to natural change. Through assessing the predicted effects of the scheme in relation to the targets, it is possible to determine its potential effect on favourable condition and hence on the designated status of these sites.

Table 2. Relevant conservation objectives for the Wightlink proposal

Feature/ Criteria	Attribute	Target
SAC Feature Atlantic salt meadows	Distribution and extent of low, mid, upper and transitional high marsh communities	Distribution and extent of marsh communities should not deviate significantly from an established baseline, subject to natural change.
	Species composition of characteristic low, mid, upper and transitional high marsh communities	Presence and abundance of constant species of characteristic marsh communities should not deviate significantly from established baseline, subject to natural change.
SAC Feature *Salicornia* and other annuals colonising mud and sand	Common cordgrass (*Spartina anglica*) community	No increase in extent from an established baseline, subject to natural change.
	Distribution and extent	No change in distribution and extent of annual *Salicornia saltmarsh* communities from an established baseline, subject to natural change.
SAC Feature Intertidal mudflats and sandflats	Extent	No decrease in extent from an established baseline, subject to natural change
	Topography	Shore profile should not deviate significantly from an established baseline, subject to natural change.
SPA Feature Int. Imp. populations of regularly occurring Annex I species; and Int. Imp. waterfowl assemblage, including the internationally important regularly occurring migratory species	Disturbance	No significant reduction in numbers or displacement of birds from an established baseline, subject to natural change.
	Intertidal mudflats and sandflats	As above (for SAC Feature - Intertidal mudflats and sandflats)

Those objectives that are pertinent to this AA are presented in Table 2. These focus on the changes to the extent of intertidal mudflats and saltmarsh as well as the effect of disturbance on birds (as identified above). Other conservation objectives are excluded because they have been 'scoped out' in consultation with NE and they are not relevant to this proposal. For example, objectives that relate to aspects such as sediment character (organic content, PSA etc.) or nutrient enrichment (causing changes to macroalgal mat coverage) are excluded because the scheme is not expected to cause a detectable change to these parameters. Changes to intertidal character may, of course, occur as a consequence of any alterations to shoreline extent or topography (which are the subject of separate objectives) but not as a distinct impact pathway requiring separate consideration. As discussed above the issue of the impacts from disturbance on birds is not thought to be a major impact pathway and is one that can be readily mitigated, however, it does require further brief consideration here. This is in line with NE's advice which was to focus the study on the effects on habitat extent rather than habitat character.

4. Potential Impacts of the Shoreside Works (Noise Effects)

4.1 Introduction

As discussed, above, in the original consultation letter NE were concerned that if the new piles are constructed using percussive piling methods during the most sensitive time of year for overwintering birds they have the potential to cause disturbance to migratory birds. Their advice was that no percussive piling methods shall be used between 1 October and 31 March and that vibro-piling techniques would be acceptable during this period.

NE also suggested that the impact of underwater noise migratory fish species (as interest features of the New Forest and Lymington River SSSIs) required further consideration but further consultation with EA on this issue was appropriate. The Lymington River SSSI citation recognises that the river supports a largely unmodified fish fauna including bullheads (*Cottus gobio*) and lampreys (*Lampetra* spp.), which are of international importance listed on Annex II to the EC Habitats Directive, as well as brown trout (*Salmo trutta*). None of these fish, however, are a qualifying interest feature or sub-feature for any of the international designations that are adjacent to the proposal. Although not necessary for an AA under the Habitats Regulations, the potential impact of the proposed development on fish, namely lampreys and sea trout given that they are migratory and likely to pass the proposed works, have been considered here in response to concerns from NE.

4.2 Noise Caused by Piling

The only identified impact pathway that could affect the migratory passage of fish using the Lymington River is the generation of elevated levels of underwater noise by the pile driving equipment used during the construction phase of the proposed works. Vibropiling techniques will be used during the proposed works if they are pursued during winter months (see Section 7) but at other times impact/percussive piling is likely to be the preferred approach (A Mayhew, Mayhew Callum *pers comm.*).

As described in Section 2.3, new fender piles will be needed within the main berth. It is anticipated that a total of fifteen piles will be installed over a period of about two weeks. Two standby berths are to be modified, each comprising approximately twelve piles. The period estimated for pile installation on the standby berths is likely to be three weeks. The total estimated piling period is five weeks (although the two phases are not expected to occur concurrently) with the works being carried out within working hours 8.00 to 18.00 from Monday to Friday, unless the works overrun, in which case works may be carried out on a Saturday.

With respect to fish responses to noise, Hearing thresholds (HT) are the minimum sound pressure levels at which an organism can hear a sound. These can vary considerably in fish, with the ability to hear being dependent on the physiology of the species. There are no known measurements of HT for sea trout and lampreys. Lampreys have no swim-bladder and are therefore considered to be relatively insensitive to sound (Nedwell *et al.*, 2004). Sea trout, on the other hand, are considered to have a similar auditory system to Atlantic salmon, i.e. medium auditory sensitivity with an HT of 95dB reference to 1μPa at 1m.

Response thresholds (RT), i.e. the minimum sound pressure levels at which an organism exhibits a behavioural response, such as a change in direction or movement, are also species specific. Initial work on fish indicates that the majority show significant avoidance reactions at levels 90dB or more above HT (Nedwell *et al.*, 2003a, b). Salmon would therefore have an estimated RT of 185dB reference to 1μPa at 1m.

Transmission loss (TL) is the attenuation of sound as it propagates away from the source. This loss is a function of several factors, including ground geology, temperature gradients, water depth, currents, ambient noise, acoustic wavelength, and the reflective properties of the bottom and surface conditions. In this way, underwater sound propagation has a large amount of uncertainty. TL is generally predicted from geometric losses, which can be categorised into two geometric models: spherical and cylindrical spreading (State of Washington Department of Transport, 2006). However, Nedwell *et al.* (2003a) found that losses in level with range were mainly due to absorption for measurements of impact piling in Southampton Water, and therefore used an estimated TL rate of 0.15dB/m. The State of Washington Department of Transport (2006) consider Nedwell's TL rate to be another appropriate method of predicting sound propagation in marine environments.

Both the spherical and cylindrical geometric models and Nedwell's *et al.* (2003a) TL rate have been applied to the worst-case Source Level (SL) noise during the construction works (i.e. for impact piling) in order to estimate the maximum distance that would invoke a significant response in fish that are likely to be passing at that time i.e. medium and low auditory sensitive fish (namely sea trout and lamprey respectively). Figure 2 illustrates the predicted propagation of underwater noise from impact piling and the distances that medium and low auditory fish are likely to show a change in behaviour. According to the geometric models, a significant behavioural response will occur in medium auditory fish only within a few metres of the source and Nedwell's TL estimates a response to occur up to 60m. Low auditory fish are not expected to show any response to the impact piling.

The piles will be a combination of 'H' section piles at 368x338mm in size and tubular piles of 750mm in size (A Mayhew, Mayhew Callum *pers comm.*). The pile sizes for the Nedwell *et al.* (2003a) study were a combination of 508mm and 914mm diameter so the average noise created at the Lymington berth during the impact piling is likely to be of a similar order to those experienced in the Nedwell trials. Nedwell *et al.* (2003a) estimated the underwater source level (SL) for impact piling to be 194dB reference to 1μPa at 1m and this SL has been assumed for this noise assessment. Vibropiling generates lower noise levels, and studies on caged farmed brown trout reported no discernable behavioural reaction as close as 25m from the vibropiling (Nedwell *et al.*, 2003a).

Using the upper 60m value as a maximum area of effect, any sea trout or salmon that are using the river during the construction works would still have at least 40m of subtidal channel width available to pass the narrowing around the Lymington marina. Given this and the fact that as well as the temporary nature of the impacts (day time noise only over a five week period) these fish are not included as an interest feature within the Solent European Marine Site, noise levels that would be generated from the proposed construction activities are considered to be negligible.

5. Potential Impacts From Introduction of New Ferries

5.1 Introduction and Work Done for AA

This section of the AA represents the main area of concern because the impacts of the new larger vessels on the interest features of the Solent Maritime EMS has been identified as the impact pathway that is of greatest concern to NE and to interested parties that use the Lymington River. To address this issue, ABPmer have undertaken a detailed literature review, data analysis exercise and consultation process. The key elements of this exercise have been:

- Consultation and meetings with NE and EA to agree scope of the assessment (no formal response received from EA).
- Collation of existing datasets from NFDC and CCO to describe bathymetric changes in Lymington River and elsewhere in the western Solent.
- Obtaining historical bathymetric charts from Lymington Harbour Commissioners and then entering selected cross-sections from these into the GIS format for additional bathymetric analysis.
- Reviewing the findings from past studies with the following studies being the most important: - a navigational review (ELP, 2006); field monitoring to inform the LHC navigational risk assessment (BMT SeaTech, 2008), the environmental appraisal for the new ferries (Gifford, 2007a), the saltmarsh recession study (Gifford, 2007b), a review of the new tonnages for the Lymington/Yarmouth Ferry (HR Wallingford, 1991), an assessment of estuary

processes and maintenance dredging in Lymington Harbour (ABPmer, 2002) and a series of studies describing the physical characteristics of the area and the adjacent coast (e.g. HR Wallingford, 1991; Pontee, 2004; Ke and Collins, 1993, 2002; Gifford, 2007b; SCOPAC, 2004).

- Collation of all propulsion and ship wash modelling data from Voith (manufacturers of the propulsion units, VSPs) and Vienna Model Basin (2008).
- Calculation of drawdown and backflow speeds for a W Class vessel based on methods previously applied by HR Wallingford.
- Analysis of fetch distances and wave energies along the length of the river to understand the relative contributions of ship wash and natural wind energies including storm events to existing patterns of saltmarsh erosion.
- Consultation with BMT SeaTech about natural storm wave heights within the river.
- Calculation of the amount of tidal water that floods into and out of the site on an average tide (referred to as the tidal prism) and of the changes to the tidal prism that have occurred since the two marinas were dredged in the early 1970s. This was undertaken to understand the relative influence of these developments on the functioning of the system (and to inform a conceptual model of the system).
- Consultation with the Lymington Harbour Commissioners to understand their position and source data and information.
- Consultation with the Lymington River Association to understand their concerns and source additional data in their possession.
- Consultation with Black and Veatch to obtain any additional information of the baseline characteristics of the Lymington River and agree the impacts of the proposed breakwaters (for the purposes of the in-combination assessment).

The results of this work are reviewed in the remainder of this section. Then in Section 6 mitigation measures are also described where these are needed to minimise potential adverse impacts and as far as possible provide assurance to NE about the conclusion to this assessment. Chapter 7 then reviews the in-combination effects of this development with the proposed Lymington breakwater development and finally concluding advice on the impacts of the project on the integrity of the European Marine Site are presented (although it is recognised that this decision about the effects on integrity rests with the Competent Authority and is subject to the advice of NE).

5.2 Regional and Historical Context (Conceptual Model)

The first, and perhaps the most important thing to note as part of this assessment, is that the environment conditions around Lymington River and along the adjacent coast are well understood, as are the historical changes that have taken place over the last century or more. This is evidenced in the findings from several studies, from both the unpublished and published literature, that review the regional and local conditions. Details of these studies are presented in the previous section. Using these past studies as a basis, it is possible to provide a good conceptual overview of the physical conditions in and around the Lymington River.

The principal sources of sediment supply to estuaries in the western Solent has in the past been the erosion of cliffs in Christchurch Bay but the installation of coastal defences along this stretch of coastline is believed to have reduced the amount delivered by this route by 41% (136,000m^3/year to 80,000m^3/year) after 1932 (Pontee, 2004). Analysis of sediments in the area of Lymington and Beaulieu Rivers has found that the sediments are largely of marine origin, transported by tidal currents. Fluvial sediment supplies are also very low into the western Solent, due to small catchment areas, limited run-off and sluicing of most freshwater inputs.

The positions of Hurst Spit and the Isle of Wight modify waves entering the western Solent substantially, and the wave climate is generally of low energy. However, strong winds from the south-east, with the increased fetch distance and deeper water of the eastern Solent, provide extreme wave heights that dominate the open coast in the western Solent. The intertidal foreshore in this area is subject to erosion and entrainment of fine sediment due to exposure to incident waves. Most of the entrained sediment is lost to the western Solent as exported suspended load (SCOPAC, 2004). It has been noted that storms create most entrainment of sediment which partially gives rise to the requirement for maintenance dredging within the Lymington River. The highest amounts of maintenance dredging in any year are required after winter storms, which cause the highest rates of marsh erosion and create the highest rates of siltation within the estuary (Pontee, 2004).

In the Solent, the tidal curve is subject to a double high water, as a result of the stand in water levels on the flood tide, which results in estuaries in the western Solent having an ebb tide of a shorter duration and higher velocities than the flood tide (Pontee, 2004). This means that the estuaries are ebb dominant with respect to flows speeds and this contributes to a loss of some of the sediment that is entrained by storm wave action to the Solent. However, because there is also a large slack high water in this system it provides a comparatively long period of time over which sediment can settle out at high water (as compared with typical sinusoidal tides found in most tidal river systems). Thus, the upper section of the Lymington River (including especially the stiller waters of the marinas and mooring areas upstream of the wave screens) is clearly a sink for sediments imported from the adjacent marshes and coastal areas. Therefore these areas are subject to accretion and require regular maintenance dredging as discussed further in Section 5.3.2).

Saltmarshes in the western Solent are generally a relatively recent feature originating from the rapid spread of *Spartina* spp., starting about 125 years ago. *Spartina* spread at the expense of open intertidal mudflats and areas of eelgrass, and reached its maximum extent around 1925. The *Spartina* saltmarshes have been receding ever since due to a number of factors and in particular (summarized in Pontee, 2004):

- A significant change in coastal morphology leading to a change in wave energy (Ke & Collins, 1993).
- An overall sediment deficit within the western Solent (Lawn, 2001).
- The evolutionary tendency of *Spartina* marshes (Lawn, 2001).

Other factors such as decrease in sediment supply (NFDC, 2002) and coastal squeeze caused by relative sea level rise have also contributed to a reduction in marsh extent.

As discussed in greater detail later, historical maps show that coastal erosion has been prevalent since the late 18th century and from 1781 to present this has led to the retreat of the low water mark. Historical photographs for the period 1921 to 1994 shows that the marshes have been retreating at rates of 0.3 to 1m/year in sheltered areas but at between 2 and 6m/year in areas that are more exposed to wave action. Lateral erosion is observed to occur in response to wave action and to be greater during winter periods (Pontee, 2004). For example, average saltmarsh retreat rates at Keyhaven have been measured at 1 to 11m/year within creek systems (Pontee, 2004).

Between 1959 and 1979 the rate of erosion of the saltmarsh edge has been measured at 80 to 100m in the West Solent, representing an average horizontal erosion rate of 4 to 5m/yr, with the erosion occurring mainly on the open coast areas that face the dominant wind and wave direction, towards the south west (Ke and Collins, 2002). This observed rate of erosion agrees with earlier studies, which found a landward retreat of the low water mark of up to 500m from 1820 to 1961 in the Keyhaven to Pennington area (Hooke and Riley, 1992) and from 1781 a landward shift of 500 to 600m (Ke and Collins, 2002). There has also been erosion of the saltmarsh at the Lymington River mouth; before the 1940s the marsh could be divided into two distinct areas: high marsh and lower marsh. The lower marshes evident in a photograph from 1924 had disappeared by 1959. Also present was a spit on the eastern side of the river mouth, which has since disappeared although it is unclear when this occurred.

The mudflats in the western Solent adjacent to the marshes are also eroding and their rate of erosion is increasing with time (Ke and Collins 1993) from 4m/year between 1907 and 1975 to 7m/year from 1975 to 1993. Thus the Lymington-Keyhaven coastline has reported to be losing 154,000m^3/year of sediment from all intertidal areas, while the volumes from the marsh alone are 38,000m^3/year. However, the marsh surfaces are accreting at 2-5mm/year which appears to be sufficient to keep pace with sea level rise (Bradbury, 1995).

5.3 Within-Estuary Conditions and Processes

5.3.1 General Estuary Characteristics

The Lymington River is an approximately 4km long tidally-dominated system with limited riverine/fluvial inputs of water and sediment. The double high water results in the system (and others on the Solent) having a short ebb period and thus stronger flows than on the flood tide. For example, in Horn Reach the peak ebb speeds of 0.35m/s were recorded compared to 0.14m/s on the flood (HR Wallingford, 1991), although these measurements predate a capital dredge in the area (1998/99) which will have resulted in a minor reduction in flow speeds. Very little difference in flow between those measured at the surface and those at depth were identified (HR Wallingford, 1991). More recent data collected for the navigation risk assessment (BMT SeaTech Ltd., 2008) has shown that, during the January measurement period (when a spring tide of 2.63m range was experienced), the maximum flow in the channel near the Pylewell Boom navigation post was 1.1 knots (0.57m/s), while that measured in Horn Reach on a similar tide was 0.33 knots (0.17m/s).

As noted above, sediment supply to the estuary is primarily of marine origin and the natural supply has reduced significantly since the 1930's following the installation of coastal defences in Christchurch Bay (Pontee, 2004).

The estuary is characterised by extensive saltmarshes, particularly at its mouth, although the processes of *Spartina* die-back and lateral erosion of marshes observed along the open coast are also evident within the estuary.

Historically the estuary has been sheltered from winds from most directions, although there is a long southerly fetch from the Isle of Wight. For this reason wave screens have been installed in the Lymington River to protect the upstream berths. Significant loss of saltmarsh at the mouth of the estuary has increased the exposure to southerly winds.

The estuary has also been substantially influenced by historic development and anthropogenic changes and further details about these are presented in the following section (Section 5.3.2). Further details about the sediment sources and historical morphological changes in the estuary are then presented in Section 5.3.3 and a review of the changes to the navigation channel is presented in Section 5.3.4.

5.3.2 Man-Made Changes within Lymington Harbour

Lymington town has a long history of port/sailing activities with the principal historical changes being the upper estuary road causeway (1731), the reclamation of saltings (1833) and the reclamation of the ferry terminal (1884). More recently (since the 1960s) the areas upstream of the wave screens (installed in 1990) at the entrance to Lymington Harbour, the channel and intertidal areas have been subject to considerable anthropogenic change. Table 3 presents a summary of the developments and dredging that has taken place within Lymington Harbour. The main changes were the deepening works to create the two marinas in the late 60s early 70s and the subsequent maintenance dredge and capital dredge commitments to maintain these berths. The most recent capital dredging was undertaken in 2006 in the area outside the Yacht Haven in order to provide marina berths and replace moorings that were lost in the outer estuary due to the increased exposure that is being experienced there.

Maintenance dredging on the river takes place annually with different areas maintained over a 5-year cycle to preserve appropriate depths in the marinas, the mooring areas either side of the navigation channel and the navigable channel upstream of the ferry terminal. All maintenance dredging occurs upstream of the crab pot piles which are located just south of the wave screen (Ryan Willegers, LCH *pers. comm.*). Over the 75 years from 1926 to 2001 the total maintenance dredge was around 803,200m^3 (or 10,600m^3/year) (Pontee 2004). There has though been an increase in recent years and the total volumes currently dredged from Lymington River are approximately 30,000m^3 per annum. However, the volumes are predicted to increase in successive years and the Harbour is experiencing a general trend of accumulation (Ryan Willegers, LHC *pers. comm.*).

Prior to 1998/99 the margins of the navigation channel in Horn Reach were maintained (east and west side of the channel) on an 'as required' basis as part of the routine maintenance dredging of the river. The navigation channel itself has not required maintenance dredging. The margins of the channel support moorings for leisure craft. In 1998/9, following a safety review, the navigation channel was widened through a capital dredge of a 525m strip on the eastern edge of the navigation channel. The area dredged was below the MLWS mark. In addition that year an element of routine maintenance dredging occurred in Horn Reach. The FEPA consent was for capital and maintenance dredging and in total 23,057m^3 were dredged that year. Since 1998/9 Horn Reach has been maintained as part of the 5 year rolling programme on the river (Ryan Willegers, LCH, *pers. comm.*).

All those areas that have been subject to capital dredging of the intertidal area are of particular importance to this report, as these changes to the intertidal area will have caused increases to the tidal prism and therefore the tidal currents (see next section) particularly in the main channel.

In addition to the historical developments and capital and maintenance dredging, the estuary is subject to a high level of vessel activity. The 'C' class ferries have been in operation since 1973 and are considered to contribute to the maintenance of navigable depth in the main navigation channel (which does not require maintenance dredging). Operation of the ferries also affects the hydrodynamic regime in various ways (ship generated waves, ship induced drawdown, ship return currents (backflow), vessel slipstream (thruster flow velocities)) (HR Wallingford, 1991). The 'C' class ferries are known to have caused some scour within both the berth areas and at the terminal, due in part to the inability to declutch the engines from the thrusters, during waiting times. The relative significance of ferry hydrodynamic forces are discussed in more detail in Section 5.4.

Other vessels will contribute to ship-generated waves, but the smaller size of recreational vessels generally means that issues of drawdown, return currents and thruster/propeller flows are more minor.

Table 3. History of development and capital dredging in Lymington Harbour

Year	Action	Location	Notes
1972	Capital dredge	Yacht Haven	Approx area. 46,500m², Volume 230,000m³
1972	Capital dredge	Berthon Marina	Approx area. 73,000m²
1973	Introduction of 'C' class ferries	Ferry Terminal	
1998/99	Capital and Maintenance dredge	East side of Horn Reach - channel widening in response to a navigational safety review	Volume 23,057m³
1990	Wave Screen	Harpers Post	
2005/06	Capital dredge	Dan Bran (Outside Yacht Haven) - to replace moorings that were lost in the outer reaches due to erosion of the saltmarsh and the increased exposure.	Volume 46,214m³
On-going	Maintenance dredging	Berthon Marina; Yacht Haven; Dan Bran, East and West side of Horn Reach; Fortuna, Navigation Channel and mooring areas either side of ferry terminal.	Dredging carried out on a five-yearly cycle, as required. Approx 30,000m³ removed annually.

Sources: 1972 volume from Pontee (2004) (areas calculated by ABPmer);
1998/99 & 2005/06: Ryan Willegers, LCH (*pers. comm.*);
On-going: Ryan Willegers, LCH (*pers. comm.*), ELP (2006)

5.3.3 Morphological Change in the Estuary

For this study a full review of the character and ecological composition on the designated intertidal habitats is not presented in detail. This is because such information is available from a range of other studies (e.g. Gifford, 2007a, 2007b; HR Wallingford, 1991) and NE have requested that the focus of the assessment is on the quantitative change (as opposed to qualitative/character changes) to the extent of intertidal habitats that could occur from the introduction of the new vessels (see Section 3). Given the strong linkages between the subtidal and intertidal, the analysis necessarily also considers morphological changes within the channel because changes in the subtidal will strongly influence the morphology of intertidal areas.

Changes to the Navigation Channel

To investigate the changes that have taken place over time in this system the following section review changes to the alignment of the Mean Low Water (MLW) and the profile and depth of the channel using available information.

Mapping of Mean Low Water (MLW) 1870, 1907, 1975, 1994, 2005 and 2006
The stability of the main estuary channel downstream of the wave breaks has been assessed through the mapping of the location of MLW from 1870 to 2006. Using data provided by New Forest District Council (Andrew Colenutt, NFDC *pers. comm.*) the

change in the position of MLW is shown in Figure 3, for 1870, 1907, 1975, 1994 and 2005 with recent additional data for 2006, as provided by Pro Surveys also included. Additional limited data for 1994 has also been provided by LHC. The sources of the data are shown in Table 4.

Table 4. Mapped Mean Low Water (MLW) data sources

Date	Data Source (Provided By)
1866/1870	OS 2nd edition 6" maps, for study coastline (Hampshire County Council)
1907	OS 3rd edition 6" maps, for study coastline, except sheet 65NE (Hampshire County Council Records Office)
1975	1:10,000 OS Raster tiles for study area (Environment Agency)
1994	Bathymetric chart provided by LHC 1:1250 (CPLYM002)
2005	Contour produced from DGM of LIDAR data (NFDC / Channel Coastal Observatory, Regional Monitoring Programme)
2006	Bathymetric Charts provided by LHC (PRO Surveys Ltd., 2006)

Due to the difficulty in identifying the exact location of the navigation channel from this data, the position of MLW has been used as an indicator of the changes that have occurred. The mapped position of MLW data is derived from several different types of data (Table 4); historic OS mapping, charted bathymetric survey data and LIDAR. For each map there are expected accuracies that can be assigned to the data. The expected planimetric positional accuracy (x,y position) is ±5m for a 6" (1:10560) map (1907) (Landmark Solutions, *pers. comm.*), and ±3.5m for a 1:10,000 map (Lee and Clark, 2002). In addition, there are differences in the way that low water has been identified and measured on OS maps (Table 5). The error associated with extraction of data from bathymetric charts is estimated to range between 1-10m. The magnitude of the error in the position of MLW that these factors may have caused is not quantifiable. In addition, vertical axis accuracy of the LIDAR data is known to be approximately ± 0.2m. Each of these expected accuracies, on a relatively flat intertidal area, results in a relatively large possible error band in the horizontal position of MLW, which for the LIDAR alone is 20 to 75m.

Table 5. Changes in Low Water Mark definitions in OS mapping

Date	Data Source (Provided By)
Pre-August 1935	Low water mark of ordinary tides
August 1935 – March 1965	Low water mark of medium tides
March 1965 to present	Mean low water

Figure 3 shows that MLW has moved landward over time, both within the channel and also on the open coast, with the highest rates observed at the mouth of the estuary. This is consistent with the evidence of historic aerial photographs (Figures 10 and 11) that indicate extensive *Spartina* swards in relatively close proximity to the main navigation channel in the early 1900's, but with a subsequent landward recession during the 20th century (Pontee, 2004).

Based on the stated position of MLW for 1975, the data would suggest that there may have been an acceleration in the landward movement of MLW between 1975 and 1994. However, some uncertainty remains concerning the reliability of the 1975 data set as to whether it represents the position of MLW in 1975 or from an earlier date or whether it represents another datum (MLWS). Caution therefore needs to be applied in inferring relative rates of change over time based on the 1975 data. Since 1994, the position of MLW appears to have remained relatively stable with little if any apparent landward movement, except possibly at the mouth of the estuary. This is consistent with NFDC findings that the position of MLW has not varied significantly between their bathymetric surveys of 2001, 2003, 2005 and 2007 (A Colenutt, *pers. comm.*.).

Within the estuary between the wave screens and the estuary mouth from the early 1900's to date, an approximate landward movement of MLW of between 50 to 100m has been observed on both the east and west banks, with the greatest rates of change in the vicinity of Enticott and Cage Boom. These areas have also shown the greatest extent of saltmarsh recession within the estuary (see Figures 10 and 11).

Figure 3 also shows that there is more erosion on the outside of the bend above Pylewell and considerably less erosion on the inside of the bend, at Cocked Hat (Cross-section 2), within Short Reach (see Figure 4 for the navigational marker posts within the river that correspond to these cross-section locations). This can also be seen also in the NFDC bathymetric cross-sectional analysis which is discussed later and which indicates that there is a possible cyclic pattern in the form of a channel meander at this location (see below). This might suggest that the estuary meander bend is increasing in size, and the channel is continuing to move eastwards and southwards.

Chart data - 1964, 1988, 1993, 1999 and 2006

The above review of previous reported analyses give rise to some inconsistencies and anomalies which are difficult to see visually and give rise to uncertainties. Part of the reason is the widely different sources of datasets and the differing aims of the studies reviewed. However to understand the channel dynamics more thoroughly, this sections reviews additional data on the subtidal channel dynamics using bathymetric data and past studies from NFDC and historic charts obtained from LHC.

NFDC have analysed a series of cross-sections taken from digital terrain models created from hydrographic survey data, using data from 1993, 1995, 1999 and 2001. The locations of the cross-sections (1, 2 and 3) are shown in Figure 5. The results of the analysis show that the channel has not changed position and the depth has been relatively constant over this time period. The width at MLW has increased by up to 78m over the same time period (Cross-section 2) and from the three cross-sections available the minimum recession of the position of MLW over the eight year period is 35m (Cross-section 1). The large increase in width at Cross-section 2 corresponds with the view presented above that the natural processes are having a major influence here through a combination of the meander increasing channel width to the east and increased exposure accelerating saltmarsh retreat. Further analysis by Black & Veatch (2007) revealed a series of anomalies in the data, including an increase in level in two areas which is not supported by anecdotal evidence. However, it must be emphasised that, the analysis carried out by NFDC was aimed at qualitatively analysing changes to the position and depth of the navigation channel, rather than MLW or the intertidal morphology (A. Colenutt, NFDC *pers. comm.*).

In order to seek clarification on the changes to the channel configuration before and during the period of operation of the C Class ferries a slightly extended time series of the changes to the channel has been carried out based on chart data held by LHC from the years 1964, 1988, 1993, 1999 and 2006, using the locations of navigation posts as reference points (although limited data was available for 1964). It was not possible to use the exact cross-sections presented in Figure 5, however, corresponding locations were chosen and are shown in Figure 6.

The aim of the analysis was to assess any changes in width and depth of the subtidal channel. Figures 7 to 9 demonstrate the variation in each profile over time. The cross-sections show a general expansion of the channel over time, with a widening and slight deepening of less than 0.5m, especially in the upper reaches. An analysis of changes in Horn Reach between 1981 and 1991 also identified a minor deepening of the channel there (HR Wallingford, 1991).

There seems to be little change in the channel shape, except at Cocked Hat Post where there has been a notable widening of the channel as per the analysis presented in the previous section. Considering these outputs in more detail shows changes in profile which are possibly consistent with meander migration noted in the earlier studies. It also indicates a possible cyclic pattern to the channel movements. The 'thalweg' and the subtidal banks moved of the order of 20m towards the south west between 1964 and 1988 and then little change (by comparison) occurred until 1999. Thereafter, the channel has moved back north east to its approximate position in the 1960s although of the order of 0.5m deeper and about 10m wider.

Careful interpretation of the other profiles, particularly Bag of Halfpence Post and Post 7 show similar trends, with a possible 'turning point' in the direction of channel movement around the mid 1990's. At Bag of Halfpence Post the pattern of movement is in the opposite direction to Cocked Hat Post and Post 7. Again, this would be consistent with the natural meandering tendency for a channel.

At Harpers Post channel has widened between 1988-2006 by 10-15m consistently on the south side but 'oscillatory' over the period to the north. At Seymour Post the cross-sectional area of the channel has remained relatively stable but with a general movement of approximately 10m to the east with greatest rates of change in the late 1980s/early 1990s (in the period of assessment). It is interesting to note that deepening has been greatest at this section of the river again with the most significant changes in the late 1980s/early 1990s.

At the section between Posts 5 and 6 (Figure 9) the channel by comparison has been relatively stable, although some deepening across the whole width of the profile to the MLW is evident. It is recognised however, that this analysis will be subject to the same errors as the NFDC results summarised above.

Changes to intertidal areas

For this assessment, the change in the intertidal area between Mean Low Water (MLW) and Mean High Water (MHW) has been measured for 1907 and 2007 using MLW lines provided by NFDC in combination with aerial photography and navigation charts, within the broader Lymington River and Harbour area (from the tidal limit to the estuary mouth). The analysis assumes that MHW has not changed due to the presence of defences and high ground. The analysis indicates that the total intertidal area has decreased since 1907 to the present day from around 235ha to approximately 149ha in 2007. The dredging of the Berthon and Yacht Haven marinas in the early 1970s account for around 12ha of this change. The data indicate that since at least 1994, there has been relatively little change in the position of MLW and thus that the extent of intertidal area has remained fairly stable.

Saltmarsh

Recent surveys have measured a maximum erosion rate of the marsh edge at the mouth of Lymington River of 8m per year, in isolated locations (Bradbury, 1995). The same report analysed the shape of the intertidal profile on the open coast in the Lymington area between 1992 and 1994; the upper intertidal zone is characterised by steep saltmarsh cliffs and a strong concave upward profile. The cliffs vary in height but are typically 0.7 to 1.5m high. The cliffing makes the saltmarsh edge susceptible to erosion by wave activity. There has also been erosion of the saltmarsh at the Lymington River mouth; before the 1940s the marsh could be divided into two distinct areas: high marsh and lower marsh. The lower marshes evident in a photograph from 1924 had disappeared by 1959. Also present was a spit on the eastern side of the river mouth, which has since disappeared although it is unclear when this occurred.

The marsh surface varies in elevation by only about 0.4m. Whilst the cross-section profiles have changed due to erosion of the marsh edges, the profile geometry stayed fairly constant with parallel recession of the profiles. Only occasionally did the profiles become flatter. In contrast to the saltmarsh erosion, there has been a continual process of sediment accumulation occurring on the saltmarsh surface over time, occurring at a rate of 2-5mm per year, which has been sufficient to keep pace with past sea level rise (Bradbury, 1995).

A recent study carried out by the Channel Coast Observatory (CCO) (2008) has analysed changes to saltmarsh throughout the Solent using aerial photography. The analysis for Lymington River shows a 63% saltmarsh loss between 1946 and 2001

(Figure 10), which equates to a 1.1% loss per annum. Most of the erosion has occurred on the open coast edges of the saltmarsh, although there is also notable recession within the estuary, particularly around Enticott and Cage Boom where the marsh has retreated by 100m or more. There is also a considerable loss of saltmarsh due to internal dissection (Colenutt, 2002; Cope *et al.*, 2008).

In comparison, the same analysis has been completed for Beaulieu River using aerial photography between 1954 and 2001, which found that between these dates there has been erosion of the open coast saltmarsh, but there has also been some erosion of the saltmarsh edge within the river. Overall, between 1954 and 2001, there has been 54% loss of saltmarsh, a 1.1% loss per annum; the same rate as has been found at Lymington. Equally, the corresponding increase in rate after 1971 was also found in Beaulieu River (Figure 11) (Cope *et al.*, 2008).

Current predictions state that 99% of the existing saltmarsh area will be lost from Lymington Estuary by 2040, therefore resulting in an increase in the area of mudflat (Black & Veatch, 2007).

Intertidal mudflats
Within the estuary, the spatial extent of intertidal mudflat will reflect a balance between recession and dissection of the saltmarshes (which create new areas of mudflat) and landward migration of MLW (which will reduce the amount of mudflat). Based on visual comparison of Figures 3 and 10a, it is likely that there has been an overall gain in intertidal mudflat since 1946. The movements of MLW along the main channel would appear to have broadly followed the recession of the saltmarsh, but internal dissection of the marsh will have created additional mudflat areas resulting in a net overall gain of mudflat over that period.

5.3.4 Causes of Morphological Change

Overall between 1964 and 2006 the cross-sections indicate the main subtidal channel has both widened and deepened at different rates. Generally widening appears to be greatest when depth changes are least and vice versa. There is also some evidence of a natural meandering tendency. Within the estuary, the position of MLW has moved landward by between 50 to 100m on both the east and west banks, with the greatest changes occurring at Enticott and Cage Boom. At the mouth of the estuary , the position of MLW has moved landward by up to 500m since the early 1900's. There has been a significant reduction in the spatial extent and density of saltmarsh (*Spartina*) both within the estuary and along the open coast with a consequent lowering of intertidal areas in these areas.

A range of factors both natural and anthropogenic are likely to have contributed to the observed changes in the morphology of the estuary, including (in no particular order):

- An estimated 15% increase in the tidal prism as a result of the capital dredging that took place for the creation of the Yacht Haven and Berthon marinas in the early 1970s. This would have increased the flows through the main channel, particularly below mid-tide level, and therefore increased the likelihood of widening and deepening of the channel;
- The possible natural meandering tendency of the estuary which may have contributed to changes in channel alignment at Cocked Hat and Bag of Halfpence;
- Hydrodynamic changes associated with ferry and other vessel movements in the estuary contributing to morphological change, particularly in subtidal and low intertidal areas;
- Increased wind-wave penetration into the estuary resulting in erosion of intertidal mudflat and saltmarsh;
- Changes in long term sediment supply/sediment balance resulting in a reduction in availability of sediment to the estuary and marshes;
- *Spartina* die-back, resulting in increased vulnerability of trapped sediment to erosion;
- Cliffing of *Spartina* marshes at the mouth of the estuary increasing their vulnerability to lateral erosion.

It is difficult to quantify the relative contribution of the different factors to overall morphological change. Within the estuary, the die-back of *Spartina* and subsequent erosion of trapped sediment has clearly affected the morphology of intertidal areas. Long-term changes in sediment supply as a result of the construction of coastal defences in Christchurch Harbour in the 1930's may have contributed marsh decline. While in some sheltered estuaries, die-back of *Spartina* has not resulted in subsequent erosion of trapped sediment (e.g. Western Yar), the Lymington Estuary is more exposed to the prevailing winds such that wind waves are able to erode intertidal areas during storm conditions (see Appendix A for an assessment of wind waves in the estuary). The increases in tidal prism will also have contributed to some of the changes in the subtidal channel alongside natural changes such as the possible meander. The possible contribution to overall change from ferries is explored in more detail in Section 5.4.

Outside of the estuary on the open coast, the main causative factors for morphological change are generally considered to be:

- A significant change in coastal morphology leading to a change in wave energy (Ke & Collins, 1993).
- An overall sediment deficit within the western Solent (Lawn, 2001).
- The evolutionary tendency of *Spartina* marshes (Lawn, 2001).

5.4 Effects of Existing and Future Ferries

5.4.1 Introduction

In order to understand the potential effects of the new ferries that are proposed to be introduced to this system, the following sections consider the interaction that the existing C class ferries have and the expected differences that will occur with the introduction of the new W class ferries. The main changes and impacts associated with the existing and future ferries have been identified as:

- Ship generated waves (ship wash) causing increased erosion on intertidal areas;
- Ship induced drawdown causing erosion on lower intertidal areas;
- Ship return currents (backflow) causing erosion to the bed of the navigation channel;
- Vessel slipstream (thrusters generated flows) causing erosion to channel banks;
- Effects of ferries on sediment supply/sediment budget..

5.4.2 Ship Generated Waves

Limited information on ship waves generated by the existing 'C' class ferries is available from BMT Seatech (2008). Measurements in January 2008 at two locations within the estuary (Pylewell Boom & Enticott) recorded maximum wave heights of 0.1m and generally below 0.05m at speeds of up to 6 knots. In addition to the measured data, wave height predictions are available from the following studies:

- Tank measurements of bow and stern wave heights (BMT Seatech, 2008) which predicted maximum wave heights of 0.06m for 'C' class vessels and 0.1m for 'W class vessels (at operational draft of 2.1m) at 6 knots (see Figures 12 and 13);
- CFD predictions of bow and stern wave heights (at 2.8 and 12.8m from the centre line) which predicted wave heights for 'W' class ferries of around 0.15m (bow) and 0.1m (stern) at 6 knots (for an operational draft of 2.3m compared to proposed operational draft of 2.1m) (Voith 2008);
- ABPmer calculations of ship wave height using a method described by Verhey & Bogaerts (1989) (see Appendix A) which indicated ship waves between 9-23cm for 'C' class vessels and 8-20cm for 'W' class vessels.

The available information suggests that ship waves for the 'C' class and 'W' class ferries are likely to be of similar magnitude although the size of the ship waves is considerably influenced by vessel speed, with larger waves produced at greater speeds.

Currently, the ferries operate to the speed limits within the Harbour of 6 knots below Harper's Post and 4 knots north of Harper's Post. However, it is recognised that in the past ferries have operated at up to 8 knots below Harper's Post, and this was recorded by LHC in 2007, once AIS was installed both on the ferries and at LHC (Ryan Willegers & Colin Freeman, LHC *pers. comm.*). Following the introduction of AIS in April 2007 there has been a trend of speed reduction to the point where there is now good adherence to the 6 knot limit (Ryan Willegers LHC *pers. comm.*).

To set the ship waves from ferries in context, an analysis has been carried out to describe the relative energies acting on the saltmarsh edge and the intertidal within Lymington River produced from the natural background wind-wave climate and ferry-generated waves. The methodology uses the wind records from Lee-on-Solent (for which location wind frequency analysis data is available) from 1984 to 1997 to calculate the wind wave energies for several points within Lymington River, based on the available fetch distance. The methodology and results are explained in Appendix A.

The assessment uses the fetch length at mid-tide level for various points within the estuary to calculate the energy reaching a given point (Figure 14), as it is at this stage of the tide when the wave action, both natural and arising from the ferries, acts on the intertidal areas. The proportion of wave energies resulting from the existing ferries at operating speeds of 6 and 8 knots is compared with that from wind waves; and also with the predicted proportion of wave energies from the new 'W' class at the 6 knots speed limit.

The results presented in Table 6 show the relative energy levels generated from wind and ferry waves, at each of the positions shown in Figure 14. Locations 1 to 5 are on the eastern side of the channel, 6 to 11 are on the western side and 12 to 16 are in mid-channel. The results show that the relative contribution of ship waves to total wave energy varies significantly depending on vessel speed. At 6 knots, 'C' class and 'W' class ferries both contribute less than 10% of the total annual wave energy at any location. The ferries contribute a relatively greater proportion (by a factor of 2 to 4) of total annual wave energy to the western shore (which is protected from the prevailing winds) compared to the more exposed easterly shore.

It is important to note that attenuation will reduce the wave height and hence energy on reaching the intertidal locations from both sources. This assessment method does not take into account the changing water level in terms of the water depth and the varying fetch lengths as a result and therefore only gives an order of magnitude of the relative effect of the natural forces and the ferry generated forces for the existing conditions. However, the use of mid-tide level gives an indication of these relative magnitudes at the level of the intertidal mudflat.

Table 6. Relative energies from wind and ship waves

Location	'C' Class Ferry at 8 Knots		'W' Class Ferry at 6 Knots		'C' Class Ferry at 6 Knots	
	% Wind Energy	% Ferry Energy	% Wind Energy	% Ferry Energy	% Wind Energy	% Ferry Energy
1	87.3	12.7	98.9	1.1	97.6	2.5
2	91.6	8.4	99.3	0.7	98.4	1.6
3	95.8	4.2	99.7	0.3	98.6	1.4
4	94.1	5.9	99.5	0.5	98.1	1.9
5	97.8	2.2	99.8	0.2	99.5	0.5
6	93.4	6.6	99.5	0.5	97.9	2.1
7	88.9	11.1	99.0	1.0	97.5	2.5
8	78.7	21.3	97.9	2.1	94.9	5.1
9	66.7	33.3	95.6	4.4	95.1	4.9
10	73.6	26.4	97.3	2.7	96.3	3.7
11	68.4	31.6	96.5	3.5	92.7	7.4
12	70.9	29.1	96.9	3.1	93.6	6.4
13	76.2	23.8	97.6	2.4	94.4	5.6
14	79.5	20.5	98.0	2.0	95.7	4.3
15	77.8	22.2	97.8	2.2	96.2	3.8
16	86.4	13.6	98.8	1.2	96.1	3.9
Average	**82.9**	**17.1**	**98.3**	**1.7**	**96.4**	**3.6**

The continued erosion of intertidal areas at the mouth of the estuary will result in increases in wind wave energy within the estuary over time.

During the course of this assessment, the comparative effects of natural wave heights against the wave heights from the wash of the C class vessels were assessed over a 2 day period in January 2008 (BMT Seatech, 2008). It was found that with reasonably high winds from a north of west direction, where the fetch is relatively short, the naturally produced waves were in general higher (250mm when wind was strongest) than those produced by ferries and other boats (although one fishing vessel produced a large free wave). It was observed that as water levels fell and the wind eased, natural wave heights were reduced to 70-100mm.

The recreational boat use within Lymington River has increased in recent years, with approximately 1200 marina berths and 700 boat moorings. There are also between 12 and 15 commercial fishing boats based in Lymington Harbour. There are also a considerable number of visiting and touring boats, especially during the summer season. A 1993 census of the boat traffic observed about 75,000 movements of which 50,000 took place during July, August and September (LHC, *pers. comm.*). A census undertaken in 1998 indicated that on average there are 1000 boat movements in the river each day in August and 85 movements per day in February. The results of the latter census would suggest that boat traffic during the summer months has increased from the 1993 survey. Both the above censuses include the ferry traffic movements, which number 22,250 per year.

Recreational and other commercial boat traffic within the river may contribute to any erosion of the intertidal through wash waves, associated currents and to the subtidal through grounding events. Although the Wightlink ferries are restricted to the LHC speed limits by their AIS recorders, other Harbour users are not monitored in the same way. This is relevant when considering the likely causes of the existing erosion. Whilst the blockage from individual boats is considerably smaller than for the ferries, the power boats can travel faster and at higher states of the tide potentially outside the navigation channel. Anecdotal evidence indicates that vessel wash from other vessels can at times be greater than the ferries (HR Wallingford, 1991). As the size of the vessel-induced waves is largely a function of speed it is possible that some of the erosion reported is due to this source. It is not possible to accurately quantify the impact on the intertidal, but it is important to acknowledge that there are a large number of other vessel movements within the river and Harbour. This potential effect would also have increased due to the construction of the large marinas in the early 1970s, compared to earlier years.

5.4.3 Ship Induced Drawdown

Around low water, ferries transiting through the channel may occupy a significant proportion of the overall cross-section (see Figure 15). The wetted cross-section of the new 'W' class ferries is approximately 20% greater than for the 'C' class ferries.

The displacement of a relatively high proportion of water in the cross-section can create relatively rapid flows off the vessel and onto the adjacent intertidal areas. This effect is known as drawdown. The extent of drawdown is primarily a function of:

- The blockage ratio (ration of vessel wetted cross-section to channel cross-section) – the higher the blockage ratio, the greater the potential drawdown;
- Vessel speed;
- Proximity of vessel to intertidal areas – the closer the vessel is to the bank, the greater the potential drawdown on the adjacent intertidal area;
- Length of vessel – the longer the vessel, the smaller the drawdown effect .

Depending on the extent of the drawdown and the associated flow speeds over the intertidal, these forces provide a potential mechanism for causing resuspension of sediment from the surface of the affected mudflat, potentially causing erosion. For the purposes of this assessment, existing information on intertidal drawdown in the estuary is available from a number of sources as follows:

- In 1991 HR Wallingford measured intertidal drawdown in Horn Reach for the existing 'C' class ferries. This study recorded a vertical change in water levels of 0.2m with the water being drawn down over a distance of 10m. The associated velocities were calculated at between 0.5 to 1m/s.

- HR Wallingford (1991) also calculated theoretical changes in water levels of 0.2 to 0.3m for a vessel travelling at 5 knots in Horn Reach with a blockage ratio of 0.17 based on the method of PIANC (1987).
- BMT SeaTech Ltd (2008) measured drawdown at Pylewell Boom and Enticott over a falling tide in January 2008 for 'C' Class ferries travelling at up to 6 knots. Towards low water, a drawdown of 0.14m was recorded at Pylewell and 0.17m at Enticott. Drawdown at other states of tide was much smaller.
- CFD modelling of drawdown has been undertaken by Voith (2008) for the 'W' class ferries. This indicated changes in water level of 0.15 to 0.2m depending on distance from the side of the vessel. This assessment was based on an operational draught of 2.3m compared to the proposed operational draught of 2.1m these predictions are therefore likely to be conservative.
- BMT SeaTech Ltd (2008) estimated the relative magnitude of 'W' class drawdown compared to 'C' class based on a comparison of squat measurements. This analysis indicated that 'W' class drawdown might be between 70 to 90% greater than for 'C' class ferries for speeds between 4 and 6 knots.

While there is reasonable agreement between the assessments and predictions, there are also some differences. For example, based on the CFD analysis, the maximum size of the drawdown is predicted to increase for the new ferries to 0.2m at 6 knots at 10m from the centre line, in comparison to 0.15 to 0.17m measured for the existing ferries, which is an increase of 18 to 33%. These predictions are lower than those estimated by BMT SeaTech (2008) of a 70 to 90% increase in drawdown. However, the BMT SeaTech estimate relates to the increase in average drawdown, which for the existing ferries was measured to be considerably smaller than the maximum, at approximately 0.05m.

In addition to these sources of information a further analysis of drawdown was undertaken by ABPmer for the purposes of this study. This extra analysis involved the application of the same methods as that used for the 1991 HR study (as listed above) and was used to predicted and compare the drawdown for C class and W class vessels. The HR Wallingford (1991) study indicated that intertidal drawdown effects had the potential to cause erosion in Horn Reach at that time. Since that study, the capital dredge undertaken in 1998/99 has significantly widened the channel in that area and considerably reduced the blockage ratio for 'C' class ferries and therefore a re-analysis was warranted. This type of analysis is subject to certain limitations when applied to an estuarine environment because of the inherent variability of the subtidal channel bathymetry (the technique is more suitable for canalised systems). These limitations mean that the technique does not provide absolute values for drawdown and especially not at the speeds which the ferries operate (i.e. 6 knots). However, the results obtained are useful for comparing the relative effects of the two sizes of ferry and for understanding the potential effects of the vessels a speed of around 4 knots and also of the relative response that occurs from changing these speeds. This analysis worked most effectively in the narrowest, most channelised and, thus the most sensitive, section of the estuary at Harper's Post and it is the results from this section of the estuary that are reviewed below.

The ABPmer calculations show that the maximum water level reductions might be increased by between 30% and 50% following the introduction of the W class vessel. In each case a reduction in vessel speed accrues expected reductions in the degree of water height depression. A reduction of 0.3 knots from 4.3 to 4 knots (which was the speed range for which the analysis could be most efficiently applied) resulted in the W class vessel causing an equivalent water depression change to a C class vessel operating at the higher speeds.

These results describe the relative scale of drawdown change that are likely to take place immediately alongside the vessel. It is also understood that the degree of water height reduction which occurs from drawdown will decrease with distance from the vessels. This is indicated by the CFD modelling outputs in Figure 16 which show the wave height for a ferry with a draught of 2.3m travelling at 6 knots in a water depth of 4.85m, at two distances of 10 and 20m from the centre line of the ferry in a plane parallel to the midline of the ferry, which represent distances of 2.8 and 12.8m from the side of the ferry, respectively. In both plots the drawdown effect of the ferry's passage through the water can clearly be seen, with a lowering of the water level of up to 0.2m over the length of the vessel at 10m distance and 0.15m at 20m distance.

In the narrowest section of the estuary around Horn Reach the channel at low water is 80m wide at MLWS (0.5m CD) and for a C Class ferry travelling along the centre line of this channel there would be 34m on each side between the ship at the waterline and the spring low water mark. For a W Class ferry there would be 32m on each side. As the CFD analysis is indicating a drawdown of 0.2m at 10m from the vessel and 0.15 at 20m, the represents a 25% reduction in effect within this 10m band. A further reduction would be expected to occur before the drawdown effects reaches the intertidal and, based on a minimum distance of 32m, a reduction of a further 25% to around 0.1m might be expected. Further down the estuary where the channel width are greater then drawdown effect will be reduced because of this change in drawdown height with distance from the vessel.

It is noted that there does not appear to have been any landward movement of MLW within the estuary since 1994 notwithstanding continuous operation of 'C' class ferries during this period (and at generally higher speeds than are proposed for the 'W' class ferries). On this basis, any current impacts associated with drawdown are assessed as being minor.

5.4.4 Ship Return Currents (Backflow)

The passage of vessels causes an increased flow beneath and around the ship in a parallel but opposite direction to the direction of navigation and this has the potential to cause erosion of the subtidal channel, particularly in shallow water depths when the blockage ratio is at its greatest and such flows are at their fastest. This increased return current is referred to as backflow and has the potential to cause erosion of intertidal habitats directly or could, through increased deepening of the channel, alter the stability of the channel sides such that the morphology and extent of the adjacent designated areas could be affected.

The rate of backflow depends on the speed of the ship through the water, the cross-sectional area of the channel and that of the ship below the waterline. The ratio of these areas is described by the blockage ratio. The previous studies carried out by HR Wallingford (1991) included calculations of the effect of the return currents created by the movement of the ferries through the most restricted channel section at Horns Reach. In this study the blockage ratio of the existing ferries was calculated to be 0.17 in Horn Reach, and based on this ratio, and a ship speed of 5 knots, the average return current was calculated to be 1.94 knots (HR Wallingford, 1991). As discussed in the preceding section though, there has been a capital deepening of the channel in this area since the HR analysis was conducted and thus the cross-sectional area has increased. Therefore, ABPmer revisited these analyses using the same methods that were used by HR and BMT SeaTech (2008) also separately calculated the backflow velocity, for the new and existing ferries at the two applicable speed limits of 4 knots and 6 knots.

The results of the BMT analysis are shown in Table 7 and this indicates that the W class vessels are expected to cause a 33% increase in backflow speeds at 4 knots (from 0.6 to 0.8 knots or 0.3 to 0.4m/s) and a 54% increase at 6 knots (from 1.3 to 2 knots or 0.7 to 1.03 m/s). The analysis concurred with that carried out by ABPmer. This analysis was subject to the constraints that were discussed in the preceding section, however, they indicated that, at 4 knot speed, the W class vessels would cause around a 26% increase in backflow speeds (from 0.6m/s to 0.76m/s). At 4.3 knots the difference was 40% (from 0.72m/s to 1.01m/s).

Table 7. Backflow velocities for the 'C' and 'W' class ferries

Ferry	Vessel Speed (Knots)	Backflow Speed (Knots)
'C' class	6	1.3
	4	0.6
'W' class	6	2.0
	4	0.8

The velocities of backflow currents are higher for the 'W' class ferries, and according to the HR Wallingford (1991) report, are probably of sufficient velocity to erode the bed for periods of passage over low water. This is to be expected given that the existing 'C' class vessels are believed to be contributing (along with natural flows and increased flows caused by other anthropogenic factors) to erosion of the subtidal channel to the extent that no maintenance dredging is required along the length of their navigable route even in the more depositional (and maintained) upstream sections of the estuary.

Assessment of the channel cross-sections (Figures 7 to 9) provides circumstantial evidence for some minor deepening of the navigation channel since the late 1980s (up to 0.5m at some locations). This could possibly be attributable to backflow impacts from the 'C' class ferries, although it might have been expected that such impacts would have occurred earlier in the 1970's following introduction of the 'C' class ferries, if the impact of backflow was substantial.

The preceding analysis of intertidal morphological changes has provided no definitive evidence that the contribution that the C class vessels might be making to subtidal morphological changes are causing indirect effects on intertidal morphology.

The backflow calculations have been estimated based on the ships operating under a worst-case scenario of the water level at LAT and at high water levels there will be a decrease in backflow. In addition, it is important to note that the channel bed is considered to be mainly coarse sand, gravels and stones and the backflow velocities will not be sufficient to cause mass erosion. At the speeds predicted though, fine sediment within the gravel matrix will however, be winnowed until the coarser material armours the bed at which point erosion will cease. The maximum backflows could, from time to time move some stones a short distance re-exposing finer sediment which could be eroded. It is likely therefore that the new ferry would cause some intermittent channel erosion at certain locations until a new equilibrium establishes. Such changes are likely to be confined to the shallower reaches of the estuary for example, around Bag of Halfpence Post.

In addition to describing the return flow changes imposed by the change in vessels, these analyses by BMT and ABPmer can also be used to indicate the influence that vessel speed has and the benefits (in terms of reduced return current speeds) that could accrue from reducing vessel speed. The ABPmer results indicated that following a reduction in the speed of a 'W' Class vessel from 4.3 knots to 4 knots the return current speed under a W class vessels would reduce from 40% greater than the C Class vessels operating at 4.3 knots to 6% greater (than C Class vessels still operating at 4.3 knots). Using the speed/backflow relationship plots produced by BMT the benefits of a reduction in speed are also in evidence. A 0.5 knot reduction in the speed from 6 to 5 .5 knots accrues a reduction in backflow of 0.5 knots (from 2 to 1.5 knots). The same plots can be used to understand the backflow speeds that are likely to have occurred historically from the C Class ferries operating at 8 knots (as noted in Section 5.4.2). An extrapolation of the speed/backflow plots for the two vessel sizes indicates that the backflow for a C Class at these speed would have been around 2.5 knots and thus was greater than the 2.0 knot predictions made here for the W Class ferries.

It is difficult to estimate the extent to which increased backflow from the 'W' class ferries might result in further deepening of the navigation channel. It is considered unlikely that the increased backflow would result in changes in channel depth of more than 0.5m. The greatest changes are likely to be observed in the shallowest areas of the channel, for example Bag of Halfpence Post. The slight deepening of the channel at some locations may also result in some minor widening of the channel at these points as a result of side slope instability. However, given that the distance between the channel banks and MLW is generally of the order of tens of metres, such changes to the navigation channel should not result in consequential changes above MLW.

The limited changes in channel depth would not give rise to significant changes in channel flow velocities and the implications of these morphological changes for sediment transport are considered to be negligible.

5.4.5 Vessel Slipstream

This section summarises the possibility of mobilisation and erosion of the channel bed and side slopes due to thrust from the ferries' propulsion units. The total installed power of the new vessels is considerably larger than that of the existing vessels, although much of this increase is due to the increased redundancy of two engines per thruster. It is understood that normal service will only employ one engine per thruster and the engines will also be de-rated (from the stated maximum speed of 14 knots), with a relatively small amount of the available power being required in normal operation. The effective increase in lateral windage in the 'W' class vessels is recognised to be large (BMT SeaTech, 2008), due to the increased height and size of the superstructure and also the greater cargo exposure. However, the actual increase in the slipstream velocity (velocity of the water jet as a result of the thruster) is only 10% (BMT SeaTech, 2008), and is not proportional to the increase in windage area. In addition the increased power of the 'W' class ferries will enable them to travel in a straighter line, and therefore to keep to the deeper areas of the navigation channel, maintaining the distance from the thrusters to the intertidal areas. Figure 17 illustrates how ferries use thrusters during turning.

Waiting within the river with the use of thrusters to maintain position causes indirect slipstream effects, where the thrusters may act on the edge of the navigation channel. Assessments by Voith (2008) indicate that slipstream effects can be significant with flows up to 5m/s at 10.5m downstream of thrusters (Figure 18). Given the central alignment of the thrusters on 'W' class ferries, 10.5m from the thrusters would represent a distance of around 3m from the side of the ferry if thrusters were oriented sideways, for example, while maintaining position in a cross-wind). Vessels would need to come within a few metres of the sides of the main channel for such velocities to be experienced at the bank. At distances of 10 to 15m from the sides of the ferries, based on extrapolation from Figure 18, slipstream velocities would be expected to return to background levels.

The positioning of the thrusters on the central line on the 'W' class ferries will decrease the opportunity for the thrusters to act on the intertidal at low water, in comparison to the 'C' class ferries, where the thrusters are positioned transversely across the ferries' hulls. However, the mass of water moved by the thrusters is likely to be larger than that of the 'C' class ferries. It has been recommended that the practice of waiting in the channel is not continued for the 'W' class ferries due to the navigational risk (BMT SeaTech, 2008), therefore any possible morphological or ecological impact would also be minimised.

Assessment of the cross-sections for the channel in the vicinity of Pylewell, the location where ferries wait in the estuary (Figure 19), does not indicate any significant change that might be attributed to slipstream effects from waiting ferries (change between 1988 and 2006 suggests whole channel has moved eastwards by less than 10m (Figure 8).

The 'W' class ferry thrusters will be approximately 0.2m[1] deeper in the water than those on the 'C' class and the increased attenuation of the slipstream means that it is less likely that the thruster jet will act on the water surface. However, the thrusters are more likely to act on the bed in low water situations. Information from the Voith-Schneider propeller calculations (Voith 2008) indicate that flow speeds will be significantly increased (>1m/s) for a depth of up to 1m (0.7 rotor diameters) below the rotor bottom (at a thrust of 100kN) (Figure 20). This would mean that increased slipstream velocities would be experienced to a depth of around 2.7m below the water surface. At low water this could result in some minor additional erosion of the bed of the navigation channel. For example at Bag of Halfpence Post parts of the channel are only 2.5m below CD (see Figure 8).

However, the bed is mainly made up of gravel and coarse sand and therefore little impact in the form of deepening is likely. Adherence to the speed limits in the channel and the introduction of 'no waiting' in Long Reach will also decrease the opportunity for the thruster flow to act on the bed. It will be possible to further assess the slipstream effects of the 'W' class ferries during the initial trials that are proposed following the introduction of these vessels. It will also be possible to manage effects through controls on vessels speed (see Section 7).

Some concern has previously been raised about the impacts at the ferry berth as a result of idling during loading and unloading operations. It is known that the 'C' class ferries have caused some scour within both the berth areas and at the terminal, due in part to the inability to declutch the engines from the thrusters during waiting times. There has also been capital deepening in and around these areas. However, the recession of saltmarsh in this area has been too large to be attributable to the effects of the thrusters at berth. Also, the new W class ferries will be able to switch off thrusters at berth so this is expected to decrease the localised scour in these areas and possibly allow some increased sedimentation within the currently over-deepened areas. The thrusters will cause disturbance as the ferry leaves the berth so the

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1 BMT SeaTech Ltd (2008) indicates that the mean depth of the thrusters for 'W' class vessels will be 1.7m below an at-rest waterline of 2.3m draft, compared to 1.3m for the 'C' class. However, assuming an operation draft of 2.1m for the 'W' class ferries would mean that the thrusters were only 20cm lower than for 'C' class ferries.

environment will find a revised equilibrium but no substantial changes to local bathymetry is expected.

5.4.6 Effects of Ferries on Sediment Supply/Sediment Budget

During periods of low water on spring tides, water levels in the navigation channel may reduce sufficiently such that backflow and vessel slipstream velocities of the existing 'C' class ferries are sufficient to cause disturbance of fine sediment in shallower areas of the channel. Such sediment can become entrained in the water column and subsequently transported by the prevailing tidal currents. This mechanism is considered to contribute to maintaining the depth of the navigation channel in addition to the scouring effect of the natural peak ebb flows. On the ebb tide, the scouring effect of the ferries could increase the export of sediment from the navigation channel out of the estuary. On the flood tide, such scouring could contribute to a minor enhancement of sediment supply up-estuary and possibly to intertidal areas.

In the context of sediment supply to the estuary, material that has deposited in the navigation channel is unlikely to subsequently become available to feed intertidal areas as a result of natural processes, because such material is only likely to be remobilized on peak ebb flows and thus exported from the estuary. Disturbance of such material by ferries at low water is therefore unlikely to have significant implications for sediment supply or the overall sediment budget for the estuary.

The introduction of the 'W' class ferries has the potential to slightly increase backflow and vessel slipstream directly beneath the vessel. This may increase the relative contribution of 'W' class ferries to maintaining the depth of the navigation channel compared to natural ebb flows. However, based on the assessments of backflow and vessel slipstream in preceding sections, these changes are likely to be relatively minor, because the existing 'C' class vessels already cause similar disturbance at low water. The implications for sediment supply and overall sediment budget associated with the introduction of the 'W' class ferries are therefore considered to be negligible.

5.4.7 Conclusion on Ferry Effects

The movement of ferries through the estuary causes a number of hydrodynamic changes within the estuary which may have the potential to affect estuary morphology in the long-term.

The analysis of ship waves indicates that the ship waves from 'C' class and 'W' class ferries are likely to be of similar magnitude at the range of passage speeds occurring in the estuary. Ship waves for 'W' class vessels travelling at 6 knots may be lower than for 'C' class vessels travelling at their historic speed of 8 knots.

Ferry waves contribute a small proportion of total wave energy compared to wind waves in the estuary. The maximum height of ferry waves (up to a predicted maximum of 25cm, but generally observed to be less than 15cm) is also considerably smaller than the largest wind waves (for example, up to 1m at Cage Boom – see Appendix A). HR Wallingford (1991) note that wave heights of up to 15cm would generally not be sufficient to cause intertidal erosion in the estuary. The contribution of ferry waves to intertidal erosion in the estuary from either the 'C' class or 'W' class ferries is therefore assessed as being minimal in comparison to wind waves.

There is some uncertainty on the relative magnitude of drawdown for W class compared to C class. Indicative information suggests that the drawdown for 'W' class ferries will be greater than for 'C' class ferries at comparable speeds. Careful control over vessel speed and positioning relative to the channel banks can significantly reduce drawdown impacts and could be used to ensure that drawdown impacts of 'W' class ferries are no worse than for 'C' class ferries.

The HR Wallingford study has demonstrated that drawdown from 'C' class ferries at low water on spring tides could be a factor contributing to intertidal erosion in Horn Reach at the time of that study. Following the widening of Horn Reach in the 1990's and better control over vessel speeds, the potential for intertidal erosion to occur in this section of the estuary will have reduced. In downstream areas of the estuary, the waterline width and channel cross-sectional area are considerably greater such that drawdown effects would be expected to be smaller. Indicative information from CFD analysis suggests that drawdown might decrease by around 25% between 2.5m and 12.5m from the side of 'W' class vessels. For vessels travelling along the centre line of the channel, the distance to the bank at low water of spring tides would range from between 30m to more than 50m down the length of the estuary suggesting that changes in water levels at the bank (and thus the extent of drawdown over the intertidal) will be considerably lower than the theoretical maxima close to the vessel.

The predicted backflow from 'W' class ferries is likely to be greater than for the existing 'C' class ferries. At low water, the increased flow velocities associated with the backflow will have the potential to cause erosion of the bed of the navigation channel, particularly in shallower areas of the channel, for example at Bag of Halfpence Post. However, it is of note that the navigation channel will have been subject to backflow velocities higher than those predicted for 'W' class at 6 knots from the past operation of the 'C' class ferries at 8 knots.

There is some circumstantial evidence that the existing navigation channel has deepened by around 0.5m between 1988 and 2006. This could possibly be as a result of backflow impacts from the 'C' class ferries introduced in 1973, although such changes might have been expected to occur in the 1970's if drawdown impacts were a significant pressure. Any erosion of the bed of the navigation channel as a result of the introduction of the 'W' class ferries is expected to be very limited and localized and, as a worst-case, unlikely to exceed 0.5m. Such deepening could create an instability in the existing channel side slopes leading to a subsequent widening of the channel. However, such impacts would not be expected to propagate into adjacent intertidal areas because MLW is generally some tens of metres landward of the main channel. The minor deepening of the channel would be expected to have a negligible impact on sediment transport within the estuary.

Slipstream from the ferries can cause localised increases in flow velocities. Where ferries seek to maintain position in cross winds close to channel banks, there is potential for slipstream velocities to act directly on the channel bank. However, analysis of the cross-section in the vicinity of the waiting area at Pylewell has not identified significant changes that might be attributable to such impacts. While the 'W' class ferries have more powerful thrusters than the 'C' class ferries, the slipstream impacts on channel banks are likely to be less because:

- The 'W' class thrusters are located on the vessel centreline and will thus always be relatively further away from the channel banks compared to 'C' class thrusters. This will more than offset the increased power of the 'W' class thrusters in normal operation;
- As part of navigational safety, the practice of waiting in the estuary will be greatly reduced compared to the current operation.

Slipstream impacts may also occur on the bed of the channel, particularly at low water. It is estimated that slipstream effects will be detectable down to at least 2.7m below the water surface. While most of the channel is already at or below these depths (and thus would not be significantly affected) at some locations depths are less than this across part of the width of the channel. At low water this could result in localized flow velocities of up to 1m/s or more in the shallowest reaches of the navigation channel. Such flow velocities could re-erode deposited material and, locally could result in some winnowing of the channel bed, similar in nature to predicted backflow impacts. Based on the current bathymetry of the channel, any changes in bed levels would be expected to be very minor (less than 0.2m and across only part of the channel width) and localized (over distances of tens of metres along the length of the navigation channel). These impacts are thus unlikely to significantly affect the morphology of the navigation channel or resultant natural flow speeds within it. Nor would such changes be expected to cause changes to intertidal areas. The overall consequences for the morphology of the channel, intertidal areas or sediment transport are therefore assessed to be very minor.

The passage of ferries along the navigation channel at low water has the potential to erode deposited sediment on the channel bed. Such re-erosion of deposited sediment is considered to be a contributory mechanism to maintaining navigable depth in the estuary in addition to the peak ebb flow velocities which are also sufficient to erode fine sediment from the channel bed. The significance of vessel re-erosion of deposited material in the overall context of estuary sediment supply is considered to be minor, because once deposited in the channel, there are no natural mechanisms that might remobilize such material on a flood tide (and thus make it available to intertidal areas upstream). At worst, the re-erosion simply accelerates a process that would occur naturally as a result of peak ebb flow velocities. The introduction of 'W' class ferries may result in an increase in erosive forces on the channel bed and increase the relative contribution of vessels to maintaining channel depth compared to ebb flows. However, in the context of estuary sediment supply and sediment budget these changes are not significant.

Overall, the collective studies that have been undertaken to understand the effects of the new W class ships (those done externally and the additional analyses carried out by ABPmer), indicate that the new vessels will at most have a minor impact on the morphology of the low water channel. The changes in the channel are unlikely to translate into impacts in the intertidal. The only potentially significant influence on intertidal areas is considered to be the impact of drawdown at the low water mark of spring tides, but the magnitude of this impact in the wider reaches of the estuary is likely to be considerably less than previously recorded in Horn Reach before that section of the estuary was deepened.

Summary Points: Section 5.4

1) The new 'W' class ferries are predicted to create ship-wash waves of a similar magnitude to the existing ferry operations.
2) The relative contribution of ship waves to total wave energy on intertidal areas of the estuaries is calculated as being very small compared to wind waves.
3) The height of the largest ship waves (25cm) is significantly smaller than the largest wind waves (c 1.0m)
4) Ship waves are not considered to be a significant cause of intertidal erosion in the estuary
5) Indicative information suggests that the drawdown associated with 'W' class ferries could be greater than for 'C' class ferries travelling at an equivalent speed.
6) The impact of drawdown in the lower estuary will be less than for Horn Reach because of the greater cross-sectional area and waterline width in the estuary below Horn Reach
7) It is not possible to quantify the long-term morphological implications of potential intertidal erosion as a result of drawdown. However, it is noted that there has been no significant change in the position of MLW since 1994 during which ferries have been operating continuously, suggesting that any impacts of drawdown from current ferry operations are minor.
8) The risk of drawdown-induced erosion from 'W' class ferries can be managed through careful control of vessel speed and positioning relative to channel banks; such mitigation measures can be applied to ensure that the impacts of drawdown from 'W' class ferries is no worse than the existing 'C' class ferries.

9) The 'W' class ferries are likely to create increased backflow compared to 'C' class ferries operating at similar speeds. However, it is noted that backflow from 'C' class ferries in the past is likely to have been greater than for 'W' class at 6 knots.

10) As a worst case assumption, the backflow from 'W' class has the potential to cause minor additional erosion to the bed of the navigation channel, but this would not exceed 0.5m even at the shallowest locations within the channel. Any minor deepening of the channel could potentially result in increased channel width as a result of side slope instability.

11) Any changes in channel morphology should not propagate into intertidal areas because the position of MLW is generally some tens of metres beyond the edge of the navigation channel.

12) The slipstream velocities outside of the footprint of the 'W' class ferries are unlikely to be greater than for the existing 'C' class ferries because of the central positioning of the thrusters on 'W' class ferries.

13) The risks of channel bank erosion from the 'W' class ferries slipstream is likely to be reduced compared to 'C' class ferries because the new operating arrangements will reduce the number of occasions on which ferries will wait in the estuary.

14) Slipstream velocities on the channel bed associated with 'W' class ferries at low water in the shallowest reaches of the channel are likely to be greater than for 'C' class ferries. This could give rise to some minor (<0.2m) and localised erosion within the channel (across part of channel width for tens of metres) at a few locations. Such erosion, if it occurs would not be expected to be significant in terms of the overall morphology of the channel or for such changes to affect adjacent intertidal areas.

15) The passage of ferries at low water has the potential to re-erode deposited sediment in the navigation channel. This contributes to the maintenance of channel depths alongside side natural ebb flow velocities. The implications of this impact for estuary sediment supply are assessed as negligible because there are no natural processes that could transport such material from the navigation channel to adjacent intertidal areas.

6. In-Combination Effects With Other Plans or Projects

Under the Habitats Regulations, it is necessary to consider effects that a development has on a European Marine Site 'In-Combination' with other plans or projects that are approved or are in the planning domain. A comparable, but legally separate and technically different requirement, for understanding 'Cumulative' effects also exists under the EIA regulations. Cumulative impacts refers to occasions where another project could have an impact via the same pathway (e.g. if both proposals altered tidal heights or caused disturbance to birds) and could therefore result in a change that is of greater or lesser significance than the effects of this proposal in isolation. In-combination effects refer to impacts which may or may not interact with each other and which could specifically affect the same receptor or interest feature (i.e. a habitat or species for which a European Site is designated) via the same or different pathways. For instance, bird species could be affected in-combination by disturbance from one proposal and habitats loss by another.

In those instances where an impact from a proposal is shown to be negligible or '*de minimis*' then there will be no such in-combination effects with other proposals. In this case it has been concluded (in consultation with NE) that the confidence in a negligible or '*de minimis*' is not sufficiently high to exclude the need for an in-combination assessment. For this project the main development identified in consultation with NE and other parties is the LHC proposal for installing breakwaters to protect the harbour area.

The proposed Lymington breakwaters scheme comprises two low-crest rubble mound breakwaters, one on either side of the main navigation channel at the upstream end of Long Reach. Figure 21 shows the scheme in planform. The current aim is a phased construction over 20 to 30 years, with the breakwaters being extended in length toward the land at each Phase to counter the predicted rate of loss of saltmarsh (Black & Veatch, 2007).

The presence of the breakwaters will only have small on the tidal prism directly and therefore is not predicted to create any significant changes to current velocities in the context of the whole estuary. However, there will be changes to erosion and deposition patterns, caused by changes in currents and protection of areas from wave attack particularly during storm due to the presence of the breakwaters. For example, there may be changes to the flow directions and reduction in the current velocities in the lee of the structures, although these are thought to be negligible. Some restriction to the channel cross-section at High Water will occur, although this is reduced by the staggered nature of the breakwaters. This has the potential to locally raise flow speeds in the vicinity of the breakwaters over the upper half of the tide which may be sufficient to cause some localised erosion of the intertidal area. Although the rubble mound nature of the breakwater is designed to dissipate wave energy, it is possible (particularly during storms) that wave reflection may occur with the potential for localised erosion in front of the structures. From the analysis of the change in cross-section of the channel, there is evidence of meandering processes which may have a long-term cyclic pattern. The locations of the breakwaters are therefore likely to cause change to the meandering process at this section of the estuary which would change the erosion and accretion patterns and the configuration of the low water channel. Such changes could take many years to develop.

Overall therefore, it can be concluded that there will be no significant additional in-combination with the breakwaters and this is confirmed by taking the conclusions of the Environmental Statement (ES) that has been prepared for this scheme (Black & Veatch 2007). The overall impacts of the breakwater on the intertidal are predicted in

Table 8 and this shows that all predicted impacts are negligible or minimal. Therefore, mitigation measures for the breakwaters are not considered within the Environment Statement as none of the impacts are considered to be significant (Black & Veatch, 2007).

Table 8. Impacts of the breakwaters on the intertidal areas

Action	Impact
Construction	Suspension of bed material away from the site – negligible impact
Presence of Breakwaters	Loss of footprint area of intertidal (absolute value unknown) – consequent gain in intertidal vegetation considered to be a positive impact).
	No change to the tidal prism.
	Minimal changes to flows.
	Minimal changes to erosion / deposition patterns, but with some local erosion around the breakwaters.
	Wave reflection: localised increase, not considered to be significant.
* For definitions of the significance terms see Black & Veatch (2007).	

(Source: Black & Veatch, 2007)

7. Mitigation and Monitoring Measures

7.1 Mitigation of the Shoreside Works

The impacts of the shoreside works in terms of the noise created can be reduced by using vibro-piling during periods when overwintering birds are likely to be present and using the adjacent intertidal habitats (i.e. between 1 October and 31 March). This was a recommendation within NE's letter to the MCEU and should be adopted as a precautionary measure as part of this work.

Outside of this window, percussive piling methods can be used because there will not be a significant adverse effect on migratory fish species and these are not an interest feature of the Solent Maritime EMS. Therefore, for the purposes of this assessment no mitigation measures are proposed.

7.2 Mitigation of the New Ferries

Although the available evidence indicates that the current 'C' class ferries are not significantly affecting intertidal areas (i.e. there has been no change in MLW since at least 1994), it is expected that NE will want further assurances about the mitigation and monitoring commitments that will give them the highest possible confidence that there will be no adverse effect following introduction of 'W' class ferries.

The only viable way to achieve this is to ensure that the operation of the 'W' class ferries and their interaction with the estuary is firmly integrated into the estuary users Risk Assessment that LHC are developing. For this Risk Assessment, the relevant risk control recommendation measures recommended by BMT SeaTech (2008) are as follows:

1) Make ferry waiting in the river the exception and unhindered passing the rule;
2) In peak season, increase the Harbour Master's patrols in Short Reach, especially in the region of the passing place;
3) Ensure that the navigation posts in the river mark the limits of the navigable channel and provide a visual indication of the channel in all conditions, including fog;
4) Install visual tide boards on navigation posts; and
5) Ensure that a structured programme of trials is undertaken with the new ferries (see next section).

Measures 3 and 4 (as quoted here) will increase the likelihood of the ferries maintaining an appropriate course within the navigation channel, away from the shallow intertidal areas.

A reduction in speed (below the 4 knot upstream and 6 Knot main channel limits) is not recommended by the Risk Assessment (BMT SeaTech Ltd, 2008), but adherence to the speed limits is a requirement due to the health and safety aspect of using the new ferries in the river. The option to reduce the speed of the new vessels further, so that the hydrodynamic effects are reduced to that currently imparted by the C class vessels should be explored as part of the sea trials. Based on the findings of these sea trials, it may be appropriate to impose some additional restrictions on vessel speed over extreme low water periods to minimise risks from drawdown, although the necessary speed reductions are likely to be minor.

Based on the assessment in Section 5, any impact of the introduction of 'W' class ferries on intertidal habitats is expected to be very small. Confidence in this conclusion is high (see Section 8.3) however, it is not possible, on the basis of existing information, to fully demonstrate that all such impacts are negligible because not all pathways (mainly the effect of drawdown) can be quantified. To provide further assurance in avoiding possible impacts on the European site from the introduction of the 'W' class ferries, Wightlink is committed to contributing to habitat mitigation trials in the estuary. Subject to obtaining the necessary consents, these trials are likely to take the form of an intertidal recharge using maintenance dredged material from the estuary. The mitigation is being secured through a legal agreement between Wightlink and Natural England.

7.3 Monitoring of the New Ferries

It is recommended that monitoring should be undertaken in two key areas:

- Monitoring and assessment of hydrodynamic changes introduced by 'W' class ferries as part of sea trials;

- Longer-term bathymetric monitoring of navigation channel and intertidal areas.

A provisional framework is already in place for assessing the hydrodynamic impacts of the 'W' class ferries as identified within Phase 1 of the developing navigation risk assessment work (BMT SeaTech Ltd., 2008). On the assumption that initial handling and familiarisation trials have been completed satisfactorily with the new vessel, this Phase 2 programme will involve trails of the following aspects:

- Both classes of ferry at representative draughts;
- High water spring arrival and departure with no passing or waiting;
- Mid-tide arrival and departure with no passing or waiting. Tide level to be compatible with mid-ebb on 22/23 January 2008;
- Low-tide (spring) arrival and departure with no passing or waiting. Tide level to be compatible with the 0.45m level measured at 16:10 on 22 January 2008;
- Repeat the above with W-class/W-class and W-class/C-class passing;
- Emergency stopping under control and stop-and-hold on the river for both W-class and C-class ferries;
- Waiting in the passing area at or near low water to determine the extent to which the thrusters cause the river to be set in motion. If this is serious, then the recommendation to avoid waiting will be endorsed.

Within these trails the following aspects would be checked:

- Wash and drawdown;
- Evidence of increased ship-ship interaction (and therefore increased risk) when passing in the river using the existing leads;
- Whether the speed limits in the river remain satisfactory;
- The effect of speed through the water on wash;
- Thruster slipstream effects on the river and other users, with observations of effects upstream as well as downstream of the thrusters;
- Effect of the ferries on moored vessels from interaction and wash;
- Control of speed profile on the route to avoid waiting in the river;
- Fields of view from the wheelhouse when the river is busy, to compare with present vessels;
- Effect of the ferries on the wind, to provide evidence of the magnitude of wind shadow.

The results of this work will be needed to inform, and complete, the navigation risk assessment and to ensure that the safe conditions that are currently prevalent in the estuary continue. In addition to this work, the speeds of the vessels are now being, and will continue to be, monitored to ensure that the ferries do not exceed the speed limits. Over the last year the speeds of ferries within river have been monitored by the LHC's using their AIS system which identifies whether there are any exceedences of agreed speeding limits based on speed 'overground'. Furthermore, on the new W class ferries, Wightlink will have speed recorders that will measure both 'speed through the water' and 'actual or overground speed' as well as recording directional parameter. These measures will provide assurances that the speeds are adhered to in future years.

It is anticipated that routine bathymetric surveys will continue to be undertaken by NFDC and LHC on a biannual basis. Such information should be sufficient for assessing any morphological changes within the estuary that might be attributable to new ferry operations.

8. Conclusion

8.1 Overview and Understanding of the Estuary System

In terms of understanding any effects on the intertidal and subtidal areas it is recognised that a lot of valuable reviews and surveys have been undertaken. These have been used in this assessment to:

- Understand the physical changes that have taken place in the estuary;
- Develop a conceptual understanding of the estuary system; and
- Understand the relative contributions of ferry operations to observed changes.

Outside of the estuary on the open coast, the main causative factors for morphological change are generally considered to be:

- A significant change in coastal morphology leading to a change in wave energy (Ke & Collins, 1993);
- An overall sediment deficit within the western Solent (Lawn, 2001);
- The evolutionary tendency of *Spartina* marshes (Lawn, 2001).

A range of factors both natural and anthropogenic are likely to have contributed to the observed changes in the morphology within the estuary, including (in no particular order):

- An estimated 15% increase in the tidal prism as a result of the capital dredging that took place for the creation of the Yacht Haven and Berthon marinas in the early 1970s. This would have increased the flows through the main channel, particularly below mid-tide level, and therefore increased the likelihood of widening and deepening of the channel;
- The possible natural meandering tendency of the estuary which may have contributed to changes in channel alignment at Cocked Hat and Bag of Halfpence;

- Hydrodynamic changes associated with ferry and other vessel movements in the estuary contributing to morphological change, particularly in subtidal and low intertidal areas;
- Increased wind-wave penetration into the estuary resulting in erosion of intertidal mudflat and saltmarsh;
- Changes in long term sediment supply/sediment balance resulting in a reduction in availability of sediment to the estuary and marshes;
- Spartina die-back, resulting in increased vulnerability of trapped sediment to erosion;
- Cliffing of *Spartina* marshes at the mouth of the estuary increasing their vulnerability to lateral erosion.

8.2 Summary of Ferry Effects

Within the context of ongoing natural and anthropogenic change, this assessment has evaluated the potential impacts of existing 'C' class and proposed 'W' class ferries. The main conclusions from this assessment are:

- The contribution to intertidal erosion in the estuary from ship waves from either the 'C' class or 'W' class ferries are unlikely to be significant because:
  - The new 'W' class ferries are predicted to create ship-wash waves of a similar magnitude to the existing ferry operations at equivalent vessel speeds;
  - The contribution of ferry waves to overall wave energy within the estuary is very small;
  - The maximum height of ship waves is much smaller than the maximum height of wind-waves within the estuary;
  - The energy associated with average height ship waves is not large enough to cause erosion of intertidal areas in the estuary.
- The predicted drawdown from 'W' class ferries is greater than for the existing 'C' class ferries and there is some potential for such drawdown to cause erosion on the lower intertidal. However, such erosion is likely to be limited because:
  - Current evidence suggests that the position of MLW throughout the estuary has not changed significantly since at least 1994, suggesting that drawdown associated with the current operation of 'C' class ferries is not having a major impact on intertidal areas;
  - At most locations in the estuary, the cross-sectional area of the channel and the waterline width at low water are significantly larger than at Horn Reach (where the original assessment of drawdown was made by HR Wallingford);
  - It will be possible to manage the speed of 'W' class ferries during extreme low water periods to ensure that drawdown impacts are no worse than the existing 'C' class ferries.

- The predicted backflow for 'W' class ferries is greater than for the existing 'C' class ferries at the same speed, however, it is noted that backflow from 'C' class ferries in the past (when they operated at 8 knots) is likely to have been greater than for 'W' class at 6 knots. The increased backflow has the potential to cause erosion to the bed of the navigation channel, particularly at the shallowest locations in the channel. Any deepening that occurs is expected to be of a minor nature (up to 0.5m deepening). The deepening may create instability in the existing channel side slopes resulting in an eventual widening of the channel. Such changes are unlikely to propagate into intertidal areas because MLW is some tens of metres away from the channel banks.
- Slipstream impacts from 'W' class ferries on channel banks are likely to be less than for the equivalent 'C' class ferries because:
  - The 'W' class thrusters are more centrally aligned on the vessel compared to 'C' class ferries;
  - The operational regime for 'W' class ferries will reduce the number of occasions ferries are waiting in the estuary.
- Slipstream impacts of 'W' class ferries on the channel bed are likely to be greater than for 'C' class ferries. The increased flow velocities associated with 'W' class ferry slipstream could cause additional erosion in the shallowest stretches of the channel during periods of extreme low water. A maximum deepening of up to 0.2m might be expected.
- The passage of ferries along the navigation channel at low water contributes to maintenance of navigable depths by re-eroding deposited sediment within the channel. The introduction of 'W' class ferries will increase the proportion of deposited sediment that is re-eroded by ferries compared to that eroded by natural ebb flows. However, the significance of such changes for estuary sediment supply is considered to be minimal because there are no natural mechanisms for redistributing such material to intertidal areas and the sediment is effectively already lost to the estuary system.

8.3 Confidence in the Conclusions

In terms of the confidence that can be placed on these findings it is recognised that there are limitations to some aspects of the data (e.g. compatibility of bathymetric data sets between years) that underpin the analysis. However, there is good body of scientific evidence to underpin our understanding of the general environmental conditions; the long-term natural changes to which the estuary and the region have been subject and the historical influence of the C Class ferries in this context. There is also a lot of evidence from separately-produced analyses, models and surveys which confirm our understanding about the scale of the changes that are likely to occur from the introduction of the new larger W Class ferries.

Collectively this body of evidence provides ABPmer with a high confidence about the key aspect of the historical change within the estuary and, especially, in the conclusion that there has been no substantial change to the mean low water alignment along the length of the estuary since at least 1994. There is also a high level of confidence in the predicted shipwash heights and wash effects on the adjacent intertidal. Confidence is also high in the predictions for backflow and slipstream changes and impacts.

Confidence in the predictions of drawdown are identified as being 'Medium' because it is not possible to fully quantify the extent of the drawdown change or the long-term morphological implications. Notwithstanding these uncertainties, the lack of landward movement of MLW since 1994 indicates that any long-term impacts must be small.

In total this evidence (see Section 5.1) can provide the statutory authorities with a high level of confidence about the findings of this assessment. Allied to that, the control recommendations presented by BMT SeaTech (2008) will assist with the management of navigation risks. The overall LHC risk assessment provides a framework within which the ongoing activities of the ferry service can be integrated such that the needs of all users of the estuary can be taken into consideration as part of the ongoing management of the system. LHC will have a responsibility to maintain a navigable channel and protect established berths as well as being minded to the environmental implications of future management decisions (e.g. through the production of an EIA and AA for the proposed breakwaters and through FEPA licensing arrangements). Collectively the assessment evidence and these proposed measures indicate that it will be possible to operate the new 'W' class ferries in a manner that will not have greater effects on the environment than the current 'C' class ferries.

There is no real evidence that can be collated to further enhance the authorities' confidence beyond the data that already exists. For instance further modelling techniques, beyond those already undertaken, will not be sufficiently robust to answer the questions raised by this study on their own and instead the most effective way to progress is to combine the modelling that has been carried out with real-time measurements and observations during the full trials (Ian Dand, BMT *pers. comm.*). Such trials will need to be undertaken within the framework of an agreed package of navigation requirements and field sampling work and the most appropriate way that this can be achieved is by integrating these elements within the LHC's risk assessment framework.

8.4 Effects on Site Integrity

For an AA it is necessary to determine whether the project or plan would adversely affect the integrity of the European Marine Site in the light of the site's conservation objectives. The integrity of a site has been defined as the coherence of its ecological structure and function, across its whole area that enables it to sustain the habitat, complex of habitats and/or the levels of populations of the species for which it was classified (DETR, 1994). The judgement about the effects of a project on site integrity needs to be taken in the light of the conservation objectives for the site. This study has therefore focused solely on these ecological issues and, particularly, has concentrated principally on assessing the likely effects of the new larger vessels on the integrity of the Solent European Marine Site. Any such effects will occur within the Lymington River stretch of this SAC.

On the basis of the above analysis, there is no evidence that the current 'C' class ferry operation is having an adverse effect in the context of natural changes. In particular, the evidence indicates that there has not been a significant change in MLW throughout the estuary since at least 1994. Based on the predicted changes that are expected from the new vessels it is the conclusion of this assessment that the new 'W' class ferries can be operated in a manner that ensures that they have no greater impact on the designated site compared to the existing 'C' class ferries. Final decision of this matter is to be made by the Competent Authority with advice from NE, EA and MFA.

As a final consideration it is worth recording that the original navigational review (ELP 2006) identified potential hydrodynamic and physical consequences from the new ferries and these issues were highlighted as key concerns by NE in their letter to MCEU of 24 September 2007. The ELP report identified the key potential impact pathways although they were largely unquantifiable with the evidence available at that time and they required further investigation to understand the effects on the integrity of the Solent Maritime EMS in the context of natural change. The nature and scale of the changes that are likely to occur via these pathways have since been further informed by all the subsequent studies including, most importantly: - the surveys and analyses that were undertaken for the navigational risk assessment Phase 1 monitoring work (BMT SeaTech Ltd. 2008); the vessel modelling work (Vienna Model Basin (2008) and the further analysis and review work within this AA Information document. As described above this additional information indicates that any impacts associated with the new ferry operations are likely to be extremely small in respect of the conservation objectives for the Solent Maritime EMS.

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Figures

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Special Area of Conservation
Special Protection Area
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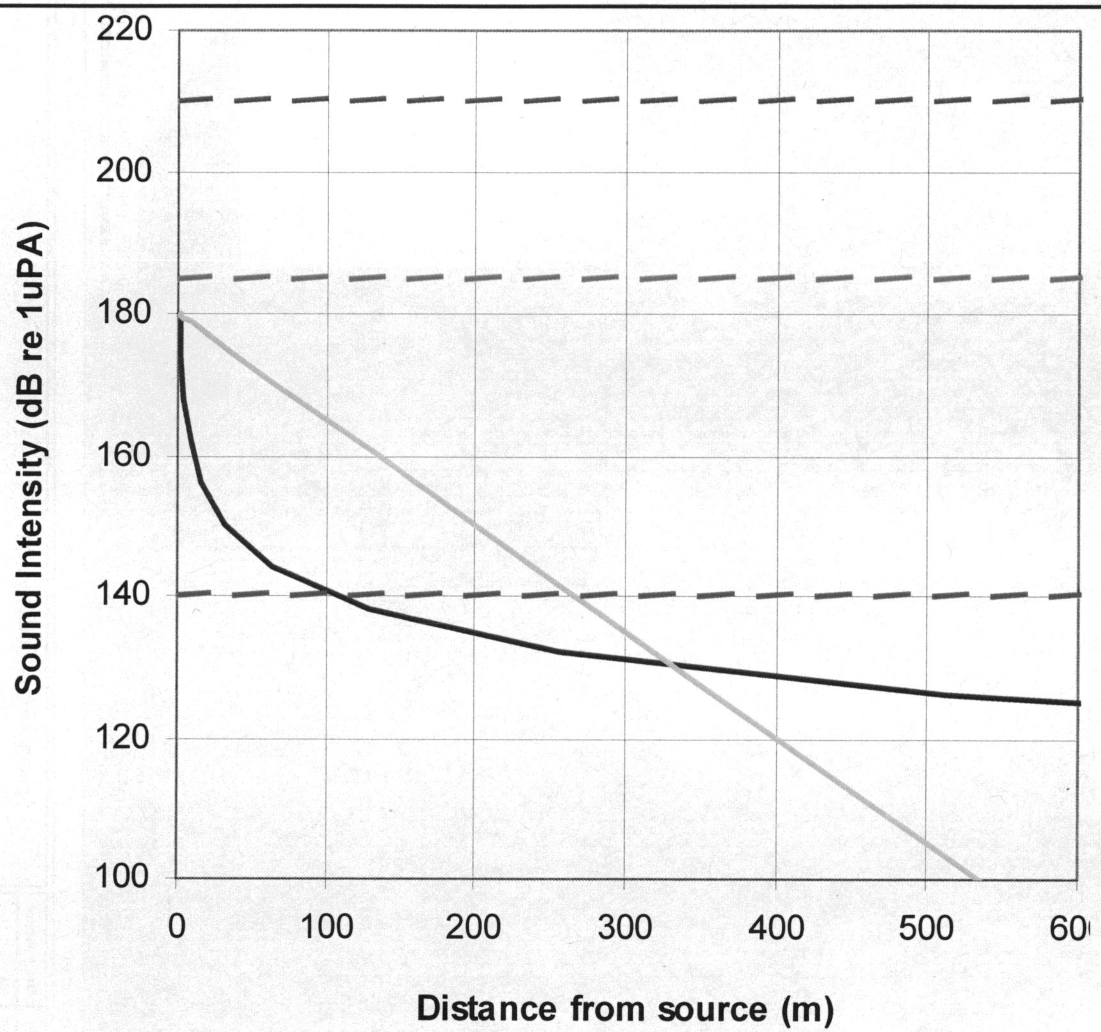
International Designations in the Lymington River Area

Figure 1



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Response distances for salmon using different transmission loss (TL) scenarios.

Figure 2

Date	By	Size	Version
May 2008	DD	A4	1
Projection		OSGB 1936	
Scale		1:8,000	
QA		RJR	
3772 - Fig_MLW3.mxd			
Produced by ABPmer Ltd			

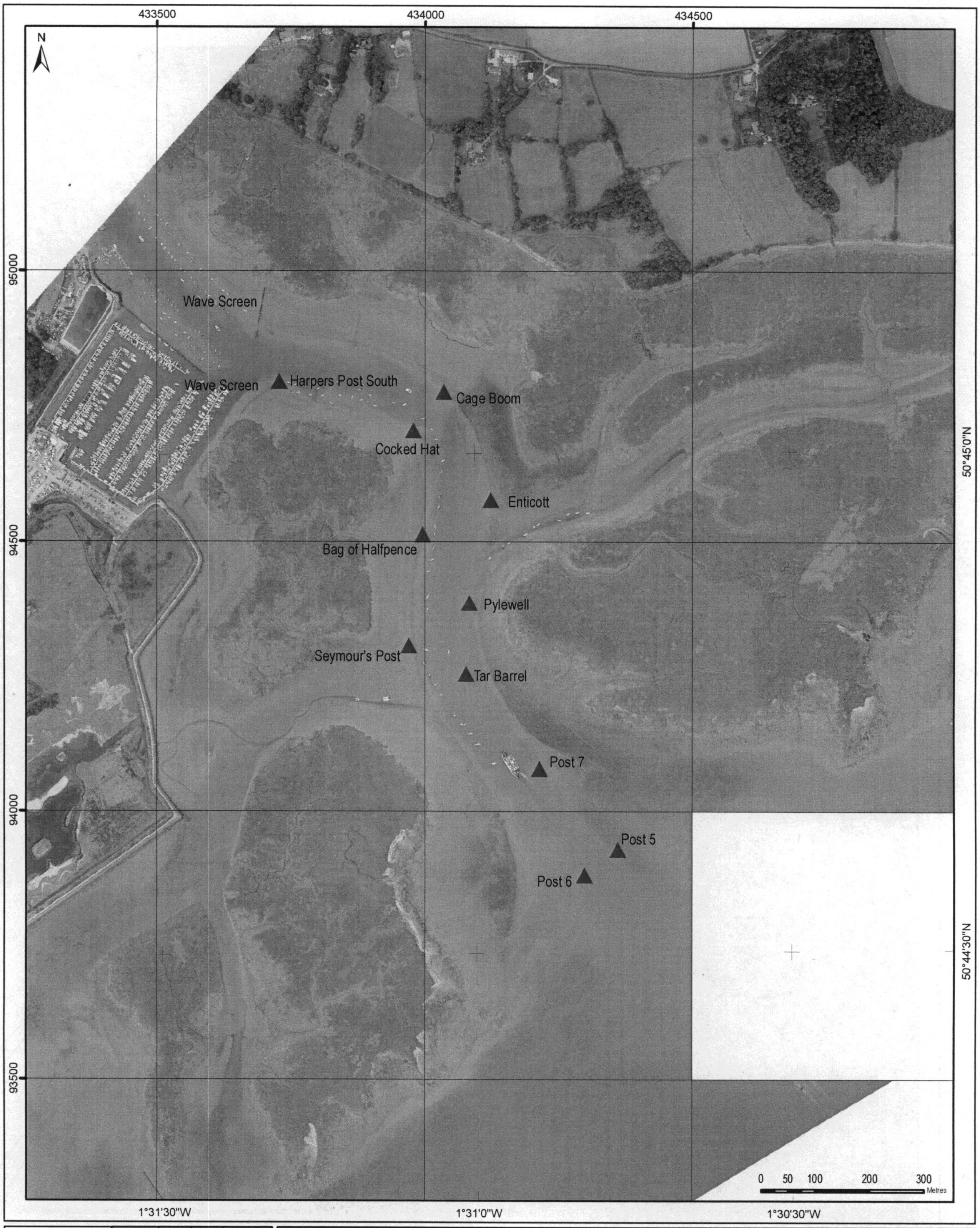
Data Sources: Image/Data courtesy of the Channel Coastal Observatory, Lymington Harbour Commisioners

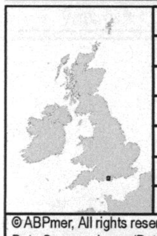
- MLW - 2006
- MLW - 2005
- MLW - 1994
- MLW - 1975
- MLW - 1907
- MLW - 1870

ABP mer marine environmental research

Changes in Mean Low Water (MLW) Between 1870 and 2006 in Lymington River

Figure 3





▲ Cross Sectional Markers

Date	By	Size	Version
Mar 2008	PAR	A4	1
Projection		OSGB 1936	
Scale		1:10,000	
QA		RJR	
3772 - Fig_Locations.mxd			
Produced by ABPmer Ltd			

Data Sources: Image/Data courtesy of the Channel Coastal Observatory

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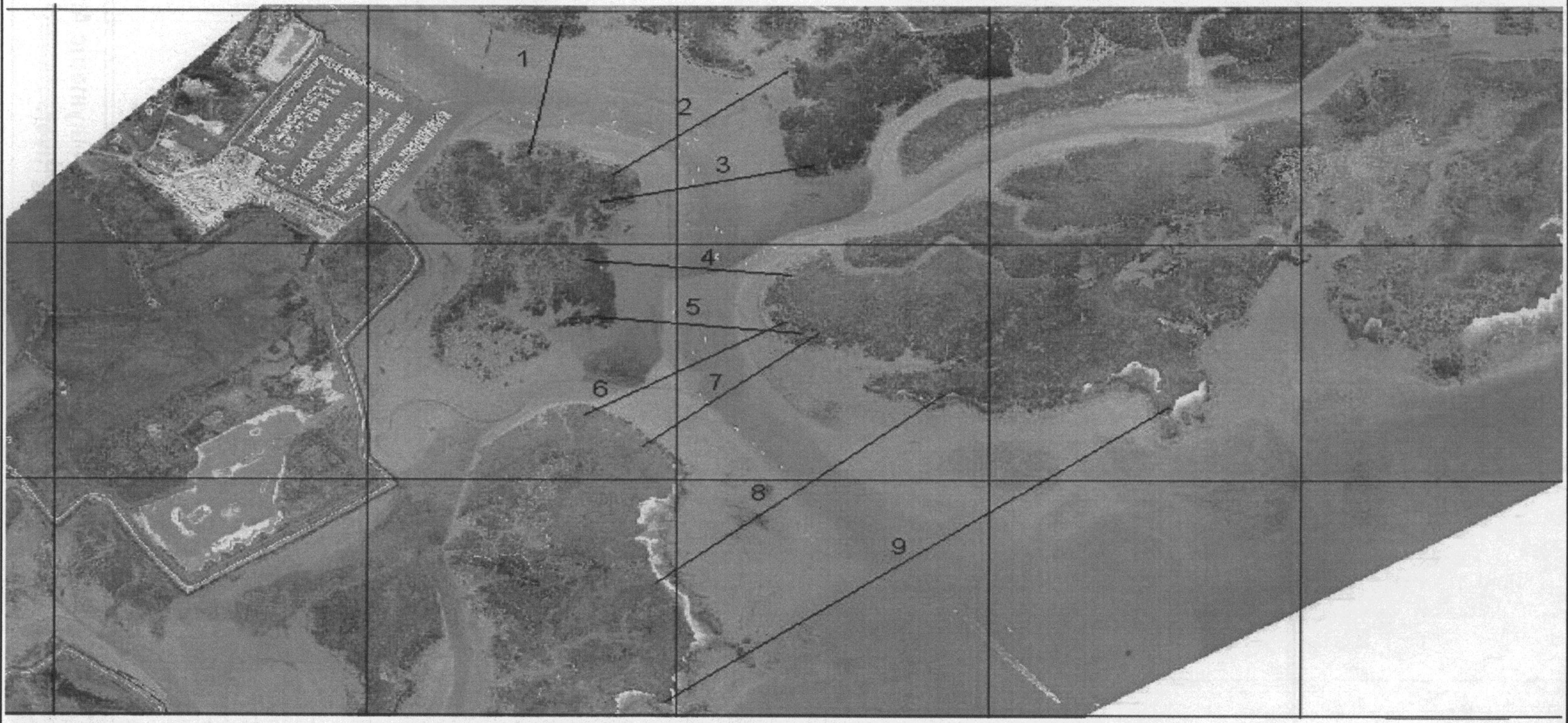
Location of Cross Sectional Markers for Bathymetric Analysis within the Lymington River.

Figure 4



Date	By	Size	Version
Mar 2008	JAR	A4	1

Reference

3722-NFDC Cross sections.xls

Produced by ABPmer Ltd.

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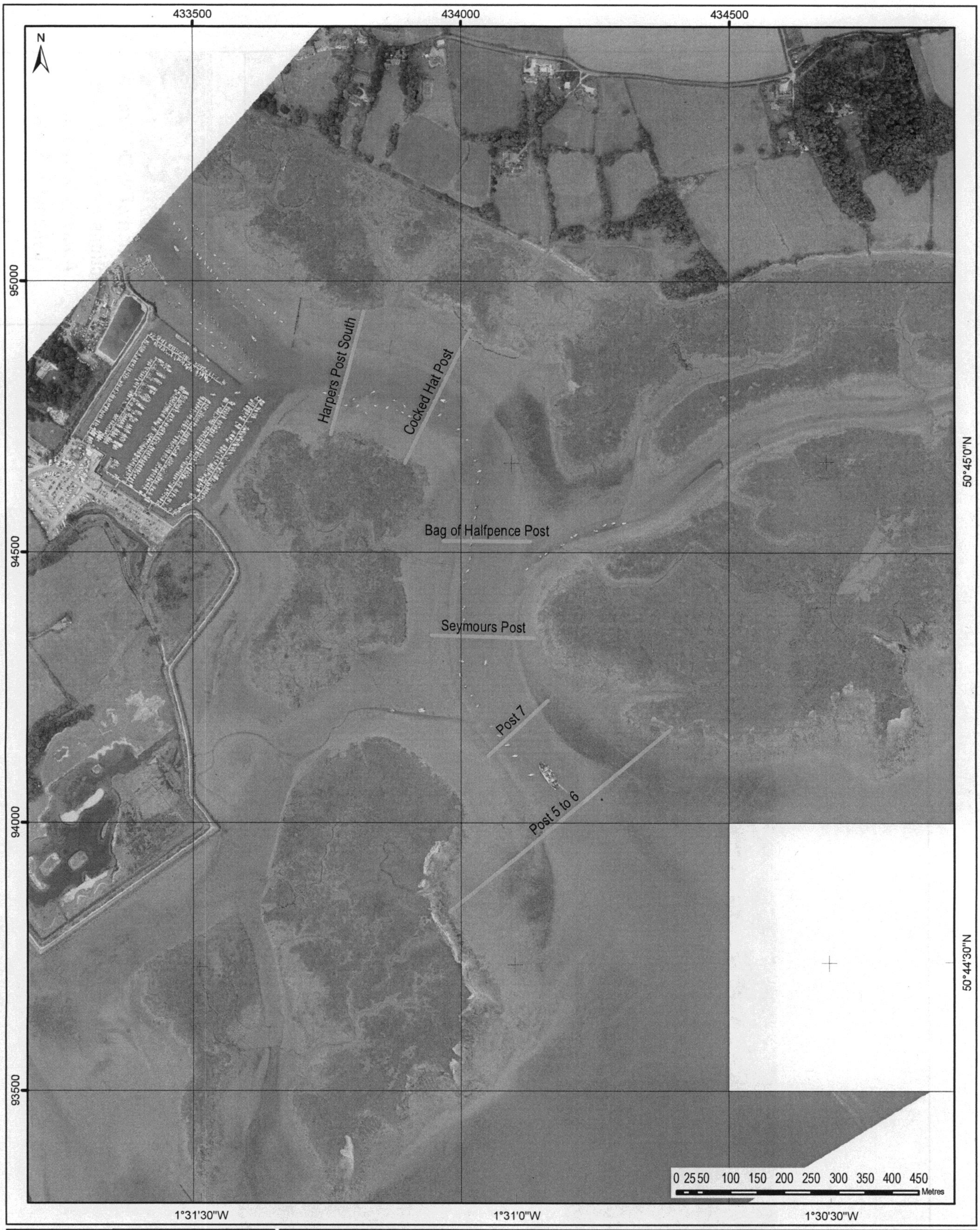
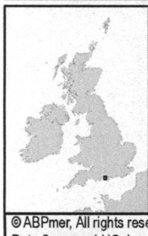
marine environmental research

Location of NFDC Cross-sections for Bathymetric Analysis within the Lymington River

Figure 5





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Projection		OSGB 1936	
Scale		1:10,000	
QA		RJR	
3772 - Fig_Profiles.mxd			
Produced by ABPmer Ltd			

Data Sources: LHC, Image/Data courtesy of the Channel Coastal Observatory

Bathymetric Profiles

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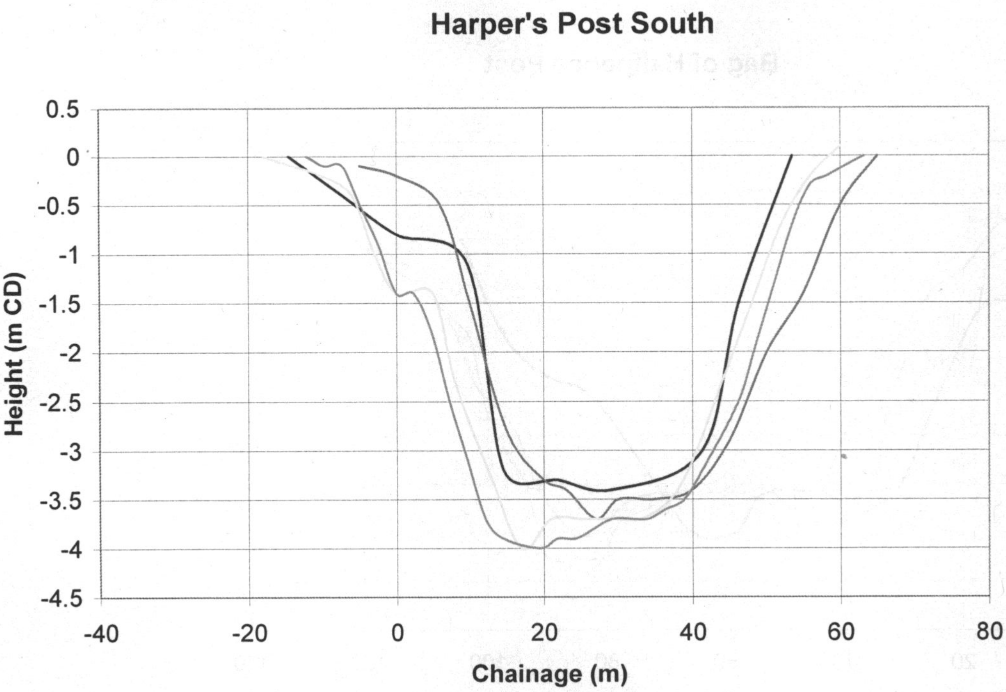
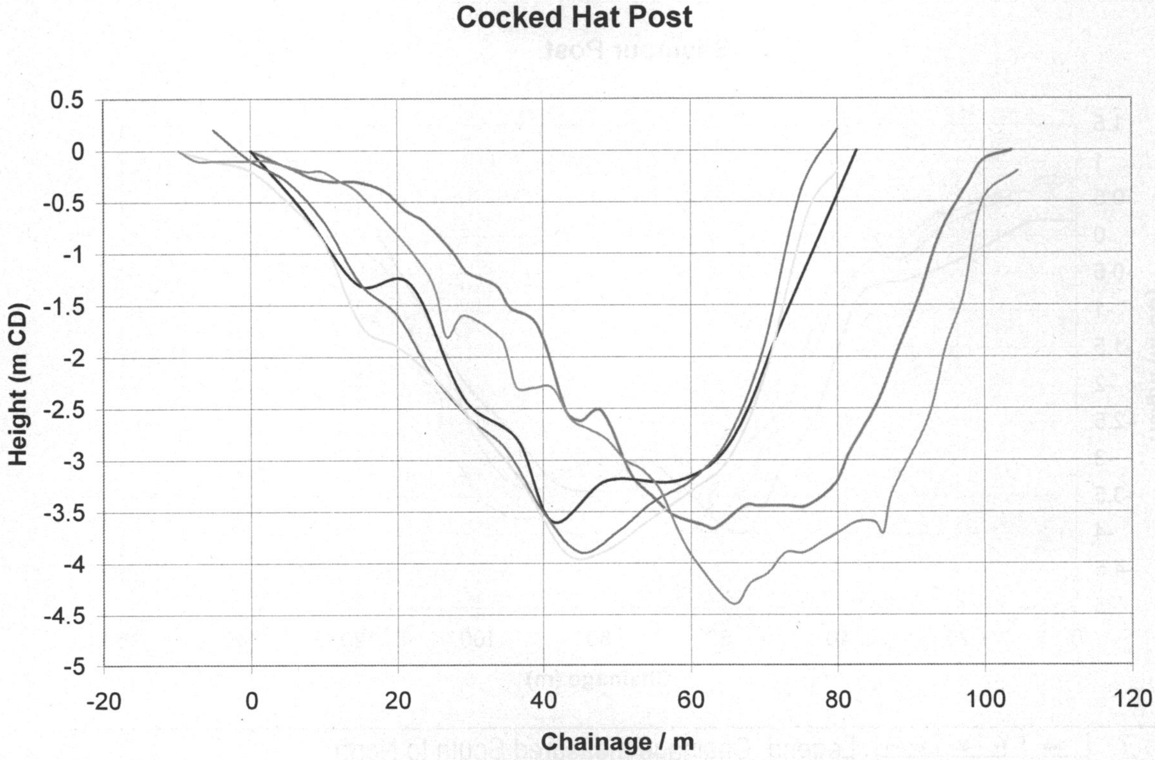
Location of NFDC Cross-Sections for Bathymetric Analysis within the Lymington River.

Figure 6





Date	By	Size	Version
Mar 2008	JAR	A4	1
Reference			
3772 - Wightlink			
Produced by ABPmer Ltd.			

Legend: Chainage measured South to North

- 1964
- 1988
- 1993
- 1999
- 2006

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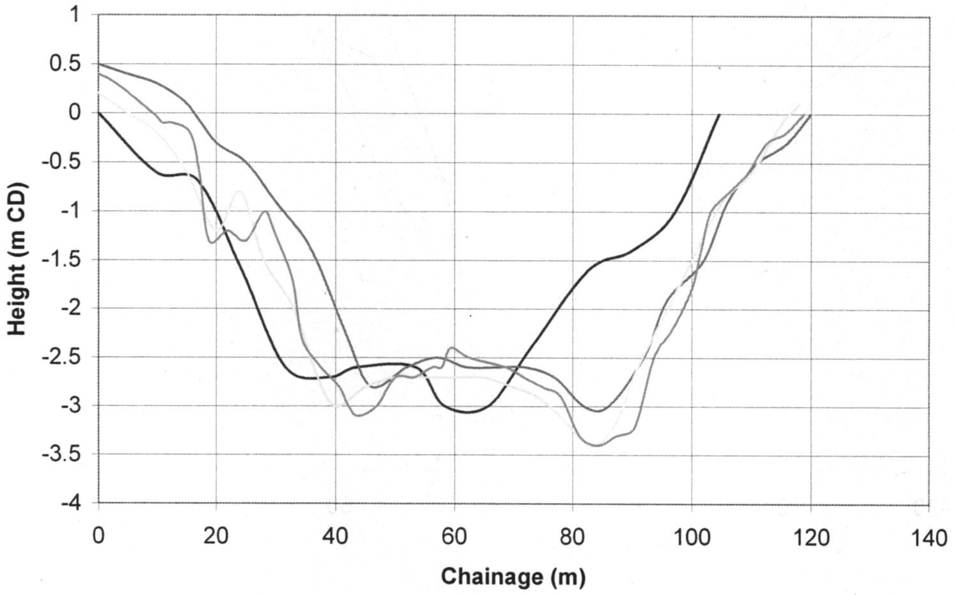
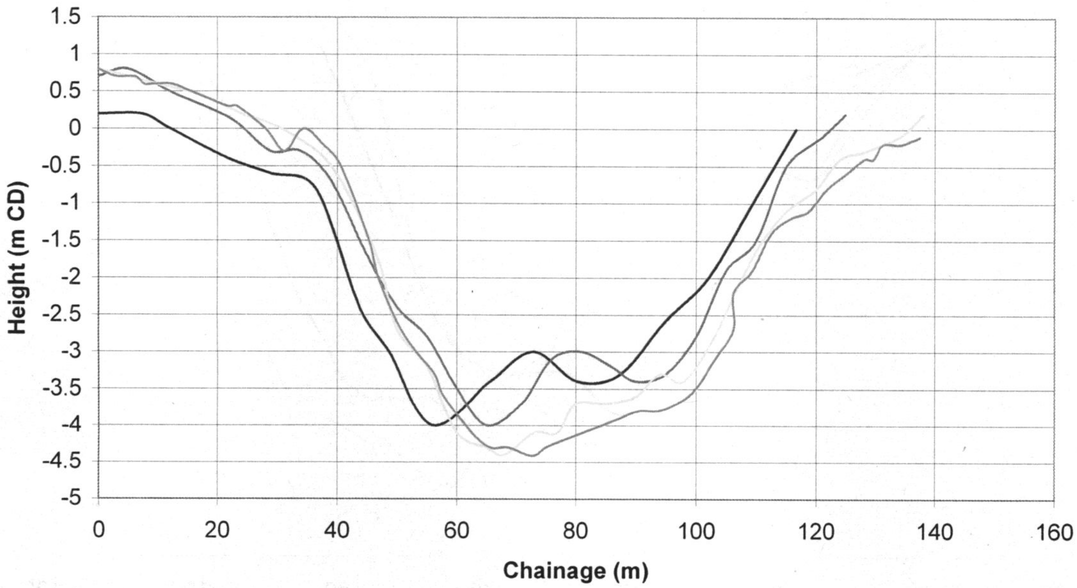
Bathymetric Cross-sections for Harper's Post South and Cocked Hat Post

Figure 7

Bag of Halfpence Post



Seymour Post



Date	By	Size	Version
Mar 2008	JAR	A4	1
Reference			
3772 - Wightlink			
Produced by ABPmer Ltd.			

Legend: Chainage measured South to North

- 1988
- 1993
- 1999
- 2006

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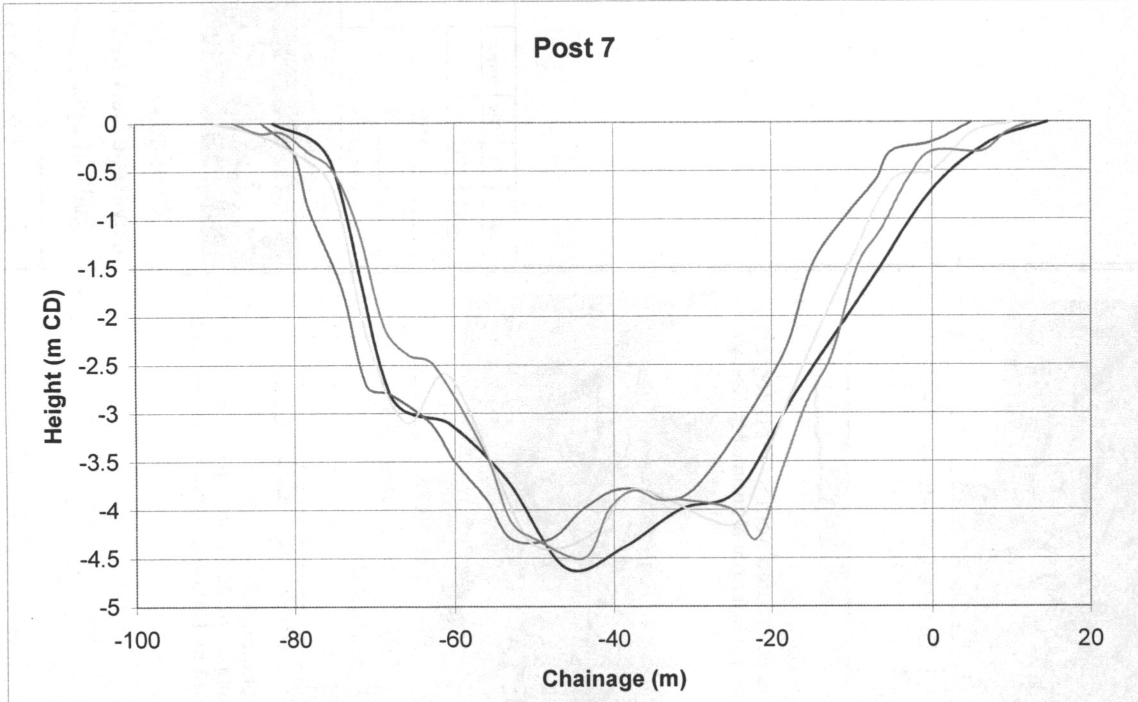
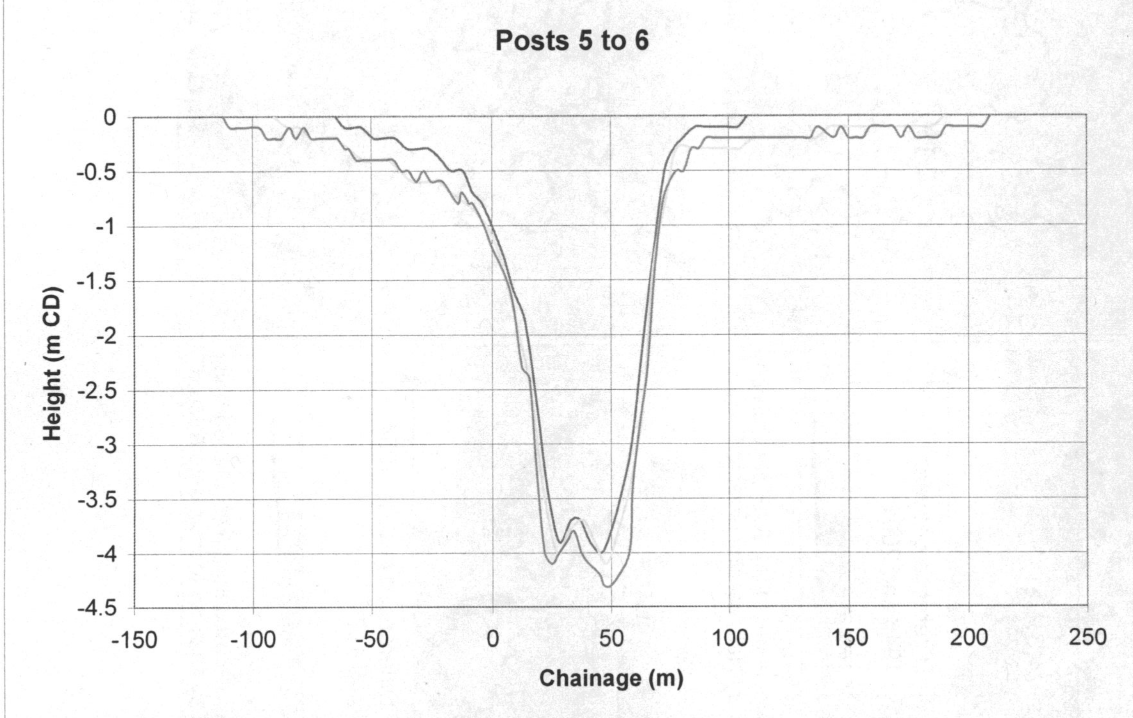
Bathymetric Cross-sections for Bag of Halfpence Post and Seymour Post

Figure 8





Date	By	Size	Version
Mar 2008	JAR	A4	1
Reference			
3772 - Wightlink			
Produced by ABPmer Ltd.			

Legend: Chainage measured South to North

- 1988
- 1993
- 1999
- 2006

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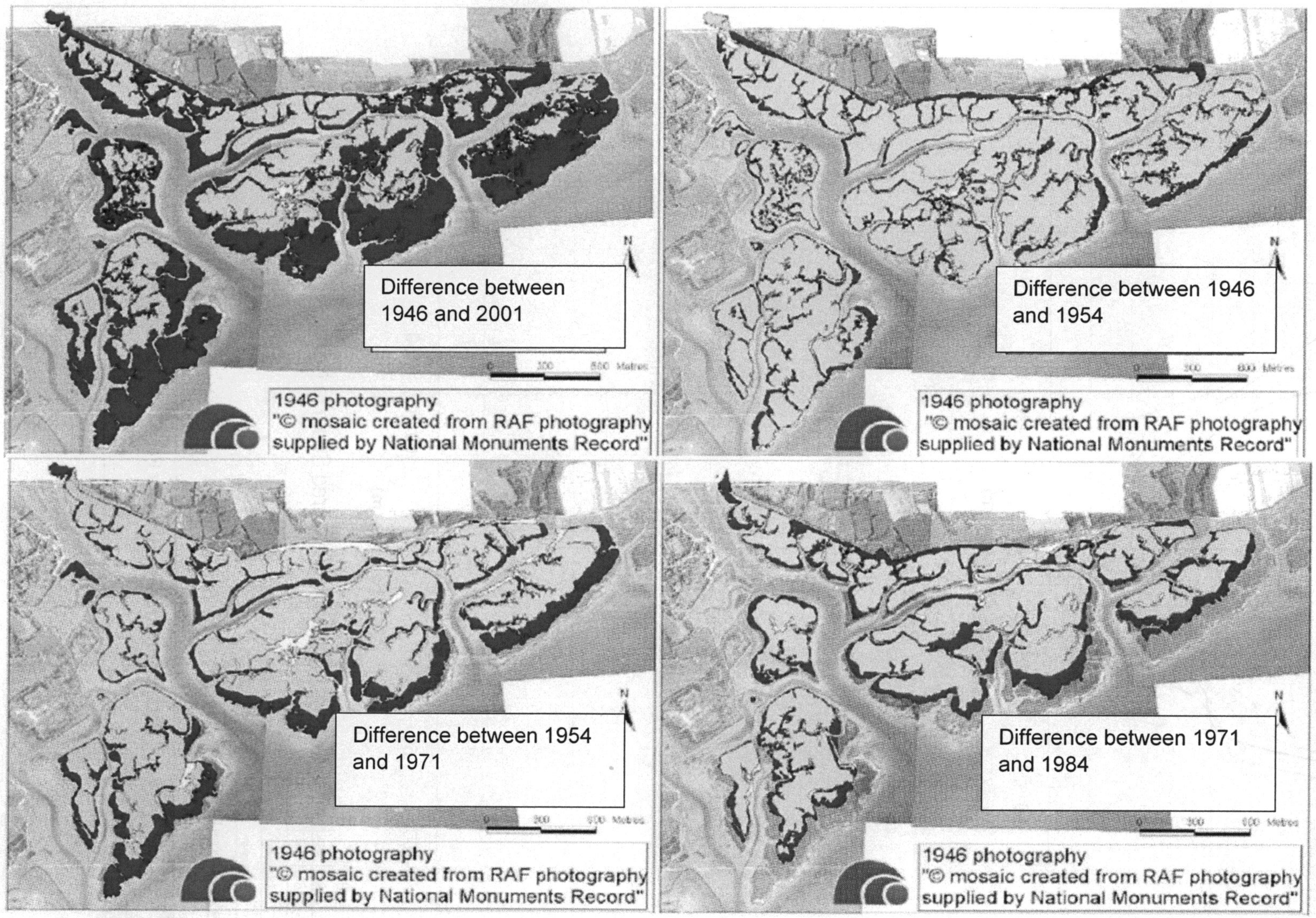
Bathymetric Cross-sections for Post 7 and Posts 5 and 6

Figure 9



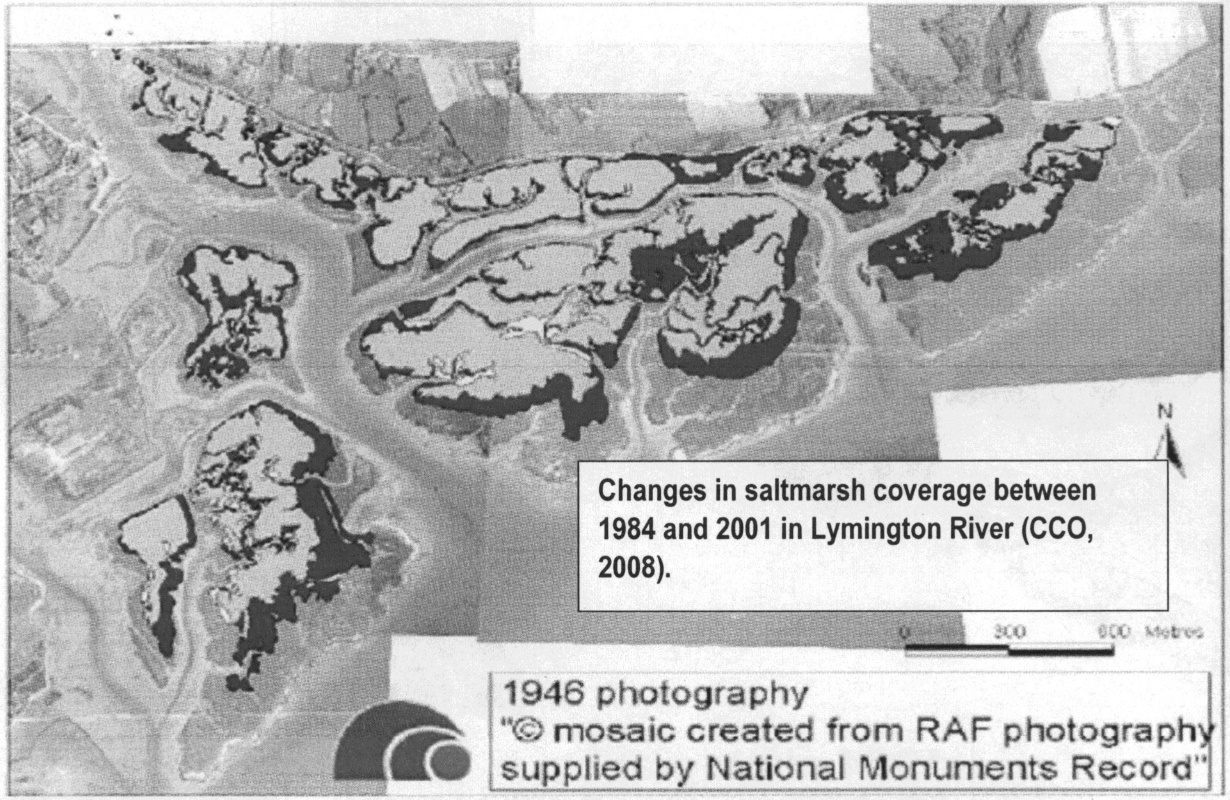
Date	By	Size	Version
May 08	PAR	A4	1
Reference			
3772-Fig_Saltmrsh_change.xls			
Produced by ABPmer Ltd.			

Cope et al.,2008

ABP mer
marine environmental research

Changes in Saltmarsh Coverage Between 1946 and 2001 in Lymington River

Figure 10a



Changes in saltmarsh coverage between 1984 and 2001 in Lymington River (CCO, 2008).

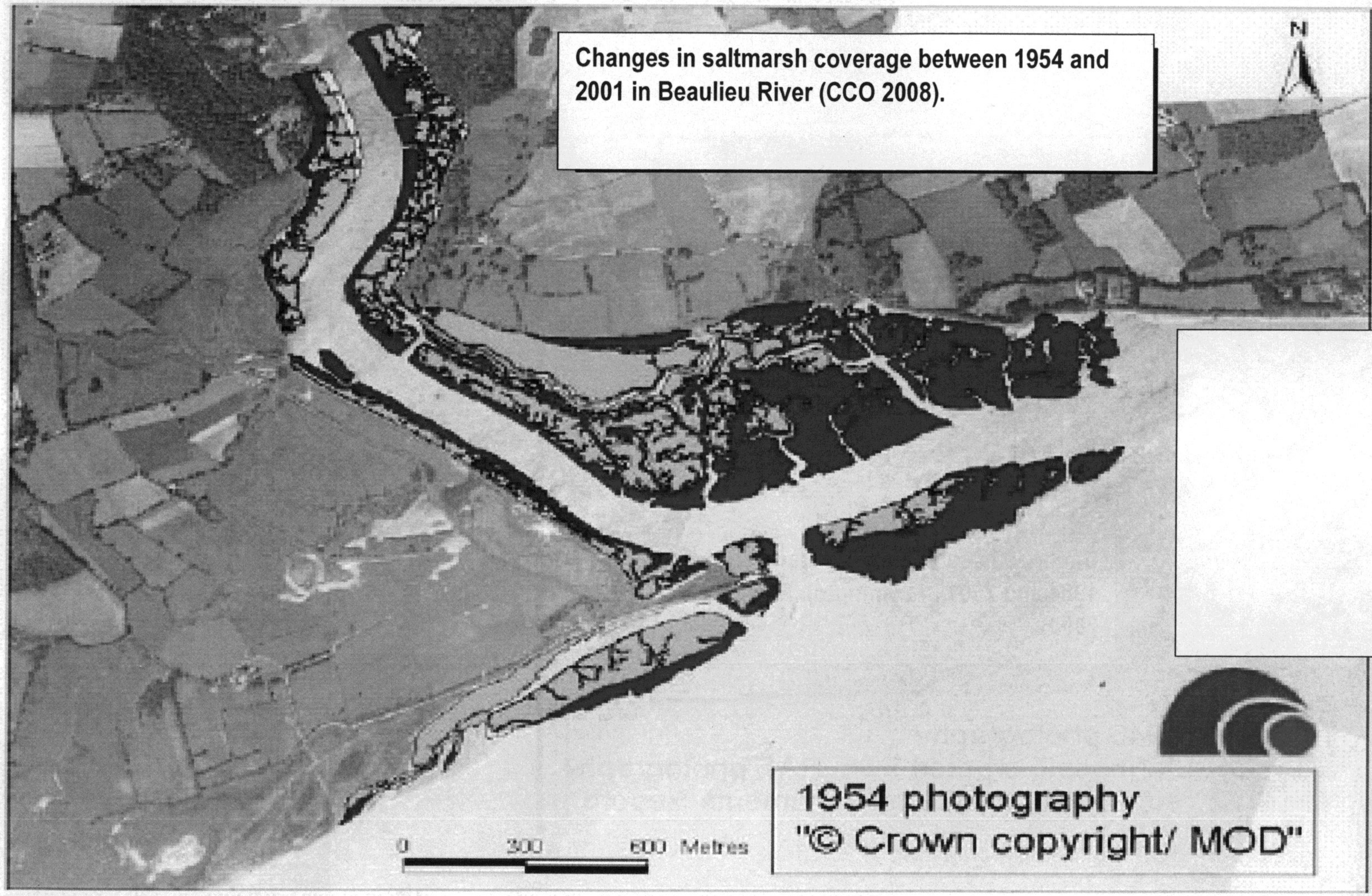
Date	By	Size	Version
May 08	PAR	A4	1
Reference			
3772-Fig_Saltmrsh_change.xls			
Produced by ABPmer Ltd.			

Cope et al., 2008

ABPmer marine environmental research

Changes in Saltmarsh Coverage Between 1984 and 2001 in Lymington River

Figure 10b



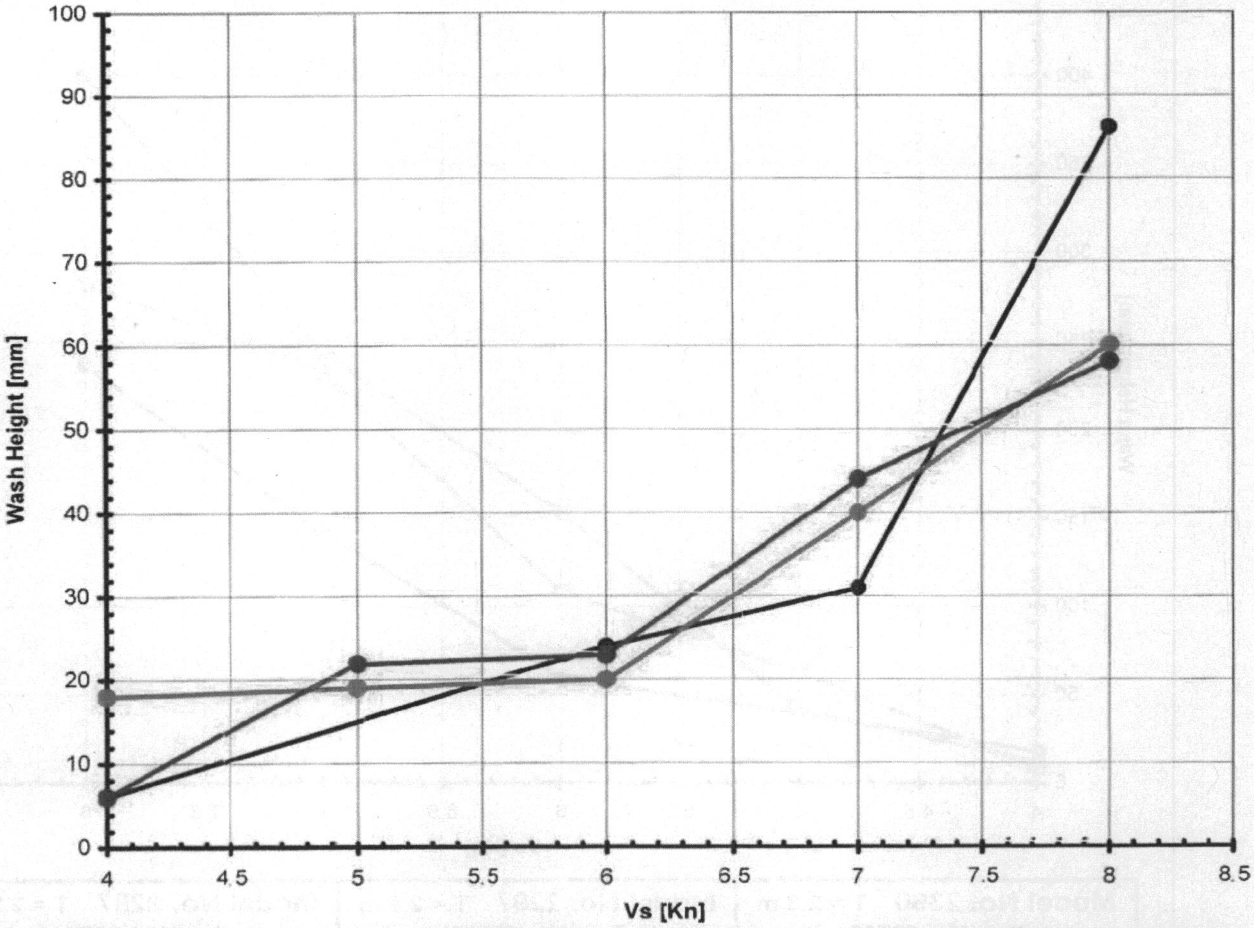
Date	By	Size	Version
May 08	PAR	A4	1
Reference			
3772-Fig_Saltmrsh_change.xls			
Produced by ABPmer Ltd.			

Cope et al.,2008

ABPmer
marine environmental research

Changes in Saltmarsh Coverage Between 1954 and 2001 in Beaulieu River

Figure 11



Model No. 2360 T = 2.3 m Test No. 28759		Model No. 2297 T = 2.1 m Test No. 28760		Model No. 2297 T = 2.3 m Test No. 28761	
V_S [Kn]	Wash Height [mm]	V_S [Kn]	Wash Height [mm]	V_S [Kn]	Wash Height [mm]
4	6	4	18	4	6
6	24	5	19	5	22
7	31	6	20	6	23
8	86	7	40	7	44
		8	60	8	58

'C' Class — Model No. 2360 T = 2.3 m Test No. 28759

'W' Class — Model No. 2297 T = 2.1 m Test No. 28760

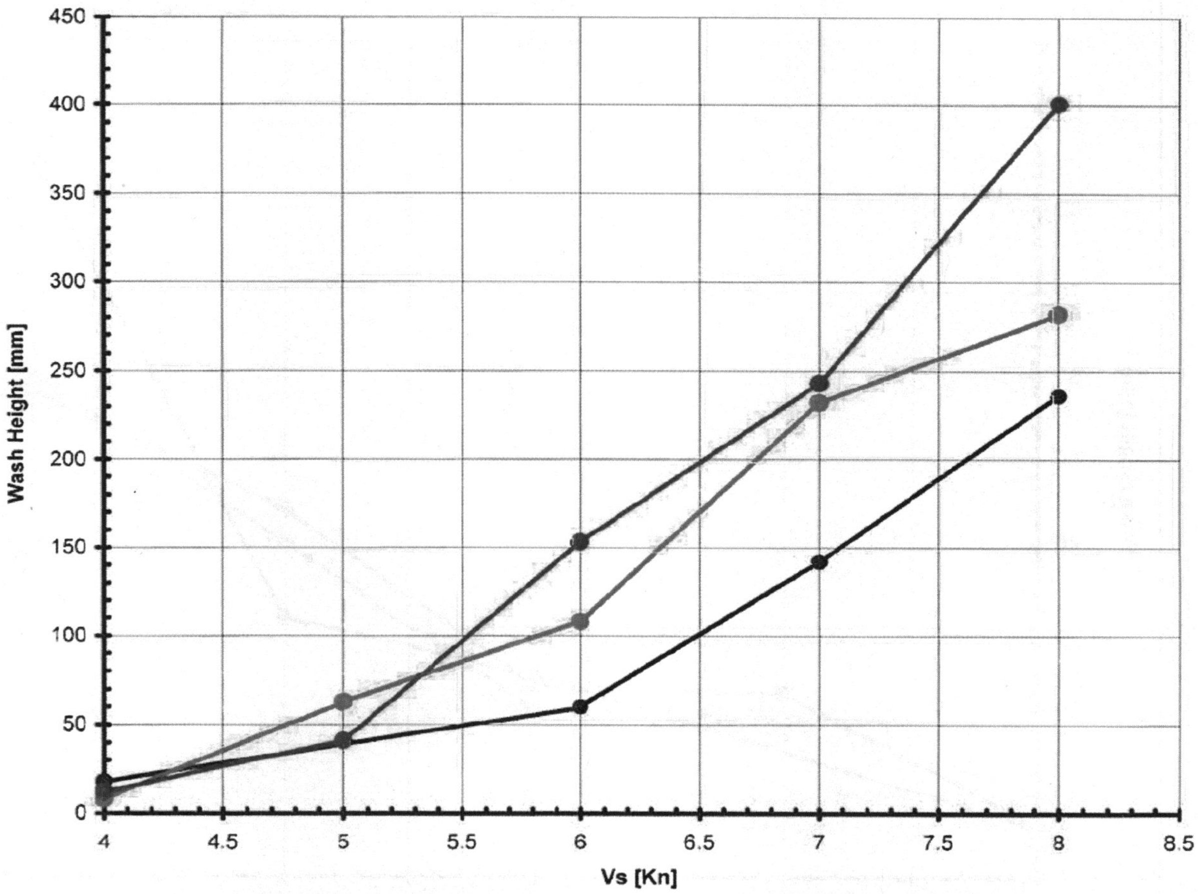
'W' Class — Model No. 2297 T = 2.3 m Test No. 28761

Date	By	Size	Version
Mar 2008	JAR	A4	1
Reference			
3772 - Vienna Wave Bow.xls			
Produced by ABPmer Ltd.			

ABP mer marine environmental research

Hydrodynamic Model Results of Bow Wave Height (after Vienna Model Basin, 2008)

Figure 12



Model No. 2360 T = 2.3 m Test No. 28759		Model No. 2297 T = 2.1 m Test No. 28760		Model No. 2297 T = 2.3 m Test No. 28761	
V_S	Wash Height	V_S	Wash Height	V_S	Wash Height
[Kn]	[mm]	[Kn]	[mm]	[Kn]	[mm]
4	18	4	8	4	12
6	60	5	63	5	41
7	142	6	108	6	153
8	236	7	232	7	243
		8	282	8	401

'C' Class — Model No. 2360 T = 2.3 m Test No. 28759

'W' Class — Model No. 2297 T = 2.1 m Test No. 28760

'W' Class — Model No. 2297 T = 2.3 m Test No. 28761

Date	By	Size	Version
Mar 2008	JAR	A4	1

Reference: 3772 - Vienna Wave Stern.xls

Produced by ABPmer Ltd.

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Hydrodynamic Model Results of Stern Wave Height (after Vienna Model Basin, 2008)

Figure 13

Date	By	Size	Version
Mar 2008	PAR	A4	1
Projection		OSGB 1936	
Scale		1:10,000	
QA		PAR	
3772 - Fig_WaveEnergy.mxd			
Produced by ABPmer Ltd			

Data Sources: Image/Data courtesy of the Channel Coastal Observatory

● Wave Energy Calculation Points

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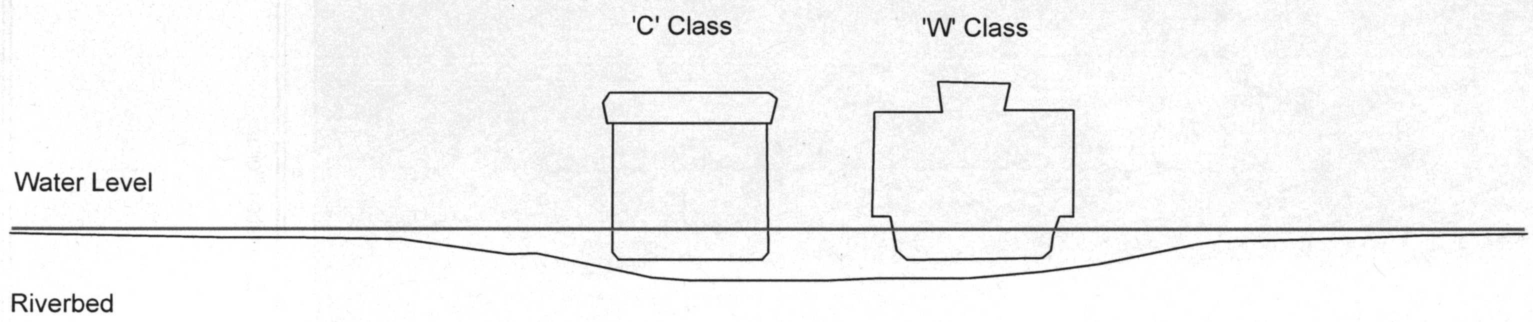
Wave Energy Calculation Points within Lymington River

Figure 14



Data Source: Hart, Fenton & Co. Limited

Date	By	Size	Version
May 2008	PAR	A4	1

Reference

3772 Ferries_Low Water

Produced by ABPmer Ltd.

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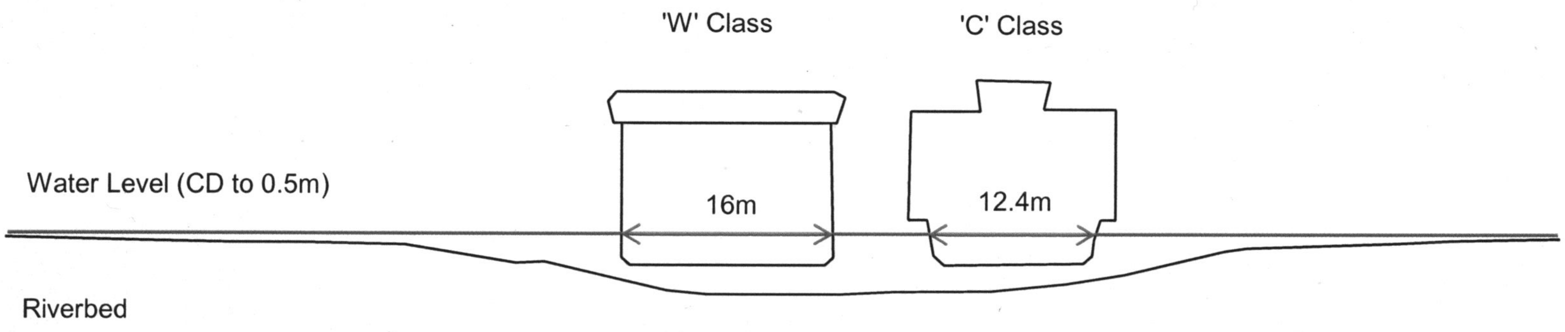
Class Ferries Relative to Low Water Channel

Figure 15



Data Source: Hart, Fenton & Co. Limited

Date	By	Size	Version
May 2008	PAR	A4	1

Reference

3772 CrossSection_and_Ferries

Produced by ABPmer Ltd.

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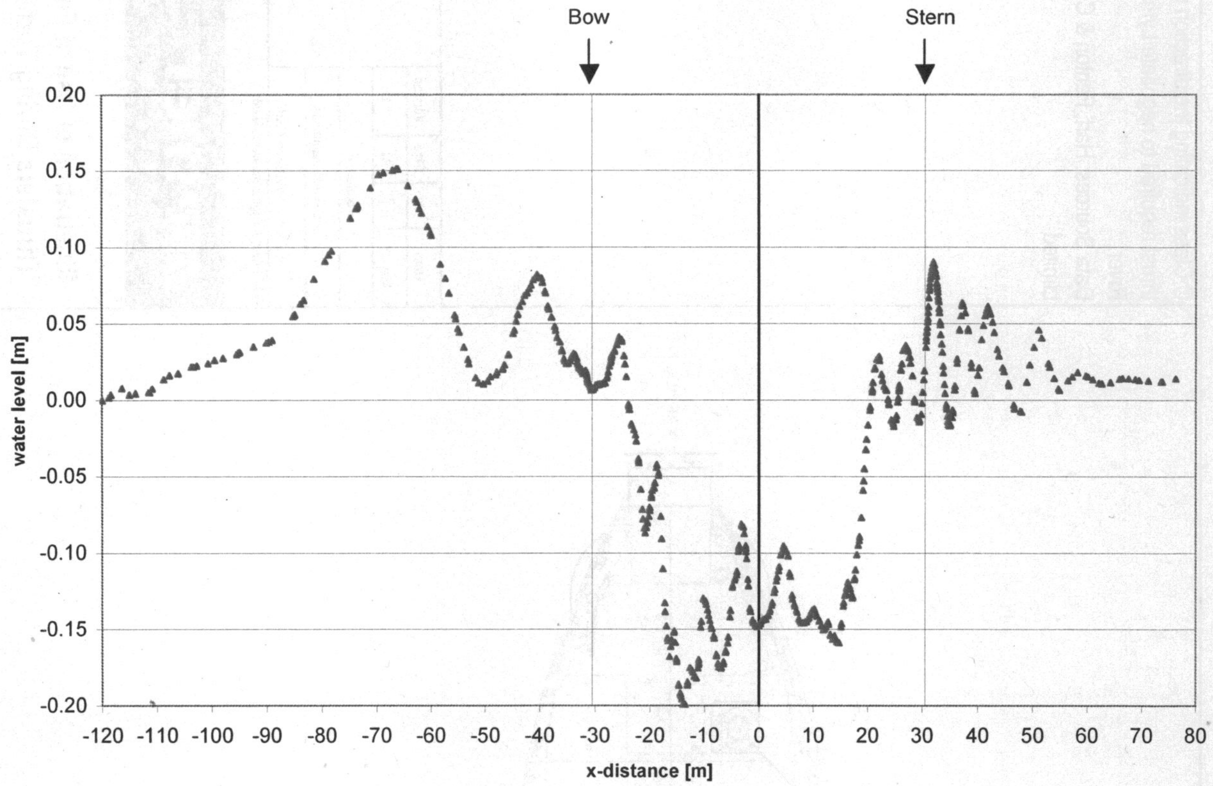
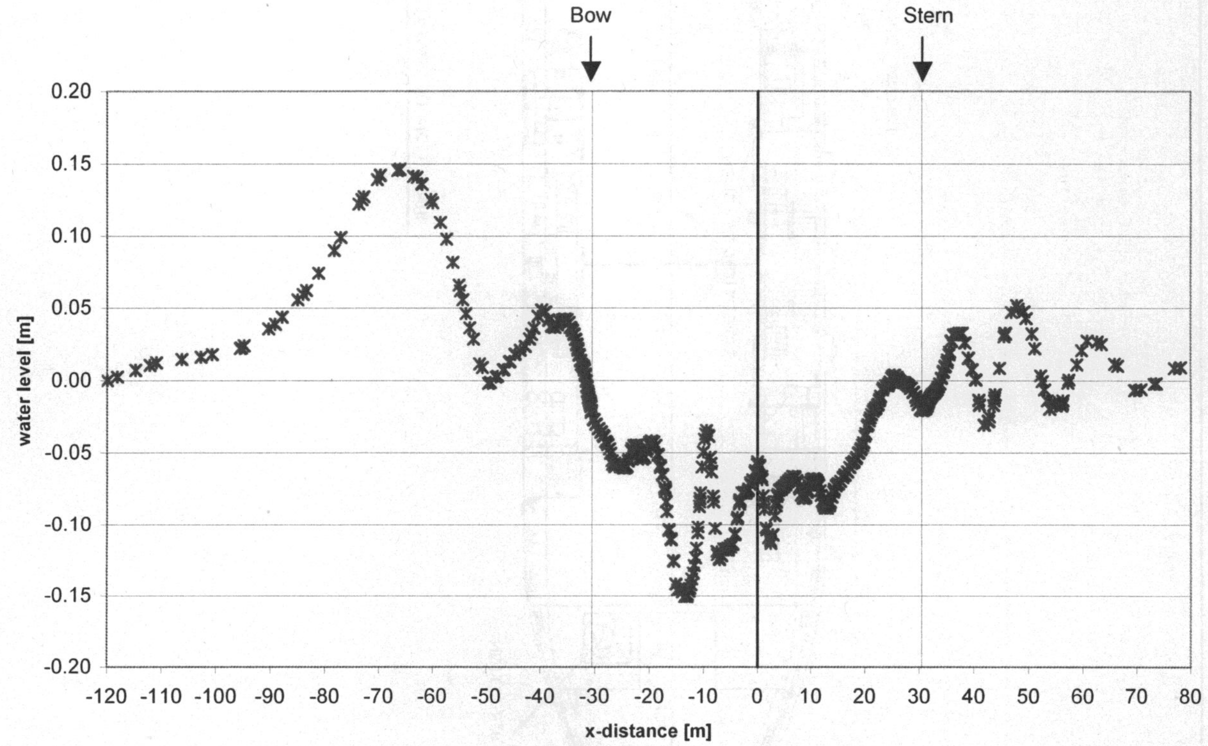
Size of 'C' Class and 'W' Class Ferries Relative to Low Water Channel.

Figure 15





Date	By	Size	Version
Mar 2008	JAR	A4	1

Reference

3469 - CFD wave heights.xls

Produced by ABPmer Ltd.

Top graph: 10 m from the centre line, 2.8 m from side of vessel;
Bottom graph: 20 m from the centre line, 12.8 m from side of vessel.

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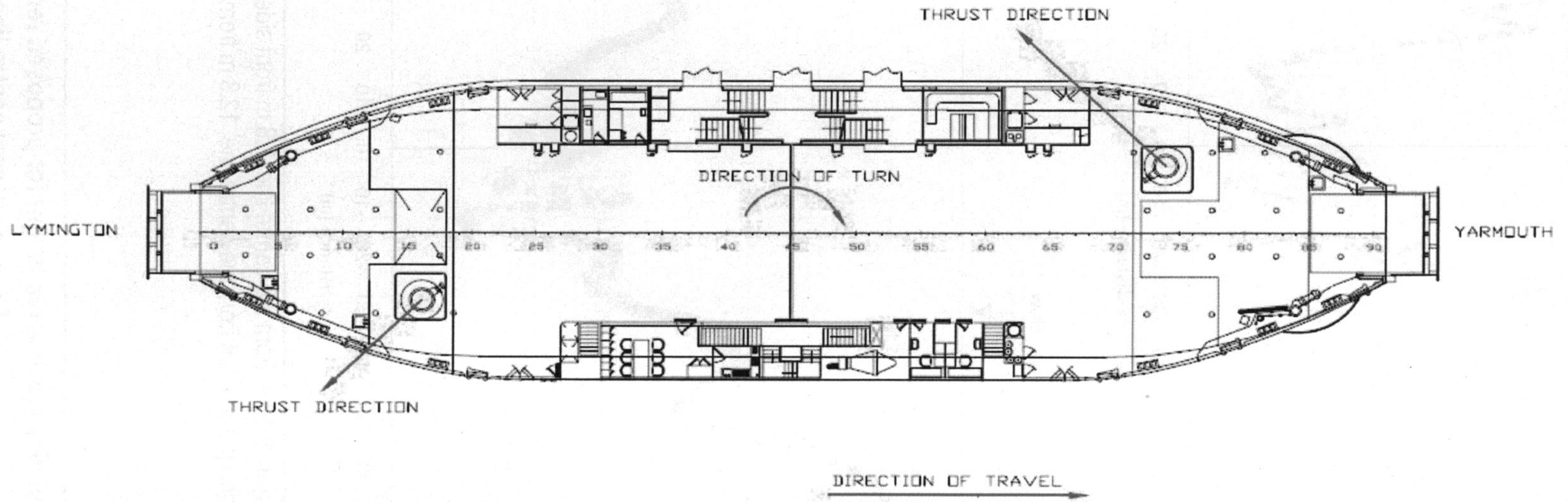
Modelled wash wave height for proposed ferries at 10 and 20m from the vessel centre line.

Figure 16



C Class indicating the direction of thrust required to negotiate Lymington River.
Data Sources: Hart, Fenton & Co. Limited

Date	By	Size	Version
May 08	PAR	A4	1
Reference			
3772 - Fig Thrust Diagram.xls			
Produced by ABPmer Ltd.			

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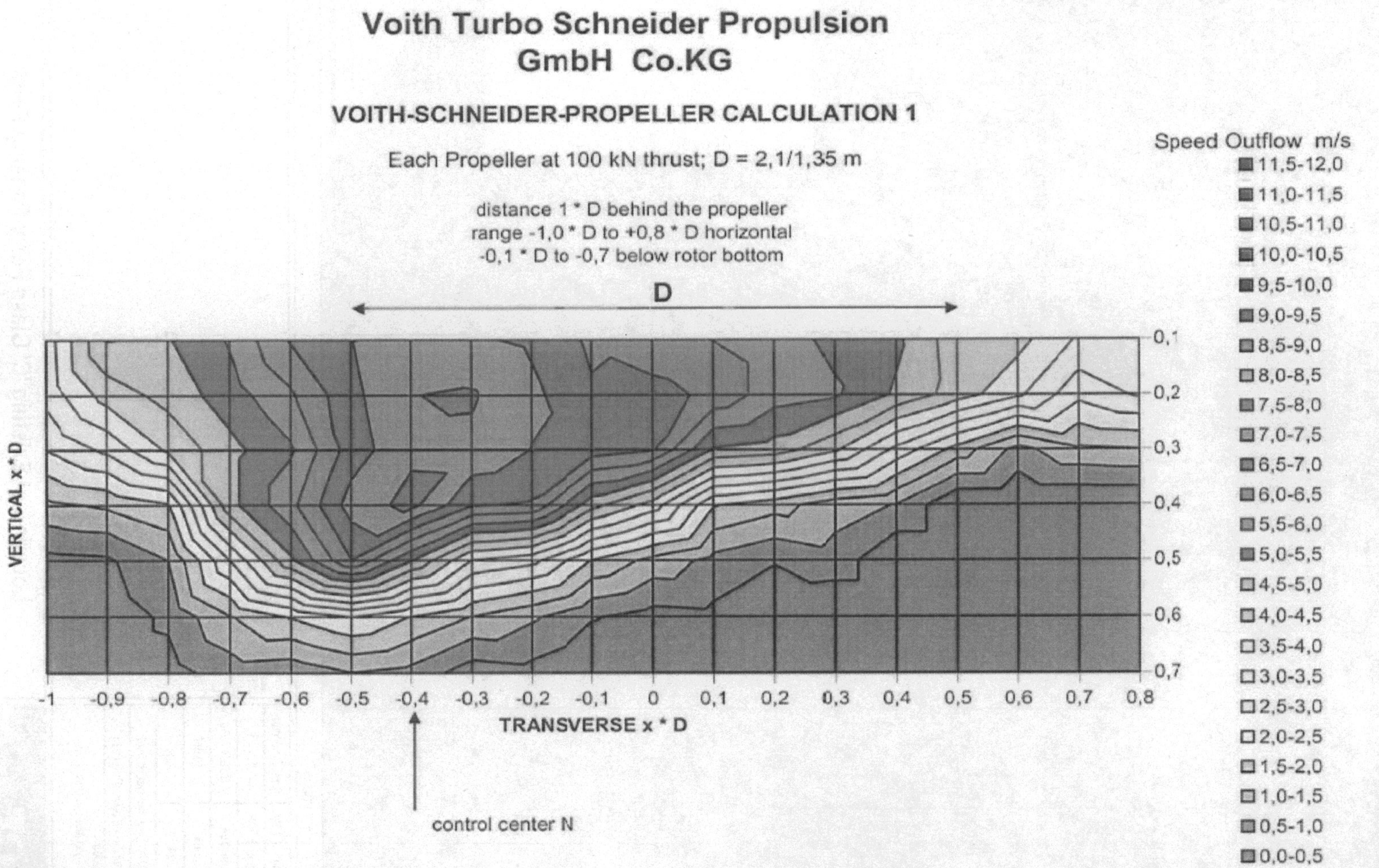
Illustration of Use of Ferry Thrusters During Turning

Figure 17



Date	By	Size	Version
May 08	DD	A4	1
Reference			
3772 - Fig_Voith_Dwnstrm.xls			
Produced by ABPmer Ltd.			

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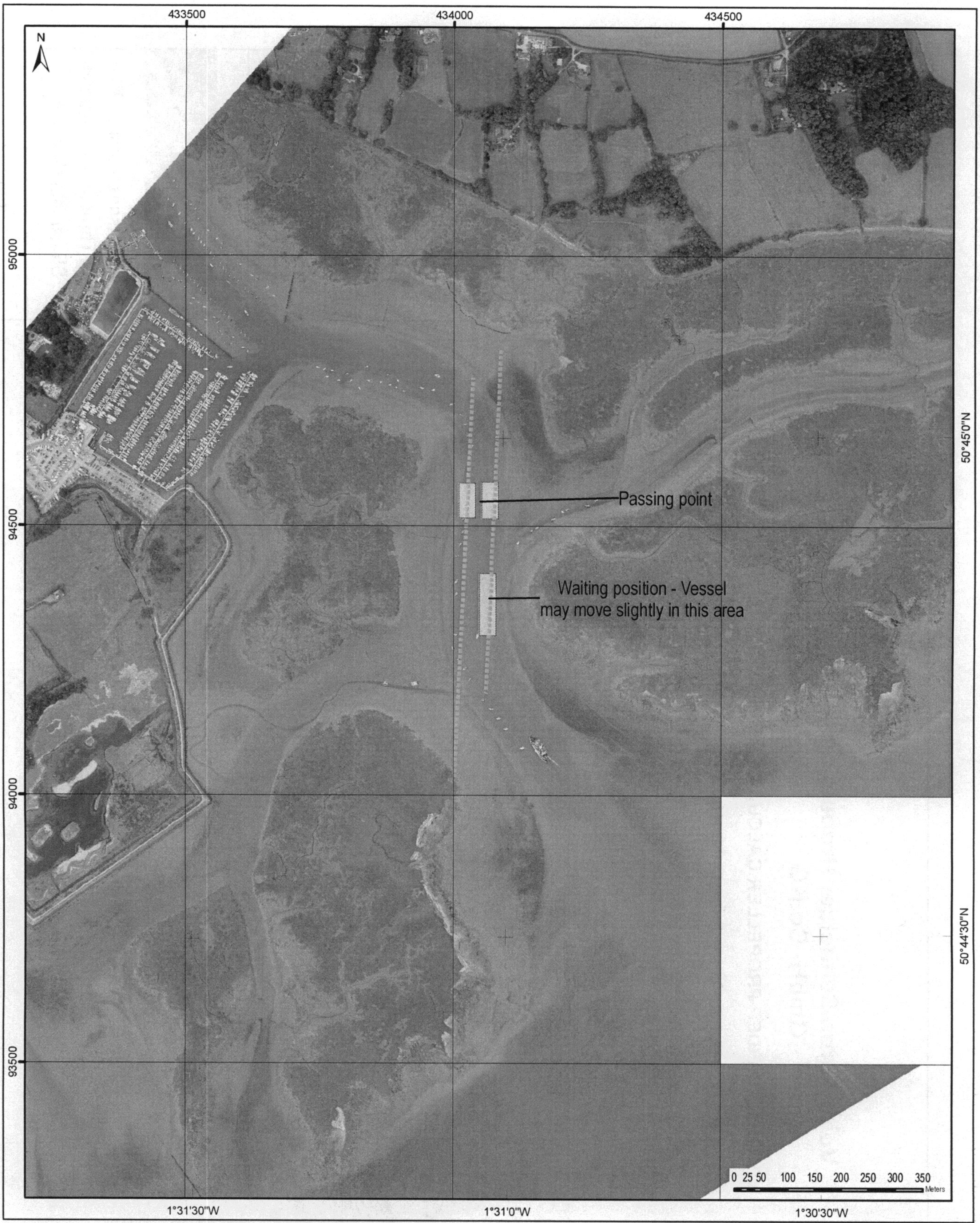
Voith Assessment of 'W' Class Thruster Downstream Slipstream Velocities

Figure 18



Date	By	Size	Version
Apr 2008	PAR	A4	1
Projection		OSGB 1936	
Scale		1:10,000	
QA		RJR	
3772 - Fig_Navigation.mxd			
Produced by ABPmer Ltd			

Navigation Line

Ferry Outline

Data Sources: Wightlink Ltd, Image/Data courtesy of the Channel Coastal Observatory

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Location of Existing 'C' Class Ferry Passing Point and Waiting Areas

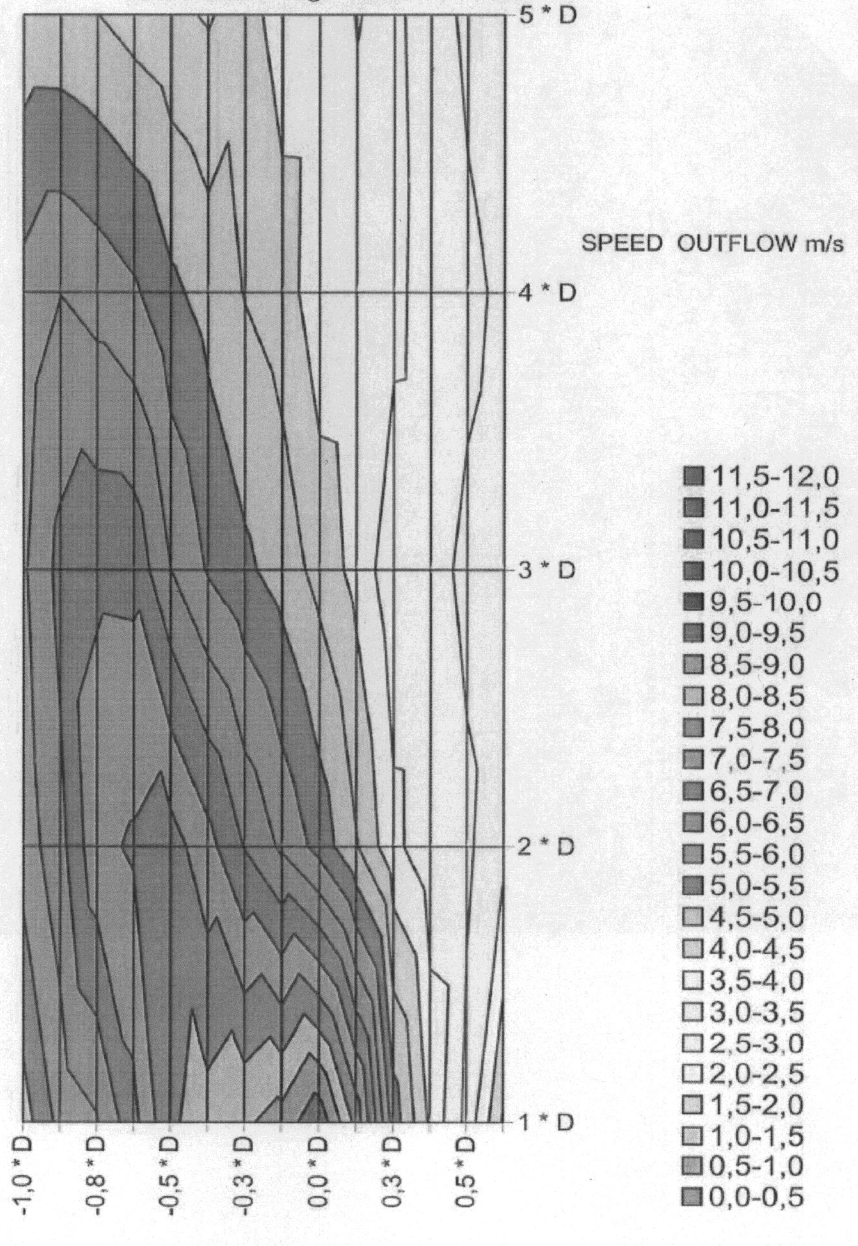
Figure 19

Voith Turbo Schneider Propulsion GmbH Co.KG

VOITH-SCHNEIDER-PROPELLER CALCULATION 1

Each Propeller at 100 kN thrust; D = 2,1/1,35 m

Range 1 * D to 5 * D behind the VSP-axis
-1 * D to +0,6 * D beside the VSP-axis
26% of blade length below rotor bottom



Date	By	Size	Version
May 2008	DD	A4	1
Reference			
3772-Fig_VoithAsmnt_Vert.xls			
Produced by ABPmer Ltd.			

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Voith Assessment of 'W' Class Thruster Vertical Slipstream Velocities

Figure 20

Date	By	Size	Version
Mar 2008	JAR	A4	1
Reference			
3772 - Fig_LymingtonBreakwater.xls			
Produced by ABPmer Ltd.			

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Proposed Lymington breakwater scheme

Figure 21

Appendix A

Comparison of Natural Wind Waves and Ferry Generated Waves: Methodology

Appendix A. Comparison of Natural Wind Waves and Ferry Generated Waves: Methodology

A1. Introduction

Wind data from Lee-on-Solent, covering two periods was used together with the knowledge of ferry movements, to compute the energy available within the wave climate generated from either source. Wind data from the period 1984-1991 was used as the baseline data in the analysis. Data from 1988-1997 was subsequently used to examine the natural variability in the wind-wave energy. The wind data has been presented as an annually normalised hourly frequency distribution, using 30 degree directional bins, and takes account of missing data (Tables A1 and A2). The distribution for the wind data sets has also been presented graphically (Figure A1) showing that the wind climate is dominated by winds from the southwest (240 degrees).

The SMB method (Bretschneider, 1958) was used to calculate the wind-wave heights given knowledge of the local fetch distances. This method has previously been used for Southampton Water. For the ferry generated waves, a method described by Verhey and Bogaerts (1989) was used to calculate the height of ship generated waves.

The available energy from either source was estimated using the square of the wave height to obtain the energy term. The two sources together provide an assessment of the baseline energy level. To compare the energies points were chosen in the centre of the main navigation channel and on either side of the channel (Figure A2).

Table A1. Wind frequency data for Lee-on-Solent (1984-1991)

Wind Speed (m/s)	Wind Direction (Degrees True +/-15°)												Total
	0	30	60	90	120	150	180	210	240	270	310	330	
	Frequency												
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.03	73	88	39	37	30	25	39	26	39	43	48	57	543
2.57	213	245	150	119	95	108	108	81	123	131	167	158	1698
4.37	230	265	200	149	130	167	137	141	281	224	170	136	2230
6.94	150	167	140	92	68	99	146	280	589	323	131	60	2244
9.77	33	44	28	21	9	34	84	211	375	169	48	10	1066
12.60	8	8	9	2	1	12	80	156	278	74	20	4	653
15.68	1	1	0	1	1	5	29	67	96	25	5	1	232
19.02	0	0	0	0	0	2	12	31	35	10	1	0	91
22.62	0	0	0	0	0	0	1	3	2	1	0	0	6
26.47	0	0	0	0	0	0	2	1	1	0	0	0	4
30.58	0	0	0	0	0	0	0	0	0	0	0	0	0
32.90	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**708**	**819**	**566**	**420**	**334**	**451**	**638**	**998**	**1818**	**999**	**589**	**427**	**8766**

Table A2. Wind frequency data for Lee-on-Solent (1988-1997)

Wind Speed (m/s)	Wind Direction (Degrees True +/-15°) Frequency												Total
	0	30	60	90	120	150	180	210	240	270	310	330	
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.03	67	62	43	41	29	24	32	22	32	42	50	49	492
2.57	197	187	155	121	108	90	81	61	98	119	159	141	1516
4.37	236	251	259	158	164	168	110	114	234	230	183	131	2237
6.94	174	202	191	103	108	121	135	228	578	344	153	69	2407
9.77	44	53	44	18	12	40	85	172	416	174	55	11	1124
12.60	12	11	6	2	2	18	63	134	314	80	26	3	670
15.68	1	1	0	0	0	4	18	62	117	20	6	1	232
19.02	0	0	0	0	0	1	6	25	39	7	1	0	79
22.62	0	0	0	0	0	0	0	3	3	1	0	0	7
26.47	0	0	0	0	0	0	0	1	1	0	0	0	2
30.58	0	0	0	0	0	0	0	0	0	0	0	0	0
32.90	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	733	767	699	443	422	465	532	821	1832	1016	633	404	8766

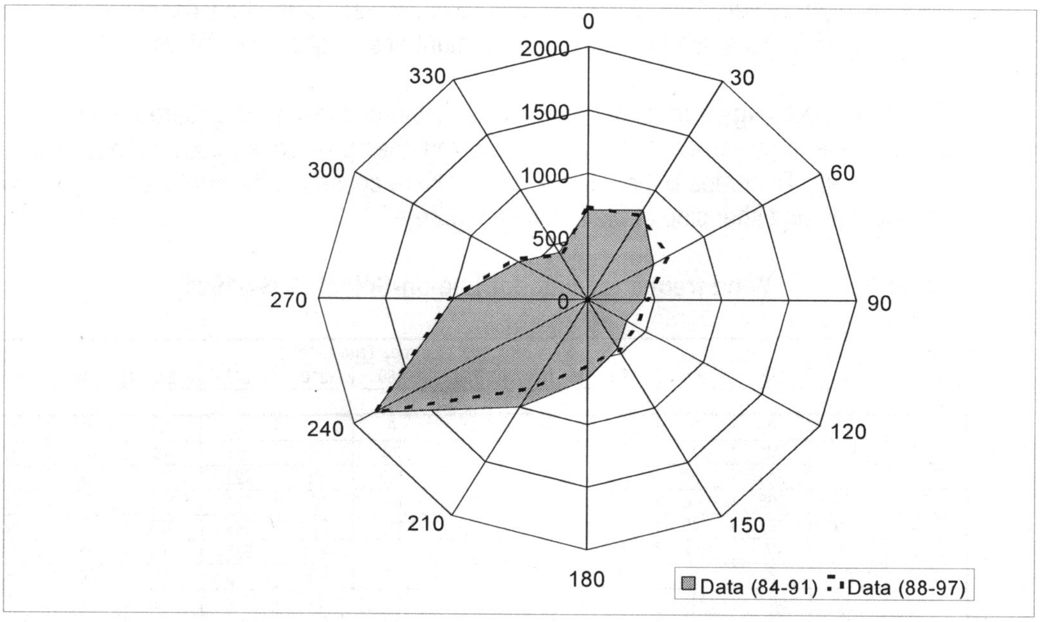

Figure A1. Annual wind frequency distribution for Lee on Solent

A2. Calculation of Wind-Wave Height

Wind-wave heights were calculated using an SMB (Sverdrup-Munk-Bretschneider) method of prediction. The SMB curves presented in Silvester (1974) were firstly curve fitted to obtain the following formulae:

$$H_s = 0.00338.\left(\frac{gF}{U^2}\right)^{0.439}.\frac{U^2}{g} \quad \text{for} \quad \frac{gF}{U^2} \leq 100 \qquad (1)$$

and

$$H_s = 0.00414.\left(\frac{gF}{U^2}\right)^{0.3947}.\frac{U^2}{g} \quad \text{for} \quad \frac{gF}{U^2} > 100 \qquad (2)$$

where:

H_s	= significant wave height (m);
g	= acceleration due to gravity (9.81ms^{-2});
U	= wind speed (ms^{-1});
F	= effective fetch length (m).

The effective fetch lengths for 16 points within Lymington River (Table A3 and Figure A2) were calculated within a MatLab routine developed by ABPmer. Significant wave heights for three of the locations are given in Tables A4 to A6.

Table A3. Effective fetch lengths calculated for 16 points within Lymington River

Location	Effective Fetch Length (m)											
	Direction											
	0	30	60	90	120	150	180	210	240	270	300	330
1	200	200	200	500	1000	1000	300	600	600	400	600	300
2	200	200	200	200	200	600	5000	900	600	800	1400	500
3	300	500	600	430	400	400	4800	5200	1000	1000	1000	800
4	800	700	1000	12200	6000	5200	4600	5000	500	800	1000	1400
5	400	700	2200	11800	5600	4800	4400	4800	1600	1200	800	1400
6	1200	600	700	12200	5600	4800	4200	300	300	300	300	300
7	900	400	400	12400	6000	5000	4400	200	200	200	600	400
8	800	700	400	600	6200	5200	200	200	600	600	1000	400
9	400	400	400	300	500	400	700	700	400	800	800	700
10	700	600	400	400	600	5400	500	400	600	400	400	300
11	400	400	600	600	800	300	600	400	600	400	400	1000
12	200	300	400	500	900	700	300	800	600	600	600	1000
13	300	300	300	300	600	500	5000	700	300	800	1000	800
14	500	400	700	300	300	5400	4800	500	800	300	400	900
15	800	600	300	500	6000	5200	4600	300	300	800	400	500
16	400	400	700	12000	5800	4800	4200	4800	400	400	800	700

Table A4. Significant wave heights at Point 2 (Cage Boom)

Wind Speed (m/s)	Wave Height (m)											
	Direction											
	0	30	60	90	120	150	180	210	240	270	300	330
1.03	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.02	0.02	0.02	0.02	0.02
2.57	0.03	0.03	0.03	0.03	0.03	0.05	0.11	0.06	0.05	0.05	0.07	0.05
4.37	0.06	0.06	0.06	0.06	0.06	0.09	0.21	0.11	0.09	0.10	0.13	0.09
6.94	0.10	0.10	0.10	0.10	0.10	0.16	0.37	0.19	0.16	0.18	0.23	0.15
9.77	0.15	0.15	0.15	0.15	0.15	0.24	0.57	0.28	0.24	0.27	0.34	0.22
12.60	0.19	0.19	0.19	0.19	0.19	0.32	0.77	0.38	0.32	0.36	0.46	0.29
15.68	0.25	0.25	0.25	0.25	0.25	0.40	1.01	0.48	0.40	0.46	0.59	0.37
19.02		0.31				0.50	1.27	0.60	0.50	0.57	0.73	
22.62						0.61	1.54	0.73	0.61	0.69		
26.47							1.84	0.87	0.73	0.82		
30.58												
32.90												

Table A5. Significant wave heights at Point 9 (Western side of Long Reach)

Wind Speed (m/s)	Wave Height (m)											
	Direction											
	0	30	60	90	120	150	180	210	240	270	300	330
1.03	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.02
2.57	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.05	0.05	0.05
4.37	0.08	0.08	0.08	0.07	0.09	0.08	0.10	0.10	0.08	0.10	0.10	0.10
6.94	0.14	0.14	0.14	0.12	0.15	0.14	0.17	0.17	0.14	0.18	0.18	0.17
9.77	0.20	0.20	0.20	0.18	0.22	0.20	0.25	0.25	0.20	0.27	0.27	0.25
12.60	0.26	0.26	0.26	0.23	0.29	0.26	0.34	0.34	0.26	0.36	0.36	0.34
15.68	0.34	0.34	0.34	0.30	0.37	0.34	0.43	0.43	0.34	0.46	0.46	0.43
19.02		0.42				0.42	0.54	0.54	0.42	0.57	0.57	
22.62						0.51	0.65	0.65	0.51	0.69		
26.47							0.78	0.78	0.61	0.82		
30.58												
32.90												

Table A6. Significant wave heights at Point 13 (Mid-channel in Long Reach)

Wind Speed (m/s)	Wave Height (m)											
	Direction											
	0	30	60	90	120	150	180	210	240	270	300	330
1.03	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.02	0.01	0.02	0.02	0.02
2.57	0.04	0.04	0.04	0.04	0.05	0.05	0.11	0.05	0.04	0.05	0.06	0.05
4.37	0.07	0.07	0.07	0.07	0.09	0.09	0.21	0.10	0.07	0.10	0.11	0.10
6.94	0.12	0.12	0.12	0.12	0.16	0.15	0.37	0.17	0.12	0.18	0.20	0.18
9.77	0.18	0.18	0.18	0.18	0.24	0.22	0.57	0.25	0.18	0.27	0.30	0.27
12.60	0.23	0.23	0.23	0.23	0.32	0.29	0.77	0.34	0.23	0.36	0.40	0.36
15.68	0.30	0.30	0.30	0.30	0.40	0.37	1.01	0.43	0.30	0.46	0.50	0.46
19.02		0.37				0.46	1.27	0.54	0.37	0.57	0.63	
22.62						0.56	1.54	0.65	0.45	0.69		
26.47							1.84	0.78	0.54	0.82		
30.58												
32.90												

A3. Calculation of Wind-Wave Energy

The energy per unit area of sea surface (E) for linear waves in deepwater is given by:

$$E \propto \frac{\left(\rho g H_s^{\;2}\right)}{8} \qquad (3)$$

where:

ρ = density of water (kgm^{-3});
g = acceleration due to gravity ($9.81ms^{-2}$).

For comparative purposes, only the term H_s^2 need be calculated to evaluate the available energy, since other terms are constant.

The derived values for wind generated wave heights (Table A4-A6) were used to generate a value for the energy available at the mid channel and incident on the each side of the River. The method used involved multiplying the square of the calculated wave height with the average annual frequency of occurrence from a particular direction and speed range as follows:

$$E \propto H_i^{\;2}.f_w.t \qquad (4)$$

where:

f_w = annual recorded frequency for wind;
t = duration (1 hour).

A4. Calculation of Ship Wave Height

The action of a vessel moving through water produces two distinct types of waves. Diverging waves, which are produced from the bow and stern of a vessel, and transverse waves. The interaction of these waves produces interference peaks known as ship waves. It is these waves that propagate at 35.3 degrees to the direction of travel, which are noticed by an observer on the bank of a waterway (Figure A3). The spectral characteristics of such waves are not well understood, but simplistically, an observer would notice an initial peak wave form, produced by bow ship waves with a rapid dissipation, and then followed by stern ship waves.

A method for calculating the height of the wave at a given distance from a vessel was presented in ABP Research R.495 (1995) and used a method described in Verhey and Bogaerts (1989). This method has also been applied to the present study, using the following equations:

$$H_i = h.\alpha_1.\left(\frac{s}{h}\right)^{-0.33}.F_s^{\alpha 3} \quad (5)$$

where:

H_i	= peak height of ship wave (m);
h	= water depth (m);
s	= distance from the ship to side of bank (m);
F_s	= Froude number given by:

$$F_s = \frac{V_s}{(gh)^{0.5}} \quad (6)$$

where:

V_s	= ship speed (ms^{-1});
g	= acceleration due to gravity ($9.81ms^{-1}$).

The coefficient α_1 and the exponent α_3 are derived from model and full-scale tests. These resulted in $\alpha_3 = 4$. The value of α_1 has been found to vary for vessel type and shape. For larger vessels the ratio of ships draught to a measure of the bow shape has been found to be important and follows the relationship;

$$\alpha_1 = \alpha_2.\frac{T}{L_e} \quad (7)$$

where:

T	= ships draught (m);
L_e	= distance from the bow to the start of the parallel midship section (m).

Tests on passenger ships, tankers, ferries and container ships show α_2 lies in the range 1.5 to 4. Verhey and Bogaerts (1989) recommend that for larger vessels a value of $\alpha_2 = 4$ should be used unless actual values of α_1 are known for the ship type. In the absence of known values for α_1, a value of $\alpha_2 = 4$ has been used, with L_e = 15m for most container vessels; therefore, representing a worst case scenario.

The equations used for calculating the height of ship generated waves are only applicable in deep water (wave characteristics independent of depth) and where the waves do not break. Within shallow water, wave forms will undergo some modification by interaction with the bed (shoaling), where, wave height can increase and wavelength decrease, until a critical point is reached when breaking occurs. For the ship generated waves under consideration here, breaking would only be applicable in water depths of much less than 1m. Therefore, the methodology provides an adequate basis for comparison of the relative energies incident onto the intertidal in water depths of at least 1m. As an example, for a ship wave of 0.65m at source, attenuation would reduce the height to about 0.4m at a distance of 700m, and breaking would occur in about 0.5m of water.

A5. Calculation of Ship Wave Energy

The energy available from ships waves was calculated by multiplying the square of the wave height with the annual frequency of vessel movement and the duration of wave activity (equation 8). The nature of ship generated waves on approaching the shore is quite complex and hence the duration of the peak wave activity cannot easily be expressed. For this study some visual observations have shown that the duration of the effect on the shore is approximately 30 seconds. However, the peak wave heights calculated from equation 5 only lasts for a fraction of this time, and as such the estimation of energy can be considered as an over-estimate.

$$E \propto H_i^2 . f_v . t \qquad (8)$$

where:

f_v = frequency of vessel movements;
t = duration of wave activity (hrs).

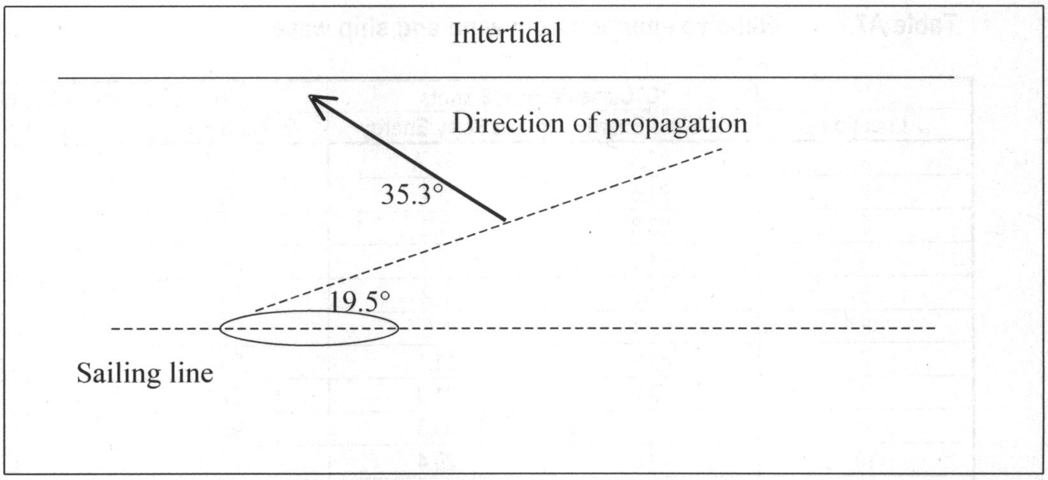

Figure A3. Nature of ship generated waves

A6. Vessel Traffic

The frequency of ferry traffic was used to examine the contribution and importance of ship generated waves. The number applied was 22,250 sailings per annum.

A7. Results - Energy Comparisons

The results presented in Table A7 show the relative energy levels generated from wind and ferry waves, at each of the positions shown in Figure 14. Locations 1 to 5 are on the eastern side of the channel, 6 to 11 are on the western side and 12 to 16 are in mid-channel. The results show that on the eastern side, which is more exposed to the predominant wind direction, the annual percentage contribution of energy is dominated by that from wind, as would be expected. On the more sheltered western shore the energy from the ferry waves forms a higher proportion of the total. It is important to note that attenuation will reduce the wave height and hence energy on reaching the intertidal locations from both sources. This assessment method does not take into account the changing water level in terms of the water depth and the varying fetch lengths as a result and therefore only gives an order of magnitude of the relative effect of the natural forces and the ferry generated forces for the existing conditions. However, the use of mid-tide level gives an indication of these relative magnitudes at the level of the intertidal mudflat.

The results show that the wave energies produced by the 'C' class ferries travelling at the previous operating speed of 8 knots are on average 17% of the total energies; whereas the average predicted energies produced by the new 'W' class ferries at the speed limit of 6 knots are substantially lower, at only 2%.

Table A7. Relative energies from wind and ship waves

	'C' Class Ferry at 8 knots		'W' Class Ferry at 6 knots	
Location	% Wind Energy	% Ferry Energy	% Wind Energy	% Ferry Energy
1	87.3	12.7	98.9	1.1
2	91.6	8.4	99.3	0.7
3	95.8	4.2	99.7	0.3
4	94.1	5.9	99.5	0.5
5	97.8	2.2	99.8	0.2
6	93.4	6.6	99.5	0.5
7	88.9	11.1	99.0	1.0
8	78.7	21.3	97.9	2.1
9	66.7	33.3	95.6	4.4
10	73.6	26.4	97.3	2.7
11	68.4	31.6	96.5	3.5
12	70.9	29.1	96.9	3.1
13	76.2	23.8	97.6	2.4
14	79.5	20.5	98.0	2.0
15	77.8	22.2	97.8	2.2
16	86.4	13.6	98.8	1.2

A8. References

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ABP mer
marine environmental research

ABP Marine Environmental Research Ltd
Suite B, Waterside House
Town Quay
Southampton
Hampshire SO14 2AQ

Tel: +44 (0)23 8071 1840
Fax: +44 (0)23 8071 1841
Email: enquiries@abpmer.co.uk

www.abpmer.co.uk