Pagham Parish Council

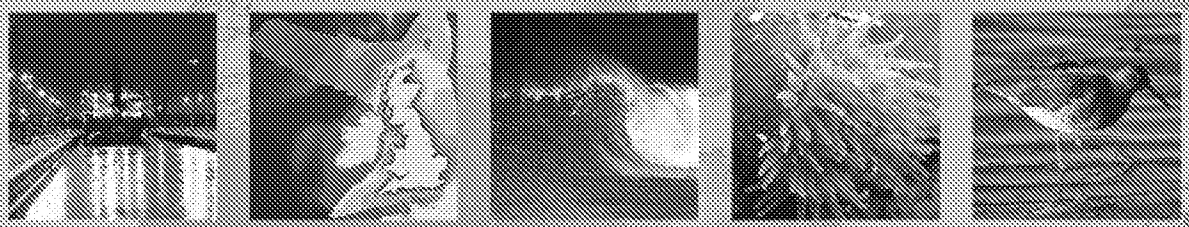
Managed Breach of Shingle Spit at Pagham: Environmental Statement

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Creating sustainable solutions for the marine environment



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Pagham Parish Council

Managed Breach of Shingle Spit at Pagham: Environmental Statement

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Non-Technical Summary

Project Background

On behalf of the local community at Pagham (West Sussex), the Pagham Parish Council (PPC), and its working group, the Pagham Flood Defence Steering Group (PFDSG), are proposing to undertake a managed breach of the shingle spit at the mouth of Pagham Harbour. The main aims of this shoreline adjustment are to move the coastline towards a more sustainable morphology[1] and address the coastal erosion, amenity and human health problems presently being experienced along the adjacent Pagham Beach.

The project represents a 'soft' solution to these problems because it seeks to mimic a process (i.e. breaching of the spit) that has happened naturally in the past and is likely to occur in the longer-term future (though probably not within the next decade). However, it does this in a predictable and controlled way to address immediate problems and also buy time for the ongoing adaptive management of this coastline.

The main erosion problems at Pagham Beach are largely being caused by the growth of the 'Church Norton Spit' in front of Pagham Harbour. Over the last decade, this spit and the Pagham Harbour tidal inlet channel has extended northwards along Pagham Beach; and this has caused/allowed the inlet channel to cut into the beach leading to rapid localised shoreline retreat. The formation of the spit, tidal channel and its fronting 'ebb delta' feature[2] are also 'locking up' shingle and not allowing it to reach the more slowly eroding up-drift sections of the Pagham foreshore via the usual sediment transport pathways.

The proposed managed breach of Church Norton Spit is designed to alleviate the problems arising in a proactive manner that works with natural coastal processes and then also allows these processes to continue being the dominant factor influencing the coastline. Compared to alternatives (as described further below), this approach can achieve more natural, cost-effective, and spatially extensive, coastal protection improvements as well as benefits to human health and site amenity.

A further benefit arises from the fact that it is very much a 'community project'. It was the local community who originally emphasised the need for it and have continued to be supportive as the design has been developed (see next sections). This proposal will inherently help the community to re-engage with the environment on their doorstep rather than viewing it as a threat to homes on the beach. Members of the community have also volunteered to play an active role in the management of the environment following the implementation of such a measure. Thus, the potential exists for greater coherence between the needs of the environment and the community.

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1 i.e. one that is more natural, self-maintaining, requires less frequent and costly intervention and has a wider range of social ecological and economic benefits than alternatives (in keeping with the principles of sustainable development as directed by the National Planning Policy Framework (NPPF)).

2 The ebb delta is the area of deposited shingle that lies in front of (on the seaward side of) the inlet and is where shingle is deposited due to the nature of the tides draining Pagham Harbour.

ARUN DISTRICT COUNCIL P/93/25/PL

In addition, the proposed breach is expected to be slightly more stable when compared to the existing tidal inlet position and is predicted to allow for a marginally improved tidal exchange in the harbour. Also, in the unlikely event that the new breach closed, it is likely to be more easily re-opened than if the current spit and inlet closed up. Thus, while environmental effects will occur from this proposal, that are reviewed in detail within this assessment (and mitigation/compensation measures identified where relevant), there will be inherent long term environmental benefits associated with this scheme (e.g. for water quality and ecology) in terms of greater assurances that the tidal functioning of Pagham Harbour will be maintained.

Report Background

In order to take this proposed project forward, PPC and PFDSG are seeking planning permission under the Town and Country Planning Act (1990), as well as appropriate consents and permissions from other regulators. To underpin a planning application, an Environmental Impact Assessment (EIA) is required and this Environmental Statement (ES) reports the findings of the EIA process.

This ES also includes the necessary information for CDC and ADC (as Competent Authorities) to produce an Appropriate Assessment (AA) under the Habitats Regulations (Conservation of Habitats and Species Regulations 2010 (as amended)). In addition, a range of other studies that are needed to underpin the planning and consents processes have been undertaken. These include a Marine Conservation Zone (MCZ) Assessment, a Water Framework Directive (WFD) Assessment and a Transport Statement.

Development of the Community Proposal

On behalf of PPC, ABPmer (with input from other relevant specialists as required) has undertaken a sequence of studies (since October 2014) to verify and develop this proposal. These studies have included: reviewing the proposed project against alternatives; identifying a preferred design; confirming the construction methods and then undertaking the required impact assessment work. During these studies, regular consultations have been held with regulators, relevant specialists and the local community. Also, throughout this process, the high nature conservation value of Pagham Harbour has been recognised as have the uncertainties that are inherent in working with nature in the way that is proposed.

The project that is proposed following this work is different from past proposals to address coastal erosion problems at Pagham Beach (including past proposals to breach the spit). The previous proposals have mainly involved (or included) using revetments or groynes to retain parts of the beach in place. The current proposal has no hard engineering or fixed structures or revetments and instead, as outlined above, seeks instead to allow natural processes to continue dominating the environment but from a new starting point. Further detail about the proposed project is presented below.

Description of the Community Proposal

It is proposed that the managed breach would be excavated where the harbour mouth/inlet was located throughout much of the latter part of the 20th century (although this position has been highly variable). This is considered to be the best position for creating a more stable breach because it will most

ARUN DISTRICT COUNCIL P/93/25/PL

efficiently accommodate the ebbing tides as they flow from the harbour. These flows are influenced by a man-made training wall at the western end of the Pagham foreshore and the breach has been carefully positioned relative to this training wall to take advantage of the channel meander that is directed by the angled training wall. The excavated shingle will then be used to locally infill an adjacent part of the existing tidal channel. The proposed project is illustrated in Image NTS1.

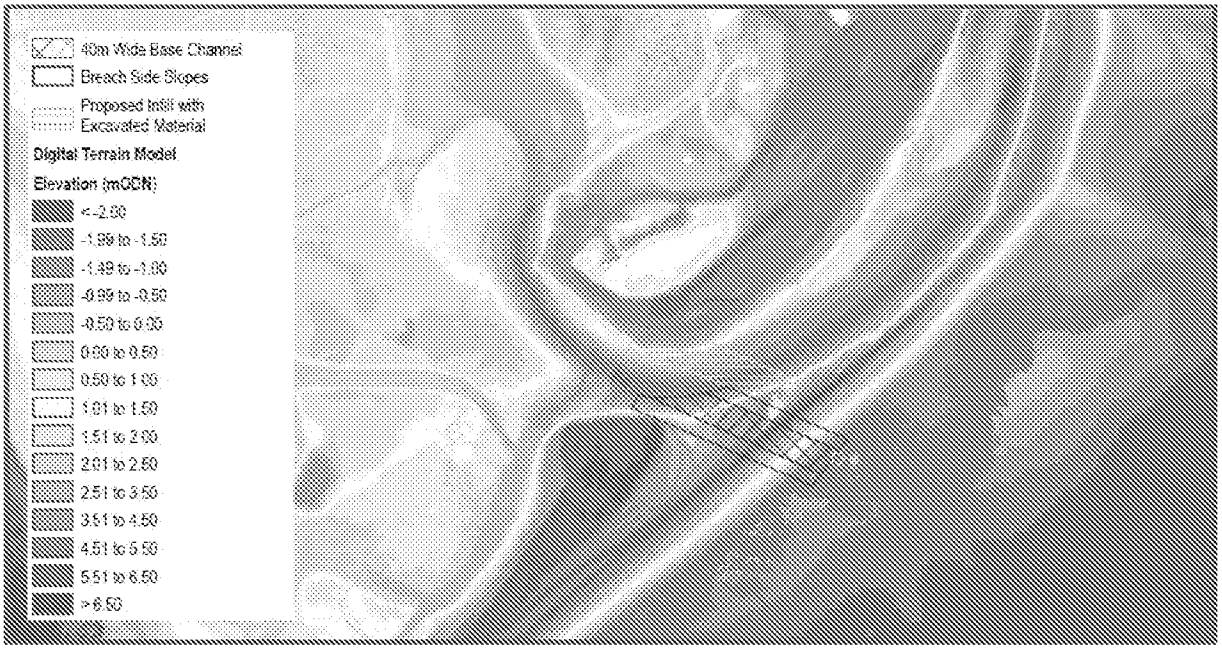


Image NTS1. Proposed project showing preferred breach design and location of infill

The proposed breach design would be 40 m wide at its base (which would be set at the Mean Low Water (MLW) elevation) and 80 m wide at the Highest Astronomical Tide (HAT) level. The excavated volume to the top (crest) of the spit within the breach area would be around 52,500 m³.

A contractor with specific experience of undertaking breaching work on shingle barriers has visited the site and provided a method statement for the work. On the basis on their advice, the work is expected to take 9 to 11 weeks to complete. It will involve plant being based in the currently closed car park at the end of Harbour Road (Pagham) which will then access the breach site via fixed and clearly defined access routes. To get plant on to the site at the start of the work, a transient shingle access route will be created across the channel towards the eastern end of the spit. This 'mobilisation route' will not be fixed in place but will, after it has been used once, be allowed to naturally erode into the environment. Thereafter the plant will largely remain on the spit until the completion of the excavation (unless weather conditions make this unsafe).

It will also be necessary to have a more established access causeway during the construction period for reasons of safety and to allow regular transits of fuel bowsers. This causeway would be created at the low-water level in a position where the excavated material is going to be placed for the channel infill (see Image NTS1). This causeway will be fixed in place using a sheet steel piling wall during the work but these temporary piles will be removed at the end of construction.

ARUN DISTRICT COUNCIL P/93/25/PL

Post-Breach Management

Once the breach has been excavated it is expected to evolve, deepen preferentially and become self-maintaining although it will continue to be subject to changes in shape over time because of the variable nature of the environment. The new breach in the position that is proposed, and with a shorter tidal channel, is likely to be more stable and less likely to close than the inlet in its current position. Once the existing channel is closed and the new breach is created, natural processes will take over and no regular ongoing management of the site (e.g. maintaining the breach position) is anticipated. However, as a contingency measure, it is recommended that the option for one subsequent breach maintenance intervention is included as part of the proposal.

While there is a high level of confidence that the breach will remain open (based on technical analysis and history of spit/breach behaviour) and will be more stable than the existing condition, there is a residual risk that it could naturally close under an extreme condition, such as might happen if there was a rapid and relatively high-volume influx of shingle. However, the existing inlet position would probably also close under such conditions (i.e. if the project was not implemented) and, if it did so, would probably be more difficult to reopen than would be the case for the managed breach.

For this project there will also be requirements for ongoing (post-breach) site mitigation, compensation, monitoring and management that are considered further below. A substantial amount of the monitoring can be undertaken through existing initiatives such as the beach survey and analysis work that is done under the Southeast Strategic Regional Coastal Monitoring Programme. Additional monitoring and evaluation of the proposed mitigation and compensation measures will also be needed. This monitoring may require technical oversight perhaps by a panel of stakeholders and under the umbrella of existing processes that are required to pursue the adaptive management of this coastline.

It should be emphasised here, that irrespective of the approach that is taken to protect the population and properties of Pagham, an ongoing process of 'adaptive management' will be required under the Pagham to East Head Coastal Defence Strategy. This means that there must always be some future oversight and, where required, intervention. However, the proposed managed breach approach will achieve more natural and longer-term benefits over a larger spatial area than the more short term, reactive and localised interventions of recent years. It therefore 'buys more time' for planning and adapting as part of this process.

Project Objectives, Need and Alternatives

On this coastline there is a clear project need and a 'do nothing' alternative is not viable (and also not in-keeping with the adaptive management requirements for this shoreline). Such an approach would leave the spit in place and Pagham Beach under continuing pressure and will not address the coastal erosion, amenity and human health problems. The other alternatives involving an active intervention in the management of the shoreline which have been considered are shown, indicatively, on Image NTS2.

ARUN DISTRICT COUNCIL P/93/25/PL



Image NTS2. Indicative alternative options

For these active intervention alternatives, the following considerations apply:

- Installing/upgrading cross-shore groynes structures (e.g. Options 1a and 1b on Image NTS2) on Pagham Beach will leave the spit in place but would influence its future development. It would offer protection to only localised parts of the beach and will not solve the problem that the shingle is locked into the spit and will be costly, unattractive and probably require ongoing maintenance. Also any attempt like this to try and 'fix' the environment in place can lead to problems elsewhere on the beach and in the future.

- Excavating a breach in the spit and trying to seal it with a training wall (e.g. Options 2a and 2b on Image NTS2) will have the same effects on the spit as the proposed managed breach but at greater cost and with extra negative impacts on the appearance and geomorphological naturalness of the site. Also, as it is another attempt to try and 'fix' the environment in place it is likely to lead to problems elsewhere on the beach in the future (especially if the shingle supply decreases).

- Closing the breach (e.g. Options 3a and 3b on Image NTS2) will leave the spit in place and will also help unlock the shingle supply to the Pagham Beach. However, it will cause a major change to the ecology of the Pagham Harbour nature conservation sites and over time there would be an increased risk of an unmanaged and uncontrolled breach anyway.

ARUN DISTRICT COUNCIL P/93/25/PL

- Progressively extending existing protection on an ad hoc basis[3] (e.g. Option 4 on Image NTS2) along the shore on an emergency basis (e.g. by using revetment, gravel bags and shingle relocation) will leave the spit in place but influence its pathway. This is a costly, localised and reactive measure that is difficult to budget for where coastal changes are often determined by sudden storm events. It also has negative amenity and human health problems and typically represents a 'hold the line' coastal defence measure rather than the agreed adaptive management approach.

- Excavating a breach further along the spit to the north-east (e.g. Option 5 on Image NTS2) would reduce the amount of spit feature that is affected but the breach would be less stable in this location and at greater risk of closure (compared to the proposed project), the volumes of shingle unlocked and allowed to reach Pagham Beach after the breach has been completed would also be lower (with reduced duration of coastal protection, amenity and human health benefits). Also preferred Little Tern nesting areas on the spit would be more directly affected in the immediate to short term.

The community project is, therefore, considered to be the best option for improving coastal protection and achieving other benefits along Pagham Beach. When compared against other alternatives it is the only approach that is designed to achieve all the following goals:

- Result in spatially larger and longer-term coastal defence benefits for the Pagham Beach foreshore;
- Bring other gains that are linked to having an improved beach structure and better coastal protection including improvements for the site's amenity value and for the 'human health' of the local community in this vulnerable coastal location;
- Represent a more cost-effective use of public money (with local community funding support);
- Involve the application of a 'soft' solution that works with natural processes at the coast, rather than fighting against them with hard engineering;
- Mimic a process (i.e. breaching of the spit) that will occur naturally in the much longer-term future (as well as being one that has happened in the past) but exerts a degree of sensitive control over this process rather than waiting for it to happen naturally in the future in an unknown form and location over unknown timescales;
- Help the community to actively re-engage with the environment on their doorstep including by using their voluntary support to assist with site management; and
- Provide greater assurance that the tidal functioning of Pagham Harbour will be maintained.

Compared to the alternatives, the community project also recognises existing and future problems and seeks to address them in a more proactive manner. By contrast, the alternatives typically attempt to fix the environment in place which is not advised on such a dynamic coastline, especially where a more natural alternative exists (as in this case here), because this can cause further problems in the future.

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3 The separate option of picking up and moving the existing protection (rock revetment and geobags etc.,) along the shore been proposed (Defra 2015a) to address problems as they occur along the beach in the future has. This is not viable because it will then re-expose the original revetment locations to erosion. It also has the same negative problems as identified for "Installing/upgrading cross-shore groynes structures".

ARUN DISTRICT COUNCIL P/93/25/PL

Assessment Methods, Study Area and Duration

To assess the impacts of this project a systematic EIA process has been adopted. The key stages of work that have been undertaken include: consultation with key stakeholders throughout the process; scoping to agree the issues that need to be assessed; and assessment of those impacts according to appropriate guidance. It also includes a review of the planning context and a thorough consideration of the alternative options that have been considered.

The main study area for the proposed project covers the tidal area of Pagham Harbour, the length of Church Norton Spit, the adjacent Pagham Beach and nearshore area of the coast. These are the areas primarily affected by the proposal. Wider neighbouring areas that are used by birds or are relevant for water quality issues are also considered in the assessment. This assessment also focusses on forecasting effects and anticipated benefits over the following broad periods:

- Immediate: days/weeks;
- Short term: weeks/months to a year;
- Medium term: years; and
- Long term: 10 to 20 years.

This community project seeks to address immediate problems and anticipate future issues over short, medium and long term periods up to around 20 years while recognising that these issues will be subject to varying degrees of certainty over this period. Over time, towards and past the 20 year period, it becomes increasingly difficult to forecast issues because the system will continue to be dynamic. Therefore, the shoreline's evolution will be subject to increasing uncertainty towards and beyond this two-decade period[4]. The following sections review the effects of the proposal over the area identified and the duration indicated and, for context, this is preceded by a review of physical environmental changes that are expected and the value of the project for coastal protection.

Physical Environment and Coastal Protection

In advance of the impact assessment work, a review was undertaken of the physical/coastal processes acting on the foreshore. This was needed to understand how the proposed project will achieve its desired objectives and also how it will affect other factors (such as the habitats and species using the site) that will need to be assessed in this EIA. As part of this review, the coastal protection and cost benefit of the proposed project were also highlighted.

The most distinctive environmental aspect of the Pagham shoreline is that shingle along the foreshore generally moves along the coast in a north-easterly direction in line with the prevailing wind/wave direction. Set against this, the tidal waters of Pagham Harbour need to drain across this pathway and these two factors can be viewed as acting in conflict with each other. Together, these processes strongly influence the dynamics of this environment. The resulting changes as experienced in the past, and anticipated in the future (with and without the proposal), are summarised below.

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4 For this reason the longer-term issues associated with climate change and sea level rise have not been reviewed in detail in this assessment (they will instead need to be considered on an ongoing basis as part of the continuing process of adaptive management).

ARUN DISTRICT COUNCIL P/93/25/PL

Past Evolution:

- The Pagham frontage has been continually changing over history with spits deteriorating or growing in response to changing environmental conditions and human activities;
- Large areas inside the harbour were reclaimed in the 1800s which reduced both the amount of coastal habitat in the harbour and the volume of water moving though the tidal inlet;
- The tidal inlet position and its shape have also varied considerably (linked to the changing spit formations) and the inlet was deliberately closed (at the Pagham side) in 1876;
- After the 1876 closure, the inlet stayed shut for 34 years but then opened on the Church Norton side after storms in 1910 (the present Pagham Beach began to form during the closure);
- The inlet was artificially relocated to the Church Norton side (1937) but after much change in the 1950s and 1960s it moved to the Pagham side where it largely stayed until 2003;
- In the 1990s, the Church Norton Spit was maintained annually by the Environment Agency (formerly the National Rivers Authority (NRA)) with around 15,000 m³ shingle removed each year from the ebb delta in front of the breach; and
- In 2003, the Environment Agency ceased the annual maintenance work due to a clear oversupply of shingle making it unnecessary to continue maintaining the Church Norton Spit.

Current Situation:

- Since 2003, the Church Norton Spit has been growing by around 100 m/year and has increasingly encroached into Pagham Beach over the last 3 years;
- It is following a path which mimics past spit changes and indicates that there is a 'typical shape' that the spit 'wants' to follow based on the prevalent shoreline conditions;
- While the spit is a visually large feature, most of the shingle/sediment is contained below it in the ebb delta and the platform upon which the spit is lying;
- The spit mainly advances in short rapid phases that are preceded by longer periods of ebb delta formation in front of the moving tidal inlet (the delta provides the platform for spit growth);
- Several studies have examined the rate at which shingle moves along the shoreline. On balance of the evidence, the average rates are around 15,000 to 20,000 m³/year;
- This rate will vary in response to changes in shingle supply and especially in response to storm events (e.g. the stormy period of 2013/14 moved over 40,000 m³ in one year);
- There are also 'spur' features jutting from the spit, moving north at around 18 m per year, which are possible conduits for shingle moving onshore and delivering shingle 'pulses';
- Although shingle is moving north to form and grow the Church Norton Spit, it is not then moving past the inlet around to Pagham Beach (it is being locked into the spit, platform and ebb delta);
- It is not known precisely when the shingle supply will start to become depleted but indications are that this is not going to happen in the short term and probably not within the next 10 years;
- To protect the western side of Pagham Beach, revetment was placed there in Nov/Dec 2013 and then upgraded/maintained over the next 15 months (at a cost of around £860,000); and
- The central Pagham Beach area (to the east of the existing groynes) is unprotected and continuing to erode while the eastern beach is eroding more slowly because it is receiving shingle lost from the central beach area.

ARUN DISTRICT COUNCIL P/93/25/PL

Future with No Breach:

- Shingle supply appears to be healthy and there is no expectation that the spit will breach in an unmanaged way (with no control over the location or benefit) in the next decade;
- The western beach and the revetment placed here will continue to be under pressure from the inlet channel trying to erode the beach. The revetment may well require ongoing maintenance;
- The spit and inlet will try to grow but cannot move into the western beach due to the revetment. They are likely to move to, and increase erosion of, the central beach in the short/medium term;
- The central beach will continue eroding due to reduced shingle supply but in short/medium term this erosion could well increase from the tidal channel cutting into it as the spit grows;
- The eastern beach erosion is expected to continue and may increase due to reducing shingle supply in the medium term;
- Over the long term, the tidal channel may also cut in to the eastern beach and accelerate erosion if the spit continues to grow and meander along the shore over the next 10 years; and
- Beach Road behind the Yacht Club is likely to become at risk of flooding in the short/medium term if the central beach is allowed to continue eroding.

Future with the Proposed Breach:

- After excavation, there is a high level of confidence (underpinned by scientific analysis and historical review) that the breach will remain open and be more stable than the existing inlet;
- Once created there will be an initial period of strong flows though the new shorter inlet and the breach is expected to quickly respond (within days/weeks) by deepening and widening to reach a new equilibrium and enhance its stability;
- During this period of adjustment there will be a short period where high waters are marginally reduced, returning to pre-breach conditions thereafter;
- With the removal of the longer inlet channel, low waters will no longer be held up towards the seaward end of the harbour and there will be more efficient tidal exchange resulting in slightly lower low water levels for this local area
- The new configuration will allow: a more efficient tidal exchange; slightly lower volumes in the harbour entrance at low water and will modestly increase the harbour's tidal volumes.
- The existing tidal inlet will be infilled and flows greatly reduced allowing the northern (severed) tip of the spit to merge into the beach creating a lagoonal feature behind within 1-2 years;
- The northern section of the spit that will be severed by the breach will then gradually decay over 8-12 years as the shingle moves along the foreshore to Pagham Beach;
- A spit is likely to reform on the southern side of the breach but may well take a few years to begin developing as it will need to widen seawards first to initially build a base for its growth;
- Thereafter, the southern (Church Norton) spit regrowth will probably occur slowly, over several years as it will be moving into deeper water (thus requiring larger volumes of shingle to grow);
- Once the northern (separated) spit has decayed, the southern spit will move inshore and seek to follow the path taken by the existing spit (its growth rate will depend on shingle supply); and
- It will take around 10-15 years for the spit to re-grow following a pattern similar to that observed over the last decade (assuming shingle supply continues to be maintained).

ARUN DISTRICT COUNCIL P/93/25/PL

Cost Benefit:

- The Pagham Harbour and Pagham Beach shoreline require the application of ongoing 'adaptive management' as dictated by the Pagham to East Head Coastal Defence Strategy;
- The current adaptive management methods involve reacting to urgent needs through the introduction of revetment (rock and geotextile bags) and application of shingle recycling;
- Over the last three winter periods these measures have cost around £900,000, including £500,000 for the 2012/13 revetment and £360,000 for later remedial/improvement measures;
- In the years preceding, there were fees incurred for shingle beach nourishment in 2010 (£600,000) and beach shingle recycling in 2009 (£43,000);
- Therefore over £1.5 million has been spent over the last 6 winters with the sum being incurred increasing over time with the growth of the Church Norton Spit;
- The proposed breach and infill works are envisaged to cost around £700,000 with further costs for mitigation, compensation and management; and
- This active adaptive measure will benefit 110 properties (which would be at risk over different timescales and certainly within the next 20 years) for at least 8 years; and
- The proposed project will also avoid flooding existing infrastructure, namely a vacuum pumping station, avoiding consequent effects on the local community.

Impact Assessment

As a result of the proposed community project, there will be a range of negative and positive environmental effects that will occur during the 9 to 11 week construction phase or the subsequent post-breach operational phase. In total, 20 different impact pathways have been identified, five of which relate to the underlying coastal process changes (see above and Section 6 of the ES) and a further 15 have been considered across the following topic areas:

- Water and Sediment Quality (Section 7 of the ES);
- Nature Conservation and Ecology (Section 8 of the ES); and
- Marine Recreation (Section 9 of the ES).

The significance of the impacts arising (and the need for any mitigation/compensation measures) across these 15 impact pathways are summarised below.

Water and Sediment Quality Assessment

- Pagham Harbour is sensitive to nutrient enrichment in the water and this is a key consideration for all works influencing the harbour;
- The project is expected to marginally improve the tidal flushing of the harbour, thus potentially improving water quality by reducing the risk of nutrient build-up and eutrophic events;
- As the excavated sediments are newly deposited coarse sand/shingle, the risk of an adverse water quality effect from sediment resuspension or organic/contaminant release are low;
- The effects of sediment being resuspended during the excavation works are considered to be immediate to short term, small scale, localised and insignificant;

ARUN DISTRICT COUNCIL P/93/25/PL

- Subject to adherence to good workings practices and guidance, there will also be insignificant effects from accidents and spillages during the construction work;
- The effects on WFD water bodies are assessed as insignificant and the project could improve the WFD status because it will marginally improve drainage of waters.

Nature Conservation and Ecology Assessment

- Pagham Harbour is an area of high nature conservation value that is nationally and internationally protected as a European/Ramsar area, Site of Special Scientific Interest (SSSI), and a Marine Conservation Zone (MCZ);
- The protected features include the shingle spits on the front, the habitats in the harbour (e.g. mudflats, saltmarshes and seagrass beds) and birds and species using these habitats; and
- Pagham Harbour, its fronting shingle spits and Pagham Beach are also nationally important for their coastal geomorphology (land shape) and geology value (clay floral fossils).
- The effects of the proposal on shingle habitat; other protected habitats; birds; other protected species; geomorphology and geology are outlined below

Shingle Habitat:

- The immediate effects of breaching and channel infilling will be insignificant as there will be no net loss of habitat and only temporary damage to small areas with low vegetation cover;
- Access routes will be agreed in advance to minimise the construction footprint and therefore the potential damage to shingle habitat will at worst be minor adverse significant; and
- The impact on shingle habitat during operation will be minor adverse significant given that it has tolerated and recovered from past breaches and a new spit is likely to grow in the future.

Other Protected Habitats:

- The temporary access causeway during construction will result in a temporary and small (4.2 ha) decrease in intertidal mudflat within Pagham Harbour of minor adverse significance;
- Intertidal mudflat is not very sensitive to the predicted temporary mobilisation of coarse sediments during excavation and infilling works and thus this impact will be insignificant;
- No other protected habitats (e.g. seagrass, saltmarsh, lagoons) will be significantly affected by the temporary changes in water levels or suspended sediments during construction;
- The temporary and minor reductions in high water levels within the harbour during operation will be very brief and insignificant for saltmarsh;
- No other protected habitats will be affected by the predicted changes in water levels immediately following the breach and as the site evolves during operation;
- Changes in sediment regime within the harbour during operation will be very small and insignificant to habitats;
- The new tidal inlet (breach) is less likely to close and more likely to be reopened naturally or artificially than the existing inlet and the impact of closure on habitats will be insignificant.

ARUN DISTRICT COUNCIL P/93/25/PL

Birds:

- The immediate impact on breeding birds will be insignificant as the breach will avoid the breeding season and will not disturb habitat that is currently being used by nesting Little Terns;
- The temporary reduction intertidal mudflat habitat inside the harbour during construction is considered to be minor adverse significant for feeding birds;
- The construction programme may well include the overwintering bird period but, given the scale of the works and tolerance of birds, any disturbance effects will be minor adverse significant;
- The impact on tern breeding habitat during operation is minor adverse significant in short term but potentially up to moderate (with increasing uncertainty) in medium to long-term;
- To offset potential breeding habitat effects, mitigation measures and the creation of a New Tern Island as compensation are proposed (reducing impact to minor adverse or insignificant);
- The small, short-term and temporary changes in water levels inside the harbour during operation will be insignificant to feeding and roosting birds;
- The creation of a temporary saline lagoon behind the severed (northern) spit will be minor beneficial significant to feeding birds;
- The increased accessibility of the severed spit during operation will result in a moderate adverse significant disturbance impact on birds;
- A range of mitigation measures, including fencing and wardening, will be implemented to reduce the disturbance impact during operation to insignificant;
- The improved navigational access into the harbour and recreational disturbance on birds, in the context of existing management and byelaws, will be minor adverse significant; and
- The new tidal inlet (breach) is less likely to close and more likely to be reopened than the existing inlet; therefore the potential impact of closure on birds will be insignificant.

Other Protected Species:

- The breach and temporary access routes do not overlap with preferred DeFolin's lagoon snail habitat and therefore the construction impacts on this protected species will be insignificant;
- No other protected species (e.g. water voles) will be significantly affected by the temporary changes in water levels or suspended sediments anticipated during construction;
- The impact of changes in water levels during operation will be insignificant to DeFolin's lagoon snail both inside the harbour and in Little Lagoon;
- Water voles are not considered to be sensitive to the predicted changes in water levels during operation and therefore the impact on this protected species will be insignificant;
- The creation of a temporary saline lagoon behind the severed spit will be minor beneficial significant to DeFolin's lagoon snail; and
- The new tidal inlet (breach) is less likely to close and more likely to reopen naturally than the existing inlet and thus the potential impact on other protected species will be insignificant.

Geomorphology:

- The immediate effect of the project will be minor adverse significant given the small change to a 'double spit' shape and because breaching is a natural part of how dynamic spits behave;
- The shape and behaviour of the spit will not change as a result of construction plant movement and therefore this impact will be insignificant; and
- The impact on the geomorphological spit feature during operation will be minor adverse significant given that it will continue to be dynamic (i.e. a new spit is likely to form and grow).

ARUN DISTRICT COUNCIL P/93/25/PL

Geology:

- There are unlikely to be any plant fossils in the shingle spit and therefore the impact on geology during excavation works and plant movement will be insignificant; and
- The impact on geology during operation is considered insignificant as the increased shingle supply to Pagham Beach will not expose, but rather protect, any underlying geology.

Marine Recreation:

- Flows around the Pagham Beach will be immediately reduced following the proposed breach and channel infill works resulting in a dramatically reduced health and safety risk;
- Access into the harbour will be improved which will significantly improve RNLI response times to incidents inside the harbour;
- The temporary lagoon that will be created behind the old spit could be of recreational value;
- A gentler and wider beach profile is anticipated to become re-established over time which will attract visitors to the area again and enable lost amenity infrastructure to be re-instated;
- Overall, the impact on the marine recreational and amenity value of Pagham is considered to be moderate beneficial significant.

Cumulative and In-Combination Effects:

In this assessment the cumulative effects of the proposed community project alongside those of other plans, projects and activities also needs to be considered. A number of plans, projects and activities were identified but the only one where there is the potential for negative interaction within this proposal is the other flood defence works that are being undertaken or are proposed by the Environment Agency in Pagham Harbour. The following findings were reached after a review of the cumulative and in-combination effects with this proposal

- There will be no cumulative and/or in-combination impacts on water and sediment quality, nature conservation and ecology, or marine recreation;
- No cumulative and/or in-combination impacts on water levels as a result of the proposed project and the Pagham Harbour defences are expected in the immediate or long term;
- The cumulative and/or in-combination impact on coastal erosion and flood protection will be beneficially significant as there will be combined additive coastal protection to properties; and
- Given the uncertainty in the long term evolution of the site, post scheme monitoring is proposed to validate future predictions and allow the site to continue to be adaptively managed.

Impact Summary, Mitigation and Monitoring

The majority of impacts identified in this ES have been assessed as insignificant or of minor adverse significance. In some cases, though, the potential exits for larger more significant adverse impacts. To offset these larger potential impacts, mitigation measures have been identified that are sufficient to reduce the residual impact significance to minor adverse at worst. The mitigation measures include:

ARUN DISTRICT COUNCIL P/93/25/PL

- Carrying out the excavation works outside of the bird nesting period (March to July) to avoid any adverse effects on breeding birds;
- Contractors adhering to best practice guidance/measures during the construction work to minimise the risk of a pollution event (e.g. from fuel spill);
- Contractors agreeing fixed plant access routes in advance with Natural England and RSPB to minimise the footprint of any impact and minimise any potential damage to vegetated shingle;
- Creating a new isolated island habitat within the harbour to offset any damage to Little Tern nesting areas over the medium to long term[5];
- Fencing to be installed and access of people and predators managed to spit areas during the summer months to minimise impacts on nesting terns and other breeding bird species; and
- The community to be actively involved in ongoing management measures (e.g. wardening).of the spit and, if required, on the New Tern Island.

As a contingency measures allowance should also be made for one subsequent breach maintenance intervention as part of the proposed project in the event of an unlikely breach closure.

There are issues associated with impact certainty for a project which seeks to mimic, and work with, natural processes at a spatially large scale. These uncertainties have been considered throughout this assessment and can be addressed in an adaptive manner through the ongoing management of the site and the coastline.

To underpin this adaptive management, there will be requirement for ongoing (post-breach) monitoring to consider how the site evolves. This will require little new survey work as is can be done under existing programmes but may require technical oversight perhaps by a panel of stakeholders. Evaluation of this data in the context of historical evolution will not only serve to validate the predictions in the ES but also enhance our understanding of how spits develop following a breach and thus provide an important contribution to the science of coastal geomorphology. Additional monitoring and evaluation of the mitigation and compensation measures will also be needed.

Conclusions

The proposal to breach the spit at Pagham is considered to be the most appropriate coastal defence and shoreline management measure for this location in view of the existing foreshore morphology. There will be many key benefits arising from this project that have been reviewed within this assessment. In particular it offers coastal protection to Pagham Beach and improvements to the amenity value and the health of those residents that live along this shoreline. It offers the opportunity for community engagement in the environment to the benefit of both the environment and the community.

Following the evidence review and assessment, there is a high level of confidence that these benefits will be realised. It is recognised though that there are some uncertainties associated with the future physical and ecological changes that will arise precisely because the project seeks to preserve the

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5 This will be a compensation measure under the habitats Regulations that will avoid an adverse effect on the integrity of the protected Pagham Harbour SPA/Ramsar area

ARUN DISTRICT COUNCIL P/93/25/PL

natural functioning of the shoreline along an inherently dynamic/mobile coastline. Also, while this is considered to be the best approach and the one delivering the longest and largest gains (for reasons described above) it should be recognised there is no permanent solution to the coastal changes occurring at Pagham. This foreshore, the adjacent harbour area and the beaches have always been changing and will always need to be managed. This proposed approach will, however, represent a more efficient use of government and community funds to achieve benefits over the immediate, short, medium and longer-term, and allow greater time for the shoreline and the community to adapt.

ARUN DISTRICT COUNCIL P/93/25/PL

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ARUN DISTRICT COUNCIL P/93/25/PL

Abbreviations

ABPmer	ABP Marine Environmental Research Ltd
ADC	Arun District Council
AEOI	Adverse Effect on Integrity
AOD	Above Ordnance Datum
ASMITA	Aggregated Scale Morphological Interaction between Tidal basin and Adjacent Coast
ATV	All-Terrain Vehicle
AWB	Artificial Water Body
BERR	Department for Business Enterprise and Regulatory Reform
BTO	British Trust for Ornithology
BWD	Bathing Water Directive
CCME	Canadian Council of Ministers of the Environment
CCO	Channel Coastal Observatory
CD	Chart Datum
CDC	Chichester District Council
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEH	Centre for Ecology and Hydrology
CjEU	Court of Justice of the European Union
ConchSoc	Conchological Society of Great Britain and Ireland
CROW	Countryside and Rights of Way (Act)
DTM	Digital Terrain Model
EA	Environment Agency
EGA	Expert Geomorphological Assessment
EIA	Environmental Impact Assessment
ENG	Ecological Network Guidance
EQS	Environmental Quality Standards
ES	Environmental Statement
FDGIA	Flood Defence Grant in Aid
FTU	Formazin Turbidity Unit
GCR	Geological Conservation Review
GIS	Geographic Information System
HAT	Highest Astronomical Tide
HMWB	Heavily Modified Water Body
HRA	Habitats Regulations Assessment
HTA	Historical Trend Analysis
HW	High Water
IECS	Institute of Estuarine and Coastal Studies
IEEM	Institute of Ecology and Environmental Management
IROPI	Imperative Reasons of Overriding Public Interest
ISA	Inlet Stability Analysis
ISQG	Interim Sediment Quality Guidelines
JNCC	Joint Nature Conservation Committee
LiDAR	Light Detection and Ranging
LNR	Local Nature Reserve
LW	Low Water

ARUN DISTRICT COUNCIL P/93/25/PL

MarLIN	The Marine Life Information Network
MCCIP	Marine Climate Change Impact Partnership
MCZ	Marine Conservation Zone
MHW	Mean High Water
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLW	Mean Low Water
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MMO	Marine Management Organisation
MNCR	Marine Nature Conservation Review
MPA	Marine Protected Area
MSL	Mean Sea Level
MTL	Mean Tide Level
NE	Natural England
NERC	Natural Environment Research Council
NPPF	National Planning Policy Framework
NRA	National Rivers Authority
NVZ	Nitrate Vulnerable Zones
ODN	Ordnance Datum Newlyn
PAH	Polycyclic Aromatic Hydrocarbon
PEHCDS	Pagham East Head Coastal Defence Strategy
PEL	Probable Effect Level
PFDSG	Pagham Flood Defence Steering Group
pMCZ	Proposed Marine Conservation Zone
PPC	Pagham Parish Council
ppt	Parts Per Thousand
PYC	Pagham Yacht Club
Ramsar	Ramsar sites are wetlands of international importance, designated under the Convention on Wetlands (Ramsar, Iran, 1971)
RBD	River Basin District
RBMP	River Basin Management Plan
rBWD	Revised Bathing Water Directive
rMCZ	Recommended Marine Conservation Zone
RNLI	Royal National Lifeboat Institution
rRA	Recommended Reference Areas
RSPB	Royal Society for the Protection of Birds
RTK	Real Time Kinematic
SAC	Special Area of Conservation
SCOPAC	Standing Conference on Problems Associated with the Coastline
SMP	Shoreline Management Plan
SPA	Special Protection Area
SRCMP	Southeast Strategic Regional Coastal Monitoring Programme
SSSI	Site of Special Scientific Interest
TPA	Tidal Prism Assessment

ARUN DISTRICT COUNCIL P/93/25/PL

UKHO	UK Hydrographic Office
UKMMAS	UK Marine Monitoring and Assessment Strategy
UWWTD	Urban Waste Water Treatment Directive
WeBS	Wetland Bird Survey
WFD	Water Framework Directive

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

ARUN DISTRICT COUNCIL P/93/25/PL

Managed Breach of Shingle Spit at Pagham: Environmental Statement

Volume 1: Report

Contents

Page

Non-Technical Summary 5
Acknowledgements 20
Abbreviations 21
1. Introduction 32
1.1 Project Background 32
1.2 Development of the Community Proposal 33
1.3 Report Background 34
1.4 Report Structure 35
2. Project Need and Alternatives 37
2.1 Project Need 37
2.1.1 Introduction 37
2.1.2 Contemporary Situation 38
2.1.3 Proposed Community Project and Its Objectives 40
2.1.4 Imperative Reasons of Overriding Public Interest 41
2.2 Consideration of Alternatives 41
2.2.1 Key Reasons for Selecting the Preferred Option (Proposed Project) 46
2.3 Conclusion 50
3. Project Description and Methodology 51
3.1 Project Description 51
3.2 Project Methodology 51
3.2.1 Access, Site Compound and Storage 52
3.2.2 Breach Methodology 53
3.2.3 Channel Infill Methodology 53
3.2.4 Removal of Piled Causeway and Demobilisation 53
3.2.5 Programme 54
3.2.6 Team and Equipment 54
3.2.7 Post-breach Maintenance 55
4. Consents, Approvals and Policy Guidance 56
4.1 Introduction 56
4.2 Relevant Local Plans 56
4.3 Environmental Impact Assessment 57
4.4 Habitats Regulations Appraisal 60
4.5 Marine Conservation Zone Assessment 60
4.6 Water Framework Directive Compliance Assessment 61
4.7 Other Approvals 61

ARUN DISTRICT COUNCIL P/93/25/PL

5. Impact Assessment Approach 62
5.1 Consultation 62
5.2 Scoping 62
5.3 Preparation of an Environmental Statement (ES) 62
5.4 Submission of the Planning Application 63
5.5 Scoping Phase 63
5.5.1 Impact Assessment Scope 63
5.5.2 Scoped-Out Issues 66
5.6 Assessment Methodology 67
5.6.1 Stage 1 - Identify Receptors and Changes 68
5.6.2 Stage 2 - Understand Change and Sensitivity 68
5.6.3 Stage 3 - Impact Assessment 68
5.6.4 Stage 4 - Impact Management 71
5.6.5 Stage 5 - Confidence Assessment 72
5.6.6 Cumulative Impact and In-Combination Assessment 72
5.7 Study Area 73
5.8 Study Duration 73
6. Physical Environment and Coastal Protection 74
6.1 Introduction 74
6.1.1 Data Sources 75
6.2 Baseline Review 76
6.2.1 Introduction 76
6.2.2 General Site Description 77
6.2.3 Hydrodynamic Regime 78
6.2.4 Sediment Transport Characteristics 84
6.2.5 Spit-Delta Interactions 86
6.2.6 Historical Changes and Recent Developments 92
6.2.7 Changes Occurring on Pagham Beach 99
6.2.8 Future Development of Spit and Beach (Without Intervention) 103
6.3 Impact Assessment 106
6.3.1 Impact Pathway 1: Effects of Changing Spit Morphology on Coastal Processes 106
6.3.2 Impact Pathway 2: Effects of Changing Spit Morphology on Hydrodynamic Regime in Pagham Harbour 112
6.3.3 Impact Pathway 3: Effects Of, and Need For, Breach Maintenance 120
6.3.4 Impact Pathway 4: Effects on Tidal, Wave and Sedimentary Dynamics in Pagham Harbour 122
6.3.5 Impact Pathway 5: Effects on Coastal Protection in Pagham Harbour and Along Pagham Beach 123
7. Water and Sediment Quality 133
7.1 Baseline Review 133
7.1.1 Data Sources 133
7.1.2 Legislation and Policy 133
7.1.3 Water Quality 137
7.1.4 Sediment Quality 147
7.2 Impact Assessment 149
7.2.1 Impact Pathway 6: Effects on Suspended Sediment and Water Quality During Construction 149
7.2.2 Impact Pathway 7: Effects on Water Quality of Spillages (e.g. Fuel) During Construction 152

ARUN DISTRICT COUNCIL P/93/25/PL

7.2.3 Impact Pathway 8: Effects on Status of Water Bodies During Operational Phase 153
7.3 Conclusions 155
8. Nature Conservation and Ecology 156
8.1 Baseline Review 156
8.1.1 Data Sources 156
8.1.2 Nature Conservation Designations 156
8.1.3 Marine and Coastal Habitats 160
8.1.4 Benthic Invertebrates 166
8.1.5 Ornithology 169
8.1.6 Other Protected Species 192
8.1.7 Coastal Geomorphology 192
8.1.8 Geology 193
8.1.9 Potential Future Baseline 194
8.2 Impact Assessment 199
8.2.1 Impact Pathway 9: Effects of Loss/Change of Shingle Habitat During Construction 199
8.2.2 Impact Pathway 10: Effects of Loss/Change of Little Tern Breeding Habitat During Construction 202
8.2.3 Impact Pathway 11: Effects of Loss/Change of Habitat for DeFolin's Lagoon Snail During Construction 203
8.2.4 Impact Pathway 12: Effects of Loss/Change of Shingle Habitat Outside Development Footprint During Construction 205
8.2.5 Impact Pathway 13: Effects on Ecology in Pagham Harbour During Construction Phase 207
8.2.6 Impact Pathway 14: Effects from Any Increased Disturbance on Overwintering Birds Due to Construction Work 211
8.2.7 Impact Pathway 15: Effects of Loss/Change of Shingle Habitat During Operational Phase 214
8.2.8 Impact Pathway 16: Effects of Loss/Change of Little Tern Breeding Habitat During Operational Phase 217
8.2.9 Impact Pathway 17: Effects on Ecology in Pagham Harbour During Operational Phase 220
8.2.10 Impact Pathway 18: Effects from Any Increased Bird Disturbance During the Operational Phase 224
8.2.11 Impact Pathway 19: Effects from Potential Closure of Breach During Operational Phase 227
8.3 Conclusions 228
9. Marine Recreation 230
9.1 Baseline Review 230
9.1.1 Data Sources 230
9.1.2 Marine and Coastal Recreation 230
9.1.3 Coastal Tourism 234
9.1.4 Summary 236
9.2 Impact Assessment 237
9.2.1 Impact Pathway 20: Effects of Changing Spit Morphology on Marine Recreational Activities 237
9.3 Conclusions 238

ARUN DISTRICT COUNCIL P/93/25/PL

10. Cumulative and In-Combination Effects 239
10.1 Baseline Review 239
10.2 Cumulative/In-combination Assessment 241
11. Assessment Summary (Impacts, Mitigation and Monitoring) 243
11.1 Summary of Impacts 243
11.2 Mitigation 248
11.2.1 Project Mitigation Measures 248
11.2.2 Compensation 249
11.2.3 Long Term Management Measures 250
11.2.4 Enhancement Measures 250
11.3 Management and Monitoring Proposals 250
11.4 Conclusions 251
12. References 252

Appendices (See Volume 2)

A. Proposed Design and Modelling Report
B. Scoping Consultation Log
C. Information for an Appropriate Assessment Signposting Document
D. Construction Maps Provided by Mackley
E. Legislation and Policy
F. Review of Nature Conservation Designations
G. Marine Conservation Zone Assessment
H. Water Framework Directive Compliance Assessment
I. Transport Statement
J. The Ecology of the DeFolin's Lagoon Snail
K. Review of Bird Disturbance
L. Little Tern Habitat Creation and Management Review

ARUN DISTRICT COUNCIL P/93/25/PL

Tables

2.1 Summary of key alternative options for coastal erosion and flood risk management at Pagham Beach 44
3.1 Estimated construction programme 54
3.2 Approximate numbers of staff and plant weeks 54
4.1 ES requirements according to the Town and Country Planning (EIA) (England and Wales) Regulations 2011 58
4.2 ES requirements according to the Marine Works (EIA) Regulations 59
5.1 Environmental topics and impact pathways that have been scoped into the assessment 64
5.2 Environmental topics scoped out of the assessment 66
5.3 Basic criteria for defining magnitude of change 69
5.4 Exposure to change, combining magnitude and probability of occurrence 70
5.5 Estimation of vulnerability based on sensitivity and exposure to change 70
5.6 Definition of receptor importance 71
5.7 Estimation of significance based on vulnerability and importance 71
6.1 Standard tidal levels 78
7.1 Criteria for defining coastal bathing water classifications under the revised Bathing Water Directive (2006/7/EC) 135
7.2 Monthly mean and annual mean nutrient concentrations for water samples collected from Pagham Harbour between 2009 and 2015 142
7.3 Contaminant concentrations in water samples collected from Pagham Harbour between 2012 and 2015 compared to Priority Substances Directive (2008/105/EC and 2013/39/EU) environmental quality standards (EQS) 145
7.4 Water quality (projected) classifications for coastal bathing waters within 5km of the proposed works as defined under the Bathing Water Directive (76/160/EEC) and revised Bathing Water Directive (2006/7/EC) 146
7.5 Mean contaminant concentration in sediment samples collected from Pagham Harbour in April 2011 compared to sediment quality criteria 148
7.6 Water Quality impact assessment summary and conclusions 155
8.1 Qualifying features of conservation designations of Pagham Harbour 158
8.2 The occurrence of DeFolin's lagoon snail during the 2013 survey 168
8.3 Qualifying bird species in the Pagham Harbour SPA 170
8.4 Qualifying bird species in the Pagham Harbour Ramsar 171
8.5 Latest high water WeBS core count data for Pagham Harbour (2009/10 to 2013/14) 173
8.6 Latest WeBS low tide data for Pagham Harbour (1996/97 to 1999/00 and 2013/14) 176
8.7 Winter WeBS core counts data for the Pagham Sea sector (2009/10 to 2013/14) 180
8.8 Winter WeBS low tide count data for the Pagham Sea sector (2013/14) 183
8.9 Breeding success of seabird species at Pagham Harbour 1994 to2014 188
8.10 Breeding success of wading bird species at Pagham Harbour 1996 to 2014 190
8.11 Response level to activity 212
8.12 Nature conservation and ecology impact assessment summary and conclusions 228
9.1 Nature conservation and ecology impact assessment summary and conclusions 238
10.1 Summary of plans, projects and activities in the wider study area 239
10.2 Summary of predicted cumulative and in-combination effects 241
11.1 Summary of impact pathway assessment, project mitigation measures where required and the residual impact 244

ARUN DISTRICT COUNCIL P/93/15/PL

Images

2.1 Church Norton Spit at Pagham (27 February 2015) 38
2.2 Exposure of the geotextile bags within the inlet channel 39
6.1 Church Norton Spit, Pagham Harbour and south-western Pagham Beach 77
6.2 Baseline neap and spring water levels and flow speeds at location (white square on map) inside the harbour near proposed managed breach 80
6.3 Modelled flow speeds (depth averaged) on spring and neap ebb and flood tides 81
6.4 Wave outputs for Rustington Buoy a) average July 2003 to February 2015 (but excl., 2013) b) average February 2014 only 83
6.5 Net sediment transport pathways around Selsey Peninsula 85
6.6 Sediment transport directions around Pagham Harbour inlet (dated 2000) 86
6.7 Spatial relationship between ebb delta (red circles/ovals) and the track of distal end of the spit (black dashed lines) 87
6.8 Example of spur progression along shoreline to southwest of Pagham harbour 89
6.9 Approximate location of Kirk Arrow Spit (in 1991 and 1999) 89
6.10 Annual littoral drift potential (in m^3/year) for the Pagham Harbour frontage (based on the inshore wave climate), 2003 to 2014 90
6.11 Spur progression along shoreline to southwest of Pagham Harbour 91
6.12 Changing configurations of the spit, inlet and delta complex 94
6.13 Positon of Church Norton Spit relative to Pagham Beach in 2008 (top) and 2013 (bottom) 96
6.14 Protection works at Pagham Beach viewed from south-west (top) and north-east (bottom) 97
6.15 Tidal inlet and coastal protection works at south-western Pagham Beach 98
6.16 Beach volume changes (2003 to 2014) along Pagham Beach (centre and east, 4dSU23) 101
6.17 Beach volume changes (2003 to 2014) along Pagham Beach (west, 4dSU22) 102
6.18 Pagham foreshore showing area of accretion between Groynes 1 and 2 106
6.19 Indicative description of the shoreline morphologies before and after breach (based on bathymetry used for numerical modelling work) 108
6.20 Coastal sections used for the ASMITA analysis 110
6.21 Indicative preferred/proposed breach design (not to scale) 113
6.22 Spring tide ebb flow speeds at 2 hours after high water before and after scheme implementation (breach as per schematic in 6.21) 114
6.23 Neap tide ebb flow speeds at 2 hours after high water before and after scheme implementation (breach as per schematic in 6.21) 114
6.24 Time Series plots of flow speeds at 3 points within the harbour before and after scheme implementation (breach as per schematic in 6.21) 116
6.25 Time Series plots of water levels at 3 points within the harbour before and after scheme implementation (breach as per schematic in 6.21) 119
6.26 End of Church Norton Spit and properties behind on a high tide 124
6.27 Beach volume changes 2013 to 2014 along Pagham Beach (centre and east, 4dSU23) 125
6.28 Beach Volume changes 2013 to 2014 along Pagham Beach (west, 4dSU22) 127
6.29 Areas of flood risk along the Pagham frontage (Environment Agency) 130
6.30 Environment Agency defence improvement areas in Pagham Harbour 131
7.1 Monthly mean (A) temperature (°C) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 138

ARUN DISTRICT COUNCIL P/93/25/PL

7.2 Monthly mean salinity for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 139
7.3 Monthly mean nitrate levels (mg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 140
7.4 Monthly mean nitrite levels (µg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 141
7.5 Monthly mean phosphate levels (µg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 141
7.6 Monthly mean dissolved oxygen concentration (mg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 143
7.7 Monthly mean dissolved oxygen saturation (%) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided 144
8.1 Pagham Harbour intertidal and transitions as viewed from the Church Norton side 162
8.2 Vegetated shingle on southwester part of Church Norton Spit 164
8.3 Vegetated shingle at the location of the proposed breach 164
8.4 DeFolin's lagoon snail (copyright Lin Baldock) 166
8.5 Sample locations for the 2013 DeFolin's lagoon snail survey 167
9.1 Coastal and marine recreation features at Pagham 231
11.1 Relict concrete training wall structure at location of proposed new tern island 249

Figures

1.1 Location of Pagham Harbour
1.2 Plan of Key Local Features
1.3 Boundaries of Chichester and Arun District Councils
2.1 Factors Influencing Erosion at Pagham Beach
2.2 Location and Design of Proposed Breach and Channel Infill
2.3 Indication of the Alternative Options
6.1 Recent Evolution of the Church Norton Spit and Pagham Beach Frontage
6.2 Schematic Illustration of Coastal Features Mapped Between 1587 and 1944
6.3 Schematic Illustration of Coastal Features Mapped Between 1957 and 2015
6.4 Changing Position of 4.9mODN Elevation Along Pagham Beach (2001 to 2015)
6.5 Projections for Future Spit Development Alongside Past and Present Channel Meanders
6.6 Properties that are Vulnerable to Erosion and Flooding Risk
6.7 Land Elevations Around Pagham Harbour Equating to Projected Extreme Water Levels
7.1 Water/Sediment Quality Designations and Monitoring Sites
8.1 Nature Conservation Designations within 5km of the Proposed Works
8.2 Pagham Harbour Designated Sites and 2015 MLW line
8.3 Marine and Coastal Habitats of Pagham Harbour
8.4 The Pagham harbour MCZ and its Feature Records
8.5 DeFolin's Lagoon Snail Survey Results
8.6 WeBS Core Count Sectors in Pagham Harbour
8.7a WeBS Alert Graphs for Dark-bellied Brent Goose and Wigeon in Southern England
8.7b WeBS Alert Graphs for Lapwing and Dunlin in Southern England
8.8 The Location of Major Wader Roosts in Pagham Harbour
8.9 WeBS Low Tide Count Sectors in Pagham Harbour

ARUN DISTRICT COUNCIL P/93/25/PL

8.10a WeBS Low Tide Count Maps for Wildfowl Species in Pagham Harbour (2013/2014)
8.10b WeBS Low Tide Count Map for Wading Bird Species in Pagham Harbour (2013/2014)
8.10c WeBS Low Tide Count Map for Wading Bird Species in Pagham Harbour (2013/2014)
8.11 The Location of Little Tern Breeding Colonies in Pagham Harbour from 2008 to 2014
8.12 The Number of Little Tern Breeding Pairs and Fledged Young in Pagham Harbour in 1945 and 1948-2014
8.13 The Location of Shorebird Nesting Areas in Pagham Harbour
8.14 Records of Water Vole in and around Pagham Harbour
11.1 Location of Proposed New Tern Island

ARUN DISTRICT COUNCIL P/93/15/PL

1. Introduction

1.1 Project Background

On behalf of the local community at Pagham (West Sussex), the Pagham Parish Council (PPC), and its working group the Pagham Flood Defence Steering Group (PFDSG), are proposing to undertake a managed breach of the shingle spit at the mouth of Pagham Harbour, West Sussex (Figure 1.1). The main aims of this shoreline adjustment (hereafter referred to as either 'the [proposed] project' or the 'community project') are to move the coastline towards a more sustainable morphology[6] and address the coastal erosion, amenity and human health problems that are presently being experienced along the adjacent Pagham Beach.

The project represents a 'soft' solution to these problems because it seeks to mimic a process (i.e. breaching of the spit) that has happened naturally in the past and is likely to occur in the longer-term future (though probably not within the next decade). However, it does this in a predictable and controlled way that addresses immediate problems, anticipates future needs, and also buys time for the ongoing adaptive management of this coastline.

The main erosion problems at Pagham Beach are largely being caused by the 'Church Norton Spit' in front of Pagham Harbour which has grown substantially over the last decade. In recent years, the spit and the Pagham Harbour tidal inlet channel have extended and migrated northwards along Pagham Beach; and this has caused/allowed a tidal inlet channel to cut into the beach leading to rapid localised shoreline retreat. The formation of the spit, tidal channel and its fronting 'ebb delta' feature[7] are also 'locking up' shingle and not allowing it to reach the more slowly eroding sections of the Pagham foreshore via the usual sediment transport pathways.

The current morphology of the spit is resulting in immediate coastal erosion and flood risk to residential properties at the eastern side of Pagham Beach (Figure 1.2). It is also posing an erosion threat to the remainder of the beach which is in a deteriorating condition and has reduced in amenity and recreational value. The proposed project will create a sustainable flood and coastal erosion risk management scheme for the community at Pagham Beach and also improve its amenity and recreational value.

The proposed managed breach of the Church Norton Spit is designed to alleviate the problems arising in a proactive manner that works with natural coastal processes and also then allows these processes to subsequently continue being the dominant factor influencing the coastline. Compared to alternatives, this approach can achieve more natural, and spatially extensive, coastal protection improvements as well as benefits to human health and site amenity.

These benefits are not all realised by other alternatives which typically seek to 'fight against' natural processes often in a more reactive and localised manner (e.g. by introducing rock

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6 i.e. one that is more natural, self-maintaining, requires less frequent and costly intervention and has a wider range of social ecological and economic benefits than alternatives (in keeping with the principles of sustainable development as directed by the National Planning Policy Framework (NPPF)).

7 The ebb delta is the area of deposited shingle that lies in front of (on the seaward side of) the inlet and is where shingle is deposited due to the nature of the tides draining Pagham Harbour.

ARUN DISTRICT COUNCIL P/93/25/PL

armouring or gravel-filled bags, shingle recycling, installing training walls or groyne, fixing the breach closed). The proposed approach is also more cost–efficient in terms of the gains achieved for the money spent.

A further benefit of this project arises from the fact that it is very much a 'community project'. It was the local community who originally emphasised the need for it and have continued to be supportive of it as the design has been developed (see next sections). This proposal will inherently help the community to re-engage with the environment on their doorstep rather than viewing it as a threat to homes on the beach. Members of the community have also volunteered to play an active role in the management of the environment following the implementation of such a measure. Thus the potential exists for greater coherence between the needs of the environment and the community. Given the multiple benefits associated with the project, it is considered to be in keeping with the principles of sustainable development as directed by the National Planning Policy Framework (NPPF).

In addition, the proposed breach is expected to be slightly more stable when compared to the existing tidal inlet position and is predicted to allow for a marginally improved tidal exchange in the harbour. Also, in the event that the new breach closed, it is likely to be more easily re-opened than if the current spit and inlet closed up. Thus, while environment effects will occur, that are reviewed in detail within this assessment, there will be inherent long term environmental benefits associated with the proposed scheme (e.g. for water quality and ecology) in terms of greater assurances that the tidal functioning of Pagham Harbour will be maintained.

The proposed project is also considered to be an appropriate 'adaptive management' measure and, as such, is in-keeping with the strategic coastal defence objectives as set out in the Pagham to East Head Coastal Defence Strategy (Environment Agency, 2009a). Adaptive management is a process that is adopted for complex coastlines and essentially involves an iterative sequence of monitoring and action. In this case the intention of the proposed project is to adjust the morphology of the environment in as natural a manner as possible and then to allow the environment to naturally readjust. This process of adjustment will be monitored and the results will feed back into ongoing strategic decisions.

1.2 Development of the Community Proposal

This proposed project has been developed following a sequence of studies that have been undertaken (by ABPmer with input from other relevant specialists as required) on behalf of the PPC and PFDSG. These studies have included: reviewing the proposed project against alternatives; identifying a preferred design; confirming the construction methods and undertaking the required impact assessment work. The project development work has involved the following:

- An initial review of options (ABPmer, 2015a) which reviewed the intervention options and identified that the most appropriate approach (in terms of creating a more sustainable shoreline morphology) involves creating a breach through the spit that functions as naturally as possible (i.e. one that allows natural processes to continue operating and avoids introducing artificial features such as cross-shore training wall structures);

ARUN DISTRICT COUNCIL P/93/15/PL

- A scoping study (ABPmer, 2015b) which highlighted the Environmental Impact Assessment (EIA) issues that are relevant for this proposed project as well as the consent requirements that will be needed to underpin a planning application for it;

- A breach design review (ABPmer, 2015c, included in Appendix A) which identified the preferred location and shape of the proposed breach in the context of the baseline environmental conditions and with reference to preceding scientific studies including through the use of:
  - Breach designs calculations;
  - Numerical modelling;
  - Reference to past case examples; and

- An Environmental Statement (this report) which assesses the environmental effects of the proposed project and includes a range of other required studies including:
  - Information for an Appropriate Assessment (AA) under the Habitats Regulations;
  - A Marine Conservation Zone (MCZ) Assessment;
  - A Water Framework Directive (WFD) Compliance Assessment; and
  - A Transport Statement.

During this sequence of scheme design and impact assessment studies, regular consultations were held with regulators, relevant specialists and the local community. Throughout this process, the high nature conservation value of Pagham Harbour has also been recognised as have the uncertainties that are inherent in working with nature in the way that is proposed.

The project that is proposed following this work is different from past proposals to address coastal erosion problems at Pagham Beach (including past proposals to breach the spit). The previous proposals have mainly involved (or included) using revetments or groynes to retain parts of the beach in place. The current proposed project has no hard engineering or fixed structures or revetments and instead, as outlined above, seeks instead to allow natural process to continue to dominate the environment but from a new starting point. Further detail about the proposed project is presented in Sections 2.1.3 and 3.

1.3 Report Background

In order to take this proposed project forward, PPC & PFDSG are seeking planning permission under the Town and Country Planning Act (1990) as well as appropriate consents and permissions from other regulators. The footprint of the proposed project overlaps with the boundaries of both Chichester District Council (CDC) and Arun District Council (ADC) (Figure 1.3). For this reason an application has been made to each Council in respect of the relevant part of the proposed project that covers each Council's area.

To begin this application process, an initial consultation meeting was held with both ADC and CDC on 27 January 2015 who advised that this planning application will require an Environmental Impact Assessment (EIA) under the Town and Country Planning EIA Regulations 2011. ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by PPC to undertake the EIA of the proposed project.

ARUN DISTRICT COUNCIL P/93/15/PL

To progress the EIA process, a Scoping Report was produced in April 2015 (ABPmer, 2015b). That preceding report presented the findings from the scoping phase of the EIA. It clarified the main characteristics of the proposed project and identified the key environmental issues that were considered to be relevant for the impact assessment. It also determined the likely scope of any survey and analysis work that will be needed to address these issues. The responses that were provided by the planning authorities and statutory consultees formed the basis of the Scoping Opinion and are provided in Appendix B.

The assessment phase of the EIA has been reported within an Environmental Statement (ES) (this report). The ES also includes the necessary information for CDC and ADC (as Competent Authorities) to produce an Appropriate Assessment (AA) under the Habitats Regulations (Conservation of Habitats and Species Regulations 2010 (as amended)). In addition, a range of other studies that are needed to underpin the planning and consents processes have been undertaken. These include a Marine Conservation Zone (MCZ) Assessment, a Water Framework Directive (WFD) Assessment and a Transport Statement.

1.4 Report Structure

The structure of this ES is as follows:

NTS — Non-Technical Summary Included at the beginning of the ES to summarise the contents of the main document in a non-technical manner. This summary is also available as a separate document.

Section 1 — Project Summary: Brief project background information and an overview of the information that has been provided in the ES.

Section 2 — Project Need and Alternatives: Background on the need for the proposed project and the consideration of alternative options.

Section 3 — Project Description and Methodology: A detailed description of the proposed project and construction methodology.

Section 4 — Consents, Approvals and Policy Guidance: Overview of the requirements to inform and accompany the licence application.

Section 5 — Impact Assessment Approach: The key issues identified during the scoping phase of the project and assessment methodology employed.

Sections 6-9 — Receptor Specific Impact Assessments: Baseline information is presented together with predictions of potential impacts arising from the proposed project on the existing environment. The significance for each potentially affected environmental feature of interest (receptor) is assessed.

Section 10 — Cumulative and In-Combination Effects: Assessment of the cumulative and in-combination impacts of proposed project together with other plans, projects and activities in the wider area.

ARUN DISTRICT COUNCIL P/93/25/PL

Section 11 Mitigation, Monitoring and Conclusion: A summary of all impacts and proposed mitigation and compensation that would avoid or reduce potential significant impacts. Potential enhancement measures and proposed monitoring requirements are also included.

Appendix A. Proposed Design and Modelling Report.
Appendix B. Scoping Consultation Log.
Appendix C. Information for an Appropriate Assessment Signposting Document.
Appendix D. Construction Maps Provided by Mackley.
Appendix E. Legislation and Policy.
Appendix F. Review of Nature Conservation Designations.
Appendix G. Marine Conservation Zone Assessment.
Appendix H. Water Framework Directive Compliance Assessment.
Appendix I. Transport Statement.
Appendix J. The Ecology of the DeFolin's Lagoon Snail.
Appendix K. Review of Bird Disturbance.
Appendix L. Little Tern Habitat Creation and Management Review.

ARUN DISTRICT COUNCIL P/93/25/PL

2. Project Need and Alternatives

2.1 Project Need

2.1.1 Introduction

The past, present and potential future evolution of the Pagham Harbour frontage and Pagham Beach, as well as a review of the processes acting on the coast, are considered in more detail in Section 6 of this Environmental Statement. However, a summary of the key factors influencing the coastal erosion and flood risk along Pagham Beach are also outlined in this section in order to understand the need for this community project.

Given the alignment of the Pagham shoreline and the fact that there is a dominant south-westerly wind, the sediment transport trend along the coast is in a south-west to north-east direction. Pagham Harbour, especially the tidal waters that flood into and drain from it and across the path of this prevailing transport route, strongly influence this sediment movement. As a consequence of this 'conflict' between the harbour tidal flows and sediment movement, the harbour frontage is characterised by a very dynamic shingle beach and spit complex (a feature which also provides the harbour with shelter from open-coast wave activity).

Today, as in the past, the evolution of the spit, harbour entrance and inlet channel is influenced by a wide variety of natural processes and man-made features that have influenced, or sought to control, these processes. These processes include, particularly, the variable supply of sand and shingle material along the coastline (from longshore drift and offshore supply) which are driven by:

- The changing interaction between waves and water levels;
- Tidal exchange in and out of the harbour;
- Wave activity in the nearshore region and constraints placed on the inlet; and
- Man-made infrastructure (i.e. the training wall within the main internal channel, and the groynes and most recent rock revetment at Pagham Beach).

The very dynamic nature of the shingle spit feature and inlet channel has resulted in considerable morphological change along this frontage. Historical reviews, covering the past 400 years, have shown that Pagham Harbour and its frontage have been subject to considerable natural and man-made change and evolution, particularly with respect to the shingle spit complex and inlet channel (harbour entrance). These historic changes and more recent evolution of the shoreline provide context to the current situation (see Section 6.2). The contemporary situation is also explored in Section 2.1.2 below.

Pagham Harbour is important nationally and internationally for its geomorphological and nature conservation interests. Further details about the designations that are in place and the range of species and habitats that the harbour supports are described in Section 8. This high conservation interest means that particular consideration has to be given (under the Habitats Regulations) to the effects that the proposed project might have on the integrity of the harbour and its environs. In particular, where a project is deemed to have an effect on integrity (or where it is not possible to be certain as to the absence of such an effect) there is a need to consider whether there are any suitable alternatives that might have lesser environmental effects. This has been done in the Section 2.2 below.

ARUN DISTRICT COUNCIL P/93/25/PL

Another implication of the Habitats Regulations is that where such an effect on integrity might occur (or cannot be excluded) then the project must be required for 'imperative reasons of overriding public interest' (IROPI) and compensation measures must be undertaken to offset any damage. For this project, there was an early recognition that an IROPI test and compensation measures were likely to be required. This was based on past UK experience in respect of projects identified as affecting integrity but also in view of the fact that this project works with natural processes which meant that there was expected to be an inherent lack of certainty as to the absence of an adverse effect. Further details about these considerations are discussed in Section 2.1.4.

2.1.2 Contemporary Situation

Over the last decade, the Church Norton Spit and the Pagham Harbour tidal inlet channel have migrated along the front of the adjacent Pagham Beach foreshore to the north-east (Image 2.1). The existing coastal morphology is resulting in an erosion and flood risk to residential properties at the south-western side of Pagham Beach which are currently being afforded protection by recent rock revetment work (Section 6.2.6).

The current morphology is also posing an erosion problem for the remainder of the beach which is in a deteriorating condition and has substantially reduced in amenity and recreational value. The main reasons for the enhanced coastal erosion and flood risk along Pagham Beach are described below and shown on Figure 2.1.



(Source: John Akerman)

Image 2.1 Church Norton Spit at Pagham (27 February 2015)

ARUN DISTRICT COUNCIL P/93/15/PL

The recent evolution of the spit and tidal inlet channel has resulted in a situation where shingle is not being allowed to move north and eastward through normal long-shore sediment transport pathways. Instead, the shingle is being stored or 'locked up' within the spit, platform and ebb delta, and is not being moved ashore because of the strong flows that occur through the now elongated tidal inlet channel. This reduction in the shingle supply is leading to beach erosion problems along Pagham Beach and increasing the flooding risk to residential properties.

The Church Norton Spit is also responsible for beach erosion on the northern bank of the Pagham Harbour inlet channel. This is driven by high current velocities within the channel, which are sufficient to expose the filled geotextile bags (and rock revetment) currently being used for coastal protection (Image 2.2).



(Source: ABPmer, 2015)

Image 2.2 Exposure of the geotextile bags within the inlet channel

Man-made features or fixed structures have also influenced the evolution of the spit, harbour entrance and inlet channel and, in recent years, are also partly responsible for the erosion issue presently experienced along Pagham Beach. For instance, whilst the migration of the Church Norton Spit is predominantly controlled by the balance in longshore drift and the influence of the tidal inlet channel, the channel itself has become artificially impinged by the training wall that was built in 1963 and reconstructed in the 1980s to provide stability to the harbour entrance. Without the training wall, the channel would have been able to erode the distal end of the northern (Pagham) spit in order to follow a more natural sinusoidal (meandering) shape, possibly taking it away from the properties situated along Pagham Beach.

The groynes in place on Pagham Beach are designed to stabilise the beach during periods of erosion and to enhance deposition/retention when the sediment supply is sufficient. Presently, however, the most south-westerly groynes are constraining the Pagham Harbour inlet channel, which has been forced northwards towards Pagham Beach by the migrating Church Norton Spit. This has been aggravating the erosive pressure at this part of the beach.

ARUN DISTRICT COUNCIL P/93/15/PL

Under the present condition, the migrating Church Norton Spit is causing severe property-threatening erosive pressure and subsequent flood risk on the Pagham Beach, as well as deteriorating the amenity and recreational value of the area. It is also, understandably, causing distress and concern to the local community given that the current management of the foreshore and comparatively short term reactive initiatives are leaving the beach at risk of sudden unpredictable effects from future storm events. .

2.1.3 Proposed Community Project and Its Objectives

Following a review of alternative management options for the spit feature at Pagham Harbour (ABPmer, 2015a), it was concluded that the most appropriate sustainable solution for the long term is to create a managed breach through the spit feature. This preferred option has been informed by past case examples and underpinned by the large amount of research and management work that has been carried out on Pagham Harbour and Pagham Beach over many years. This past work included reviews of possible intervention options such as closing the tidal channel and protecting the Pagham Beach foreshore (Royal Haskoning, 2014a; b). Other options considered were a combined approach of breaching the spit and constructing a new stabilising cross-shore training wall. These alternative options together with the "do nothing" option are reviewed in greater detail in Section 2.2.

The community project (which is different from past proposals for reasons noted in Section 1.2) will involve excavating a breach directly in front of Pagham Harbour aligned to the existing 1963-installed steel sheet training wall (i.e. where the tidal inlet entrance was previously located throughout the latter half of the 20th Century) (Figure 2.2). The material excavated from this breach will then be used to locally infill the existing channel to the north-east of the breach. This will create a new straight and relatively short tidal inlet channel immediately in front of Pagham Harbour.

In this configuration, the breach will be at its most stable compared to other locations (see Section 2.2.1), including the current inlet condition. Once the existing channel is closed and the new breach is created, natural processes will take over and no regular ongoing management of the site (e.g. maintaining the breach position) is anticipated. However, as a contingency, it is recommended that the option for one subsequent breach intervention is included as part of the proposal. A more detailed description of the proposed project is presented in Section 3.

The proposed project would remove the tidal scouring effect away from Pagham Beach. It will also allow the separated northern end of the Church Norton Spit to integrate back into the north-eastward transport pathways and supply material to the currently impoverished Pagham Beach through natural processes. The likely morphological evolution of the site (in the short, medium and long term) after the project is implemented is discussed in more detail in Section 6.

Alongside the benefits that exist for coastal protection, beach amenity and human health, there are other benefits (as already highlighted in Section 1.1) in terms of creating a more stable breach configuration and engaging the community in the environment. A summary of the main objectives of the proposed community project, when compared to alternatives, are as follows:

ARUN DISTRICT COUNCIL P/93/15/PL

- Achieves spatially larger and longer-term coastal defence benefits for the Pagham Beach foreshore;
- Brings other gains that are linked to having an improved beach structure and better coastal protection including improvements for the site's amenity value and for the 'human health' of the local community in this vulnerable coastal location;
- Represents a more cost-effective use of public money (with local community funding support);
- Involves the application of a 'soft' solution that works with natural processes at the coast, rather than fighting against them with hard engineering;
- Mimics a process (i.e. breaching of the spit) that will occur naturally in the much longer-term future (as well as being one that has happened in the past) but exerts a degree of sensitive control over this process rather than waiting for it to happen naturally in the future in an unknown form and location over unknown timescales;
- Helps the community to actively re-engage with the environment on their doorstep including by using their voluntary support to assist with site management; and
- Provides greater assurance that the tidal functioning of Pagham Harbour will be maintained.

Of these objectives, the five key ones that have then been used to underpin the alternatives review work are underlined. These are review further in Section 2.2.

2.1.4 Imperative Reasons of Overriding Public Interest

As noted previously, under Article 6(4) of the Habitats Directive, a plan or project can only proceed provided there are "imperative reasons of overriding public interest" (IROPI) that justify the plan or project despite the environmental damage it will cause. This requires consideration of the different elements of the term IROPI and the objectives of the proposed project (see Sections 2.1.3 and 2.1.4). In this case the following considerations are relevant:

- Imperative: the proposed project is urgently required to provide the necessary public safety and human health benefits;
- Overriding: the larger and longer-term coastal defence and other benefits served by the proposed project is considered to outweigh the uncertainty over the potential risk of harm to the integrity of the European/Ramsar site as concluded in the Appropriate Assessment Information Report (Appendix C); and
- Public Interest: a public benefit will be delivered to the residents of Pagham as well as the wider community. Furthermore, the project is consistent with the recommended Adaptive Management measure for this part of the coastline and, as such, is in keeping with the objectives of the Pagham to East Head Coastal Defence Strategy.

This section and other key elements of the ES clarify the detailed issues and conclusions that are relevant to these three elements of the IROPI test.

2.2 Consideration of Alternatives

The Town and Country Planning (EIA) (England and Wales) Regulations 2011 (as amended) and the Marine Works (EIA) Regulations (Amendment) 2011 require the applicant to consider alternatives to the proposed project (see Section 4.3). In addition, as described above, under Article 6(4) of the Habitats Directive, where adverse effects on site integrity are concluded (or

ARUN DISTRICT COUNCIL P/93/25/PL

cannot be excluded as was always anticipated to be the case for this project), the proposal must follow the tests of 'no alternatives' in order to obtain permission.

In this case the possible alternative options for managing coastal erosion and flood risk along Pagham Beach have been considered in great detail over the last few years. In particular, a number of alternatives were identified and reviewed by Royal Haskoning (2014a; b) in consultation with key stakeholders. The options considered in that study were as follows:

- 1A: Upgrading existing rock revetment and training arm involving a 100m long training arm and some modest beach management;
- 1B: Upgrading existing rock revetment and training arm involving a 150m long training arm and some minor beach management;
- 2A: Cutting a new channel (breach) at existing steel sheet piled training wall involving a new 250m long training arm;
- 2B: Cutting a new channel (breach) at southern end of Pagham Beach involving a new 200m long training arm;
- 3A: Closing the channel at the end of Pagham Spit; and
- 3B: Closing the channel at the end of the Church Norton Spit

The location and indicative design of these alternative options (as they were original described by Royal Haskoning (2014b)) are illustrated in Figure 2.3.

Following this review of alternatives, Royal Haskoning (2014b) concluded that Option 1A would probably be most favoured by the regulators, Option 2A would be most favoured by the local community, whilst Option 3A was the most 'straightforward' of the six options. These three alternative options (Options 1A, 2A and 3A) were considered further in the review of options which was undertaken by ABPmer (2015a) in order to identify a preferred solution. That review lead to the selection of the proposed community project which was subject to further design development in the breach design report (ABPmer, 2015c, provided in Appendix A).

Given that a preceding option review has already been carried out by ABPmer (2015a) and also that some of the detail of these designs might no longer apply (e.g. Option 1A would probably no longer be placed at the lost Groyne 4 as originally proposed) a specific comparison of these particular design options is not repeated further within this assessment. However, these previously reviewed options do separate into the following three generic categories which are subject to further review in this section:

1) Installing/upgrading cross-shore groynes structures (e.g. Options 1a and 1b as described above);
2) Excavating a breach in the spit and trying to seal it with a training wall (e.g. Options 2a and 2b as described above); and
3) Closing the breach (e.g. Options 3a and 3b as described above).

Alongside these three alternative options, the following options have also been identified during the course of this assessment, including through consultation with Natural England and the Environment Agency:

ARUN DISTRICT COUNCIL P/93/25/PL

1) Continuing to implement reactive coastal defence initiatives as required (i.e. continuing to extend the hard coastal defences along Pagham Beach or carrying out shingle recycling as needed) which is likely to lead to progressive extension of existing revetment; and
2) Creating a breach within the spit further to the north-east than is proposed for this community project (in order to minimise the loss of spit feature).

In Table 2.1, these five options, are reviewed and compared alongside the proposed community project using the five categories highlighted in Section 2.1.3.

Additionally, another alternative option has not been considered further due to being considered as unviable. That is the option of picking up and moving the existing rock armouring on the shore to address problems as they occur in other areas along the beach in the future. This was proposed by Defra (2015a) as discussed further in Section 2.2.1.1. Were this measure to be undertaken it would then re-expose the original revetment locations to erosion and this is not considered to be a sensible approach. In addition to this major negative aspect, this approach would result in the same issues as identified for implementing reactive coastal defence initiatives and therefore there is not thought to be any need to further review this alternative separately.

For this review, the "do nothing" option has not been considered further as this is evidently not appropriate and not in keeping with the principles of adaptive management for the shoreline. This was also highlighted by Defra (2015a).

ARUN DISTRICT COUNCIL P/93/25/PL

Table 2.1 Summary of key alternative options for coastal erosion and flood risk management at Pagham Beach

Option	Key Positive Impacts	Key Negative Impacts	Does it Meet Project Objectives? (Section 2.3.4)					Outcome of Review
			Larger and Longer-term Coastal Defence Benefits	Improve Amenity value and Human Health	More Cost-effective Use of Public Money	Works with Natural Processes	Greater Resilience of Pagham Harbour Tidal Functioning	
1) Installing/upgrading cross-shore groynes structures (e.g. Option 1a, Figure 2.3) This approach includes any scenario which would introduce revetment along the beach and cross-shore structures across it. Option 1a is an example that involved upgrading the existing rock revetment and the construction of a 100m training arm (designed to improve the existing Groyne 4) and some modest beach management. Under the current situation upgrading Groyne 4 would probably not be relevant, although an equivalent approach at Groyne 3 (or even Groynes 1 or 2) might be considered.	Upgrading the existing rock revetment would improve the existing level of coastal protection in a localised area of Pagham Beach where it is implemented with a relatively high degree of confidence (assuming ongoing maintenance and management).	Whilst an along-shore revetment would only offer localised shoreline protection, building a cross-shore training wall or groyne would not necessarily offer any increased protection to the shoreline and is more likely to constrain flows in the inlet channel. An ongoing maintenance requirement (and cost) is highly likely to be required to maintain the level of protection (and that has been the experience from work undertaken over the last 19 months). The armouring is likely to require extending along the beach as the spit evolves and causes erosion elsewhere on the beach and that would become very costly over time. This approach does not solve the problem that the shingle is locked into the spit, platform and ebb delta, thus reducing the shingle supply and exacerbating beach erosion problems along the beach over time. There would also be: ▪ A 'less natural' setting than at the present; ▪ Localised construction related impacts; ▪ Changes to water quality during construction; ▪ Visual and noise disturbance during construction; ▪ Loss of designated interest features under rock revetment footprint and beach recycling works; and ▪ Reduced amenity and recreational value of the beach.	No	No	No	No	No	This option would not achieve any of the core project objectives. Whilst it would provide protection to a small section of coast, it would not protect residential properties further east along the beach as the spit grows in the medium to long term. At high cost it could continue to be extended along the shoreline (as discussed below) but that is not really in keeping with the Pagham to East Head Coastal Defence Strategy given that it will technically change from being Adaptive Management (in response to urgent need to manage erosion at the beach) to a 'Hold the Line' policy that works against rather than with natural processes. It would also reduce the amenity and recreational value of the beach. Ongoing reactive intervention is likely to be required on a progressive basis along the frontage in the short to medium term. Much uncertainty would remain about how the inlet and spit might develop and compared to the proposed project this would not be a cost-effective use of public money in the medium to long term. It is therefore not considered an acceptable alternative.
2) Excavating a breach in the spit and trying to fix it with a training wall (e.g. Option 2a, Figure 2.3) This approach includes any scenario that would entail creating an inlet channel through the Church Norton Spit and then seeking to fix (or stabilise) that breach in place with a training wall. Option 2a included a 250m training wall through the spit.	Depending upon the location of the breach, material from the existing ebb tide delta and the spit extension would be mobilised providing an increased supply of shingle to Pagham Beach and additional coastal protection in the short, medium to long term. The new inlet channel will also be directed into deeper water away from Pagham Beach. As such, erosion forces on the beach caused by strong tidal currents along the existing channel will reduce. In addition, the amenity value of the beach and harbour will improve as the supply of shingle increases at the beach and currents along the existing inlet channel reduce.	The training wall is likely to inhibit the north-easterly longshore sediment transport (in the longer-term) once the existing material along the frontage (i.e. from the ebb tidal delta) has been redistributed. This would result in potential future erosion pressures along the shoreline. This could also lead to a 'groyne effect' in the future (i.e. blocking the longshore movement of sediment and increasing the retention of material), which would place increasing closure pressure on the breach itself. It is also a relatively high cost solution especially because of the fees required for the training wall and it is less likely that a spit will naturally redevelop in the future. There would also be: ▪ A 'less natural' setting than at the present; ▪ Localised construction related impacts; ▪ Changes to water quality conditions during construction; ▪ Visual and noise disturbance during construction; and ▪ Loss of designated interest features subject to a natural supply of sediment.	Yes	Yes	No	No	Yes	This option would achieve three of the core project objectives. It would provide coastal erosion and flood protection in the short to long term and also improve the amenity and recreational value of the beach. It is more in keeping with the Adaptive Management policy for this frontage in the Pagham to East Head Coastal Defence Strategy over this period. However, intervention work is likely to be required in the longer-term if the training wall extension constrains the longshore movement of shingle and starts to result in coastal erosion along Pagham Beach. Furthermore, it is a relatively high-cost solution and the creation of an artificial training wall would work against rather than with natural processes. It is therefore not considered to be an acceptable alternative.
3) Closing the existing breach (e.g. Option 3A, Figure 2.3) This approach includes any scenario that would entail closing the inlet whether at the end of the Church Norton Spit (i.e. adjacent to the Pagham Beach e.g. Option 3B) or at/near to the Pagham Spit training wall (e.g. Option 3A). Past scenarios have included the potential option of including shingle bags or rock in order to provide a stable core at the centre of the introduced blockage.	This approach removes the potential for the inlet channel to encroach further into Pagham Beach and residential properties, thus reducing the erosion potential along this frontage. It will also restore longshore transport along this section of the shoreline (in the short to medium term). Ebb tidal delta deposits are likely to be pushed onshore leading to a resupply of shingle and further coastal erosion and flood risk protection to properties (in the short to medium term). In addition, the amenity value of the beach will improve as the supply of shingle increases at the beach. This is a relatively low cost solution (in the short to medium term).	Closure of the inlet would remove Pagham Harbour from tidal influence and result in the loss or damage to designated interest features. Having closed the inlet there is the risk of an uncertain unmanaged (natural) breach along the spit in the medium to long term. The location of the breach would be uncertain and it may be less stable than the proposed community project when it occurs. Such a breach would result in a loss of designated interest features. There would also be: ▪ Localised construction related impacts; ▪ Changes to water quality conditions during construction; ▪ Visual and noise disturbance during construction; ▪ Loss of designated interest features under footprint of works; and ▪ Amenity and recreational effects in the harbour.	Yes	Yes	Yes	Unclear (it would not do so if, as has been proposed, there is a fixed core is included in the blockage)	No	This option will achieve at least three of the core project objectives although the extent to which it works with natural process will depend upon whether a core is included in the blockage to fix it in place (which would not be recommended). Breach closure will reduce the coastal erosion and flood risk to Pagham Beach and also improve the amenity and recreational value along the beach. It is also a relatively low-cost solution. However, any shingle bags and/or rock required to stabilise the core of the channel closure would not be a 'soft' solution and would work against natural processes. Furthermore, this option will not maintain Pagham Harbour as an intertidal system and would result in a widespread loss of designated interest features. This change would only be reversed in an unmanaged way at a later date when the spit eventually breaches naturally. It is therefore not considered to be an acceptable alternative.

ARUN DISTRICT COUNCIL P/93/25/PL

Option	Key Positive Impacts	Key Negative Impacts	Does the Project Option Meet the Project Objectives?					Outcome of Review
			Long-term and Longer-Term Coastal Defence Benefits	Improve Amenity Value and Human Health	Most Cost-Effective Use of Public Money	Works with Natural Processes	Greater Assurance of Pagham Harbour Tidal Functioning	
4) Progressively extending existing revetment/ protection on a reactive basis (i.e. Option 4, Figure 2.3) This would involve continuing to extend and/or move existing hard coastal defence (either by rock revetment, geotextile bags or even maybe sheet piling) along Pagham Beach as the Church Norton spit evolves and causes erosion elsewhere on the beach.	Extending the existing hard coastal defences would improve the existing level of coastal protection to the sections of the coast where it is placed and then, over the longer-term to the wider coast as it is extended.	This is a relatively high cost solution both for the implementation and for the ongoing maintenance that is likely to be required to maintain the level of protection. There is also a continuing uncertainty for the local community as to how the inlet channel and spit will develop in the short term and when these beach management interventions would be required. It would also substantially damage the visual and amenity value of the beach. In addition, there would be: ▪ A 'less natural' setting than at the present; ▪ Localised construction related impacts; ▪ Changes to water quality conditions during construction; ▪ Visual and noise disturbance during construction; ▪ Loss of designated interest features under defence footprint; and ▪ Reduced amenity and recreational value of the beach	Yes (over the long term as it is implemented)	No	No	No	No	This option will only achieve one of the project objectives. It will provide longer-term coastal erosion and flood protection. However, the cost would be high (including for ongoing intervention work that is likely to be required on a progressive basis). It is not considered to be in keeping with the Pagham to East Head Coastal Defence Strategy given that it will be a 'Hold the Line' policy that works against rather than with natural processes. It is therefore not considered to be an acceptable alternative.
5) Excavating a breach further along the spit to the north-east (i.e. Option 5, Figure 2.3) Cutting a new inlet channel through the Church Norton Spit to the east of the existing training wall and infilling the existing inlet channel next to it.	Equivalent to the proposed community project this is a "soft" engineered option that would maintain the site's geomorphologically dynamic nature. It would improve the existing level of coastal protection (in the short to medium term) across a wider spatial area and the coastline would be allowed to develop more naturally. Tidal scouring along the existing channel and beach will be immediately removed thus reducing erosive pressure at this location. Material from the existing ebb tide delta and the spit extension will be integrated back into the north-eastward longshore transport pathway to supply material to the beach through natural processes. The amenity and recreational value of Pagham Beach would improve as the supply of shingle increases at the beach and currents along the existing inlet channel reduce.	Compared to the community project there would also be less shingle re-supplied to Pagham Beach from longshore transport and a likelihood that the spit will return to its existing position in a shorter period of time (thus less benefit for the same cost as the community project). Similar to the proposed community project, this approach will have an effect on the nature conservation and geomorphological interests of the site through the excavation of a breach through the spit. As Little Terns are nesting in this section of the spit currently it is likely to have greater direct short term effects on this species than the proposed project. A managed breach to the east of the training wall will result in the tidal inlet channel having a sinusoidal shape. This less stable channel would be at greater risk of closing than the proposed project. If it closed it may well be more difficult to re-open here than at the proposed community project location. There would also be: ▪ Localised construction related impacts; ▪ Changes to water quality conditions during construction; ▪ Visual and noise disturbance during construction; and ▪ Temporary loss of designated interest features subject to a natural supply of sediment.	Yes (to lesser degree than proposed community project)	Yes (to lesser degree than proposed community project)	No	Yes	No	This option meets many of the project objectives. It will initially provide greater coastal erosion and flood protection to properties and improve the amenity and recreational value of the beach (albeit for a shorter degree/period than the proposed project). However, a breach at an eastern location will be less stable and thus more likely to close than the one proposed for the community project. It is also more likely to overlap with the key nesting area for Little Terns and thus result in a direct and immediate loss of this supporting habitat which may be more detrimental (in the short term) than the proposed project. It would be less cost-effective than the community project because it unlocks less shingle for longshore transport leading to a shorter period of coastal erosion and flood protection. Although unlike all other previously reviewed alternatives, it works with natural processes, it is not considered to be an acceptable alternative compared to the proposed project.
6) Excavating a Managed Breach in the Spit and Closing the Existing Tidal Inlet (i.e. the proposed community project, Figure 2.2) Excavating a breach to create a new inlet channel through the Church Norton Spit at the location of the existing training wall and then also infilling the existing inlet channel next to it (see Section 3).	It is a 'soft" engineered option that will improve the existing level of coastal protection and allow the coast to develop "naturally" (although still influenced by existing man-made features i.e. training wall and groynes). The tidal scouring effect along the existing channel and beach will be immediately removed thus reducing erosive pressure at this location. Material from the existing ebb tide delta and the spit extension will be integrated back into the north-eastward longshore transport pathway supplying material to the beach through natural processes. This will provide longer-term coastal protection to properties. It also maintains the site's geomorphologically dynamic nature and helps to enhance the amenity and recreational value of Pagham Beach. Compared to the existing condition or alternatives there is greater certainty that the breach will remain open, maintaining the tidal functioning of Pagham harbour.	The project will have an effect on the nature conservation and geomorphological interests of the site (as assessed in this ES) through the excavation of a breach through the spit and local channel infill works. There are also uncertainties about working with natural processes in the manner proposed. In addition, there would be: ▪ Localised construction related impacts; ▪ Changes to water quality conditions during construction; ▪ Visual and noise disturbance to birds during construction; ▪ Visual and noise disturbance to birds during operation due to change in access; ▪ Temporary loss of designated interest features subject to a natural supply of sediment; and ▪ Relatively high cost solution but with longer-term benefits.	Yes	Yes	Yes	Yes	Yes	This option meets all of the project objectives. It will provide longer-term coastal erosion and flood protection to properties and also improve the amenity and recreational value of the beach. It is in keeping with the Adaptive Management policy for this frontage in the Pagham to East Head Coastal Defence Strategy. It is also a cost effective and appropriate 'soft' solution that works with natural processes rather than introducing fixed man-made features. Furthermore, it is representative of a breach that is likely to occur naturally in some form at some point in the future. Exerting control over this process and ensuring its form and location is at its most stable will avoid the higher level of uncertainty and instability associated with a natural breach or a managed breach at other locations (e.g. to the east). For all these reasons, this is the preferred option for the proposed project.

ARUN DISTRICT COUNCIL P/93/25/PL

2.2.1 Key Reasons for Selecting the Preferred Option (Proposed Project)

As described in Table 2.1, the community project is the option that meets all of the key objectives of the project (Section 2.1.3). The key reasons for selecting the preferred option in the context of alternative options are discussed in the following sections.

2.2.1.1 It provides a longer-term flood and coastal erosion risk management scheme

The Pagham to East Head Coastal Defence Strategy requires that an Adaptive Management[8] approach needs to be taken (Environment Agency, 2009a) and that Pagham Beach and the mouth of Pagham Harbour should be viewed as one frontage. The primary goals for this project in this context are to:

- Alleviate the pressure being placed by the tidal channel; and
- Allow a flux of shingle into the Pagham Beach shoreline to reverse recent beach erosion trends.

Along the shoreline in front of the harbour, the dominant activity is one of longshore and offshore transport of shingle with periods of natural breaching, breach movements and man-made closures. In this context, and given the need to work with natural processes, any measure that seeks to halt this longshore transport process should be discouraged. For example introducing training walls or trying to fix the environment in place on such a dynamic coastline is likely to cause problems later. The use of such cross-shore structures may solve the short term critical erosion problems in times when the shingle supply is in surplus, as is seen presently, but they are likely to also cause longer-term erosion pressures over possibly a larger area of the shoreline when the shingle becomes scarce. This is because such structures could then effectively inhibit longshore sediment transport.

The problems and challenges of using long-shore and/or cross-shore fixed revetments are already in evidence on this site because these techniques have already been employed. The emergency revetment work that has been undertaken on Pagham Beach has protected a short section of the western end of Pagham Beach from the effects of erosion by the migrating tidal channel. However, this has not created a stable coastal defence structure but one that has required regular subsequent intervention (with associated costs) to maintain its functionality. The construction of the initial emergency rock revetment in the 2013 winter cost approximately £500,000. The subsequent beach recycling efforts and urgent remedial works to the rock revetment and groyne which were being undermined by scour cost a further approximately £360,000 the following year.

Whist the revetment works address the problems being experienced where the tidal channel is cutting in currently, they do not address the fact that the spit will grow and continue to cause further tidal channel incursions along the beach. Thus, it is deferring the problem to the eastern parts of the beach as the spit continues to grow. The idea has been proposed that the existing rock armour on the beach could be moved when such pressure is placed further down the beach. For example in the Defra (2015a) review it is stated that "a key reason for the use

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8 Defined as "Managing complex coastal areas by monitoring changes and acting on them in a planned but flexible way, increasing our understanding over time".

ARUN DISTRICT COUNCIL P/93/25/PL

of rock in the revetments was that it could be moved to other areas of the beach when necessary".

This is highly unlikely to be a realistic situation. This is because once the armouring is removed from one part of the beach it will then simply leave the area of their original placement exposed to the strong tidal flows being caused by the attempted migration of a tidal channel. Therefore moving rock armouring from one previously protected location (whether the existing position or from any future location in which it needs to be placed) would simply re-expose that formerly protected beach section to tidal pressure.

The only realistic way to protect the beach over the longer-term using revetment work will be to continue extending the armouring along the foreshore. This would incur substantial costs (for installation as well as for regular management) and would ultimately also become a 'Hold the Line' strategy rather than Adaptive Management (thus not in keeping with the management strategy for this section of the coast). In addition, it is worth noting that any such further work may well have to be undertaken at very short notice in response to sudden storm events. This would leave little time for the relevant consenting and procurement works to be carried out (Dornbush, 2014) and would increase the flood risk the Pagham frontage.

The rock revetment option also involves constructing a training arm. In the current morphology, however, cross-shore groynes will not provide an effective solution. While, in general, cross-shore groyne structures can be valuable for the localised retention of sediments along a beach, any benefit at this particular site is only ever likely to be temporary as they will not halt the passage of the spit and the tidal channel.

The problems with using groynes is clear from conditions on site where the channel has broken through Groyne 4 and is continuing to pro-grade and exert further pressure on Groyne 3 and on the beach behind. Groynes 3 and 4 have helped to stall the passage of the spit by causing a diversion of the tidal channel away from the shore but, in doing so, have placed further pressure on the beach locally by helping to force the spit into the shore (i.e. along its 'preferred' north-easterly alignment).

Where the groynes not present, a progressive extension to the long-shore revetment would still be needed given the pressure exerted by the channel. However, the spit would also be more likely to progress rapidly in a parallel alignment to the shoreline and ultimately would be more likely to weaken and breach naturally at some point along its length. The existing groynes are thus effectively slowing these processes from occurring.

The managed breach and training wall option is also likely to eventually block the movement of shingle in the long term (Table 2.1). This option, therefore risks exacerbating problems in addition to the challenges of making the hard engineering work at all in such a mobile environment. None of the alternative options involving physical obstructions will thus achieve the above goals and comply with the Adaptive Management coastal defence strategy for this frontage in the long term.

The closure of the channel would provide improved coastal erosion and flood risk protection to properties along Pagham Beach. However, the likelihood of an unmanaged breach occurring would be increased the medium to long term and therefore some form of intervention would be required to re-close the breach if it was in an unsuitable location.

ARUN DISTRICT COUNCIL P/93/25/PL

The 'do nothing' option would not be in keeping with the Adaptive Management strategy for the frontage. The lack of any intervention work or maintenance activities whatsoever would not improve the supply of shingle as it would continue to be locked into the spit. It would also mean that the shingle banks along the beach would rapidly deteriorate and fail, increasing the already high coastal erosion and flood risk to properties.

Overall, the preferred option is considered to be the only longer-term 'soft solution' for this particular site in view of its history and the dynamics of the environment. This approach is considered to be an appropriate Adaptive Management measure for the entire frontage and, as such, is in keeping with the objectives of the Pagham to East Head Coastal Defence Strategy.

2.2.1.2 Improved amenity and recreational value of Pagham Beach

The preferred option involves the highest likelihood of leading to improvements to the amenity value of the Pagham Beach frontage. This amenity value has declined dramatically over the past decade, due to the combined effects of the channel-related erosion, reduced sediment supply and increased current speeds experienced along the frontage (see Section 9.1 for more details).

The risks to human health have increased on this beach despite there being a number of warning notices along this stretch of the coast. For example, a swimmer is understood to have nearly died in 2014 due to the dangerous currents around the harbour entrance, which now aligns with the Pagham Beach frontage. Visits by watersports enthusiasts (particularly windsurfers) have noticeably declined, as have general visitor numbers to the beach. The reveted section in particular is viewed as unappealing and dangerous by beach users, and avoided by many visitors. Local sailors are also experiencing increasing difficulties at the Yacht Club due to the beach narrowing and steeping, but also due to the increased current speeds experienced.

Implementing the preferred option, as well as any other breach and channel closure options would reduce the dangerous currents, as the water would then no longer enter or exit the harbour immediately adjacent to it. Thus, Pagham Beach would again be safer for, and more attractive to watersports enthusiasts and swimmers alike. More shingle would again reach the beach once the breach works had been undertaken. In time, the beach would be expected to revert to a wider, and gentler, profile.

The breach and channel closure options are more likely to create a more natural setting, although that might not be the case for some of the closure option's where they included a riveted central core that might become re-exposed and then influence the shoreline adversely future. These options differ in respect to the amount of material which would again be available for distribution via longshore drift, as well as the time period over which Pagham Beach would be expected to be better protected from erosion. The preferred option is anticipated to be that with the best outcomes with regard to these two aspects, i.e. more shingle is likely to reach the beach, and a reformed spit would take the longest to reach Pagham Beach again (see Section 6.3).

Implementing any of the non-breach revetment options would not alleviate the negative impacts which the currents and beach narrowing are having on the amenity value of the Pagham Beach frontage, nor would they reduce the risks to human health. This is because the fast currents would still be experienced adjacent to Pagham Beach, and the beach would continue to be

ARUN DISTRICT COUNCIL P/93/25/PL

starved of sediments along significant lengths (see Section 2.1.2). The revetments would still be in place, and the beach still dangerously narrow and unattractive along the length of the revetment. Whilst continuing to increase the revetments along the shoreline would improve the level of protection afforded to affected properties in the short term, the increased use of these artificial structures would progressively reduce the landscape and amenity value of the beach.

2.2.1.3 Damage to designated interest features

As noted in Section 2.1.1, under Article 6(4) of the Habitats Directive (as implemented in the UK by the Habitats Regulations), a plan or project can only proceed provided there are no feasible alternative solutions which are less damaging to the affected European/Ramsar sites (see Section 4.4). In this case none of the alternative options meet all the objectives of the project (Table 2.1) and are not feasible alternatives. The hard engineering revetment options can, for example, achieve localised protection to the shoreline. However, they will progressively damage the visual appearance of the shoreline and do not solve the broader erosion issues along the beach or address the amenity and human health issues that result from having the beach at risk from ongoing erosion. Other alternatives have larger benefits but are accompanied by high costs or high risk of damaging Pagham Harbour through closing the inlet channel.

The proposed project achieves all the required goals for cost-effective coastal protection (as described in Table 2.1) but has the added benefit that it will create a breach morphology that is marginally more stable and less likely to close than the alternative. Thus it helps with protecting the Pagham Harbour SPA and Ramsar site from closure (a concern that has been expressed by Natural England within the SPA Site Improvement Plan (Natural England, 2014)).

It has been recognised from an early stage in the development of this project (see also Section 2.1.1) that it will not be possible to conclude with certainty that there will be no adverse effect on integrity (AEOI) of the Pagham Harbour SPA and Ramsar site. However, that is also expected to apply to many if not all of the alternative options given the uncertainty associated with the future morphological development of this very dynamic coastline (see Section 2.2.1.4). The breach and closure options are all highly likely to fail in this regard and even, upgrading and maintaining hard coastal defences along Pagham Beach is likely to result in a more unstable spit and tidal inlet morphology that is more susceptible to an unmanaged (natural) breach along its length with uncertain and potentially greater impacts on interest features (e.g. if the breach were to occur through the middle of the Little Tern nesting area).

In conclusion, there are no feasible alternative options to the proposed project that deliver the project objectives and are considered less damaging to the integrity of the European/Ramsar sites affected.

2.2.1.4 Greater level of certainty of the future morphological development of the site

Linked to the points made in the preceding section, because the mouth of Pagham Harbour is a very dynamic environment and in a continuous state of flux, it is an environment that cannot be considered as a fixed environment which should be, or can be, preserved in a defined condition with respect to its overall morphology. This has implications for the harbour's hydrology and for its designated interest features.

ARUN DISTRICT COUNCIL P/93/25/PL

It is important that any intervention/management measure that is adopted is sensitive to the dynamic conditions at the harbour mouth and works with natural processes. It also needs to be recognised that uncertainties as to the site's future evolution will always exist with any option. The proposed project is designed to best achieve the required goals and with the highest degree of certainty of outcome. It does this, in particular by seeking to re-instate a morphological configuration that existed historically (breach at northern side of Pagham Harbour) to create the most stable breach formation.

The alternative options will result in a higher potential risk of an unmanaged (natural) breach along the spit than the preferred option (Table 2.1) and/or a marginally greater risk of the breach/inlet closing. In the event of an unmanaged breach, the resulting inlet is likely to be mobile and more unstable than the one proposed for the community project and the form, location and timing of such a breach are uncertain. In the event of a breach closure, there will be major changes to the functioning and ecology of Pagham Harbour.

The preferred option will allow a managed breach to be created which is likely to be most stable and will reduce the risk of it closing in future. It will also reduce the risk of a further unstable unmanaged (natural) breach from occurring with all the associated uncertainty.

2.3 Conclusion

In view of the need for the project, and the outcomes of the alternatives review, the proposed project is considered to be the most suitable and sustainable option. Overall, when compared to alternatives this approach can achieve more natural, cost-effective, and spatially extensive, coastal protection improvements, as well as benefits to human health and site amenity. It can also achieve a wider range of benefits than alternatives and is, overall, more in keeping with the principles of sustainable development as directed by the National Planning Policy Framework (NPPF)).

The proposed project is also a more appropriate 'soft' solution for this particular site that works with natural processes, in view of its history and the dynamics of the environment. As noted previously, this approach is also considered to be an appropriate Adaptive Management[9] measure for the whole foreshore (Pagham Harbour and Pagham Beach) and, as such, is in keeping with the objectives of the Pagham to East Head Coastal Defence Strategy.

9 Defined as "Managing complex coastal areas by monitoring changes and acting on them in a planned but flexible way, increasing our understanding over time".

ARUN DISTRICT COUNCIL P/93/25/PL

3. Project Description and Methodology

3.1 Project Description

The design of the proposed project has been derived through the application of a range of data analysis techniques and interpretation tools describing the relationships between flow and breach stability/shape. This 'breach stability analysis' work has also been supported by reviews of previous case-example projects involving natural or man-made breaches through shingle spit features (e.g. those at Medmerry near Selsey and Porlock in North Devon) and detailed numerical modelling investigating the potential impact of a managed breach through the shingle spit at Pagham. The results of this analysis are presented in a separate report which is included in Appendix A (ABPmer, 2015c).

The proposed breach, as excavated, will have the following design characteristics:

- A central 40 m channel at a depth of -1.80 mODN which is equivalent to the Mean Low Water (MLW) level and is comparable to the channel bed level of the existing harbour inlet channel;
- Side slopes on each side of the breach that will be set at approximately a 1:4 gradient;
- A width of 80 m at tidal elevation of +3.0 mODN level which is approximately at the Highest Astronomical Tide (HAT) level; and
- An excavated volume of around 42,000 m³ (below 3.0 mODN) with an expected additional 10,500 m³ needing to be excavated above the +3.0 mODN elevation.

The location of the proposed breach is shown on Figure 2.2. The position takes account of the topography within the harbour; proximity to the tidal channels; the position of the existing training wall; the shape of the spit; and the position of the harbour inlet historically (in 2003). The breach will follow a straight alignment to ensure that contractors can excavate it relatively easily and safely. Once created, the breach is then expected to adjust in alignment and form (and deepen at its base) as a result of natural processes. The post-excavation morphological development of the breach is described further in Section 6.3.3.

The material excavated from this breach will be used to infill the existing channel to the north-east of the breach (Figure 2.2). Once the existing channel is closed and the new breach is created, natural processes will take over and no ongoing management of the site (e.g. maintaining the breach position) is proposed. However, one subsequent breach intervention has been included as part of the proposal as a contingency (Section 3.2.7).

3.2 Project Methodology

To inform the development of the methods, a team from Mackley/Ovenden visited the site and were commissioned to provide advice on the work and a method statement for delivery. This team are specialist engineering contractors with extensive experience of undertaking beach works along the south coast (and with specific experience of undertaking breaching work on shingle barriers most notably at Medmerry). This method statement was informed by the breach design report (ABPmer 2015 a, Appendix A).

ARUN DISTRICT COUNCIL P/93/15/PL

On the basis on the advice received, the work is expected to take 9 to 11 weeks to complete. It will also involve plant being based in the car park at the end of Harbour Road (Pagham) and then accessing the breach site via fixed and clearly defined access routes. Maps showing the key locations are presented in Appendix D and the following sections review the project methodology in greater detail.

3.2.1 Access, Site Compound and Storage

The main access route to the site will be from the east on the Pagham side of the harbour (Appendix D, refer to sketch "Pagham Spit Breach - Location Plan & Access Routes"). Some daily pedestrian access may need to be via the west from Church Norton or via East Beach, Selsey. Alternative emergency access will be via East Beach, Selsey. A Heras fenced site compound will be created in the currently closed Pagham Car Park, which will also be used for turning lorries around.

To initially get the plant onto the spit, a temporary transient crossing will be created at the shallowest part of the channel near the north eastern end by using some of the existing shingle ridges on the landward side of the channel (Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes"). This mobilisation route will not be fixed in place but allowed to then erode into the environment. Access from the site compound at Pagham Car Park to the proposed crossing point will be agreed in advance with Natural England to minimise damage to vegetated shingle. Once across the channel the plant will travel directly up and over the spit and then travel along the seaward side on the foreshore to gain access to the breach site. This route should only be used once.

There will be relatively minimal movement of plant in and out of the site as no materials will be imported for the proposed works. However, plant will need to be refuelled and safe access and egress to operators will also need to be provided on a daily basis. A temporary access 'causeway' will therefore be created. This will involve driving sheet piles using a vibratory hammer across the channel at the north eastern extent of the proposed infilled channel or 'dam' to 0 mODN (AOD) to give a low water access point to the spit (Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes"). The installation of the sheet piles will involve working at all stages of the tide when below 0 mODN. This temporary causeway will provide two environmental benefits:

- It provides a defined crossing point thus minimising encroachment onto other sensitive ecological areas by establishing a permanent works footprint; and
- It will reduce fill from the dam being transported by tidal action, both into the harbour or out to sea.

To get the most benefit of the temporary causeway and to reduce programme time initial access will need to be from the landward and spit side at the same time (see initial transient access crossing above).

ARUN DISTRICT COUNCIL P/93/25/PL

At the same time, a more permanent fenced temporary access will be created via an agreed route which minimises damage to vegetation from the site compound at Pagham Car Park to the harbour side of the proposed channel dam (Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes"). Again some of the existing shingle ridges on the landward side of the channel will be used to provide access across the channel to install the sheet piles.

Once the sheet piles are in, and as the excavation commences, infill material from the breach will be placed in front of the piles and this will become the main site access. Once this route is established the sheet piles will be removed (see Section 3.2.6).

Plant will generally be stored overnight on the highest levels of the spit which are well above high tide. In the event of storm warnings, plant will be tracked across to the site compound. Beach material will be used to provide safe working platforms for the plant, maximising their working periods and the efficiency of the operation.

3.2.2 Breach Methodology

Following the approach that was undertaken at the Medmerry Managed Realignment site, the breach at Pagham will be excavated from landward to seaward initially and then seaward to landward (Appendix D, refer to sketches "Pagham Spit Breach – Step 1 to 5"). The remaining highest elevation central section will be excavated as rapidly as possible on a 'one-week sequence' of dropping spring to neap tides. This proposed excavation sequence will maintain flood defence for as long as possible over the construction programme.

3.2.3 Channel Infill Methodology

In order to protect the new infilled channel or dam, coarser material will be placed on the south side of the infill to help protect the harbour face. Once the piled causeway is in place, the inner end of the existing channel will be filled with excavated breach material up to the pile top level, and back towards the harbour to the agreed position of the new bund. The remaining material from the excavation will then be temporarily stockpiled in an agreed area to the north of the breach and just seaward of the infilling areas (Appendix D, refer to sketches "Pagham Spit Breach – Step 1 to 5"). The final push down of these stockpiles into the channel will be coordinated with the excavation of the breach to create the dam.

Once the managed breach has been created, the excavation teams will move on to the stockpiled material and load and haul the material in to the existing channel and continue infilling from a higher level, until such times as the existing channel is filled right across to the land side sufficiently securing the area from the sea pushing through. This operation will continue until the existing channel has been filled to the required design.

3.2.4 Removal of Piled Causeway and Demobilisation

The sheet steel pile that formed the basis of the initial access causeway will be removed on completion of the work, the site demobilised and the compound area left in an acceptable condition.

ARUN DISTRICT COUNCIL P/93/25/PL

3.2.5 Programme

The estimated construction programme is shown in Table 3.1. The actual programme will need to take into account when the operation is to take place (presently anticipated to be November to December 2015 or in 2016 outside the Little Tern breeding period which is April to July) to allow for potential weather risk and downtime, as well as any logistical issues with accessing the spit initially.

Table 3.1 Estimated construction programme

Task	Duration (Weeks)
Mobilise	0.6
Install sheet piles to provide temporary access route	1
Excavation of breach	5-6
Channel infilling	1-2
Removal of sheet piles	0.6
Demobilisation	0.4
Total	9 to 11

3.2.6 Team and Equipment

It is anticipated that a single team will be used for Week 1 and then a second team will be brought in for Week 2. The two teams will take approximately 4 weeks excavating the new channel for the breach and infilling of the existing channel, with another week or so completing the infilling to finished level of the original channel. Each team would operate with 1 excavator, 1 dozer and 2 dump trucks. Support will be provided from a 4-wheel drive (or tracked) tractor & Op with a towable fuel bowser. The estimated overall numbers of staff and plan weeks involved in the works assuming an 11 week programme are shown in Table 3.2.

Table 3.2 Approximate numbers of staff and plant weeks

Week	Works	Team	No Staff	No Plant	Total Staff Weeks	Total Plant Weeks
Overall (based on 11 weeks)	Supervision	Site agent and engineer	2		22	
Week 1	Site Set Up	Small team with excavator and dumper	3	2	6	4
Week 2	Temporary Sheet Piling	Small team with excavator and dumper Plant operator with Movac piling rig	4	3	4	3
Week 2	Access to spit and start excavation	One team excavating and filling	5	5	5	5
Week 3 - 10	Excavation and filling	Two teams excavating and filling	10	10	70	70
Week 11	Remove sheet piling and demobilise	Small team with excavator and dumper Plant operator with Movac piling rig	4	3	4	3
				Total	111	85

ARUN DISTRICT COUNCIL P/93/15/PL

3.2.7 Post-breach Maintenance

The breach has been designed in such a way as to be self-maintaining and minimise the risk of it closing. However, it is recommended that allowance is made for one subsequent breach maintenance intervention as part of the proposal. This is as a contingency in the unlikely event that the tidal inlet closes. Breach closure would result in the loss of designated habitat and spit features. Such an intervention is therefore considered necessary to help maintain nature conservation features. The construction and operational effects of such a breach would be the same as those already assessed for the main breach and these have been fully assessed in this ES.

ARUN DISTRICT COUNCIL P/93/25/PL

4. Consents, Approvals and Policy Guidance

4.1 Introduction

To inform this EIA, a Scoping Report was prepared and submitted to CDC and ADC in April 2015 (ABPmer, 2015b), as a basis for consultation. The principal consents that are required to support the planning application are summarised in the following sections, although there is in addition a wide range of related environmental legislation with which the proposals will need to comply. A summary of the principal legislation and national, regional and local planning context is provided in Appendix E.

4.2 Relevant Local Plans

Planning permission for this proposed project is required from both CDC and ADC under the Town and Country Planning Act (1990). In order to obtain planning permission, developers have to, amongst others, demonstrate that relevant local plans have been considered whilst developing a project. A number of local plans, both of a statutory, emerging and non-statutory nature, exist which are of relevance to the proposed project. Those which apply the most, and were taken into account during the design and impact assessment phase for the proposed project, are considered in Section E.4 of Appendix E. As the proposed project affects both the districts of Chichester and Arun, the policies and guidance of both councils were reviewed. A summary of the most relevant plans and policies is now provided; for more detail, please refer to Appendix E.

Both CDC and ADC have developed new local plans, and submitted them for independent examination to the Secretary of State (in 2014 and 2015 respectively). A decision on both is still outstanding. In the meantime, the saved policies of the respective older local plans are still in force (1999 for Chichester, 2003 for Arun).

Particularly pertinent (2003) ADC policies include Policy GEN10: Tidal Flooding and Coastal Defence and Policy GEN19: Coast Protection and Sea Defence Works. From the submitted new local plan (ADC, 2014), the following proposed policies are of specific relevance to the project: Policy W DM4 Coastal protection and Policy TOU SP1 Sustainable tourism and the visitor economy. The latter, for example, states that "sustainable tourism growth for Arun requires the protection of features that make the District attractive to visitors". The former states that coastal protection works need to be "considered in light of their impact on the visual character and value of the open, undeveloped coast, protection and enhancement of coastal habitats and the provision of opportunities to complete the coastal footpath and improve the appearance and use of the coastline in the built-up areas". Methods should be "technically sound and appropriate to the task and not have a detrimental effect on other parts of the coastline", and be in accordance with the SMP or Strategy for that frontage (which the proposed project is considered to be, see Section 2).

ARUN DISTRICT COUNCIL P/93/15/PL

The 1999 local plan for CDC includes a policy on Sea Defence and Coast Protection Works (C9), which is of particular relevance to the proposed project. From the new, proposed (2014) local plan, the proposed Policy 22 on 'Integrated Coastal Zone Management for the Manhood Peninsula' could be viewed as pertinent, as the Church Norton Spit is essentially part of the Peninsula, even though the affected community at Pagham is not on the Peninsula, nor is it within the boundaries of CDC. This policy includes pledges to "facilitate the economic, environmental and social well-being of the area, address proposals for the coastline and coastal communities set out in Coastal Defence Strategies and Shoreline Management Plans; contribute to greater safeguarding of property from flooding or erosion and/or enable the area and pattern of development to adapt to change (...), and 'provide resources to improve the process of harbour and coastal management, incorporating and integrating social, recreational, economic, physical and environmental issues and actions". Proposed Policy 44, Development around the Coast, states that planning permission will be granted for development in the coastal area, provided (amongst several others) "the development provides recreational opportunities that do not adversely affect the character, environment and appearance of the coast (...)", and "the development would not be detrimental to infrastructure for, and quality of, water-based recreation, or be detrimental to the safety of navigation".

The Pagham Parish Council Neighbourhood Plan (Pagham Parish Council, 2014) is awaiting final approval from ADC, pending some further work on assessments. This relates mainly to housing provision, but the 15-year vision contained within states, amongst others, that:

"Crucially, our plans and projects have enabled the village to be better protected from the threats of coastal erosion and flooding than in previous years. The works have helped protect many hundreds of homes and businesses".

Its Policy 8 on Tourism Development states that "Initiatives seeking to increase the number and range of holiday accommodations available across the parish will be encouraged". The Proposal 1 on Coastal Protection states that 'the Parish Council will support proposals for coast protection and sea defence works (...) to reduce flood risk and to protect against the loss of homes, businesses, tourism attractions and habitats in Pagham- - in pursuit of the relevant plans and strategies".'

4.3 Environmental Impact Assessment

An EIA of the proposed works has been undertaken in compliance with the Town and Country Planning (EIA) (England and Wales) Regulations 2011 (as amended) and the Marine Works (EIA) Regulations (Amendment) 2011. Table 4.1 and Table 4.2 summarise the requirements outlined in Schedule 4 of the Town and Country Planning (EIA) Regulations and Schedule 3 of the Marine Works (EIA) Regulations (Amendment) respectively. These tables also signpost where the information can be found in this ES.

ARUN DISTRICT COUNCIL P/93/15/PL

Table 4.1 ES requirements according to the Town and Country Planning (EIA) (England and Wales) Regulations 2011

Regulations Paragraph	Requirements For ES	ES Section
1	Description of the project, including in particular: ▪ Description of the physical characteristics of the whole project and the land-use requirements during the construction and operational phases; ▪ A description of the main characteristics of the production processes, for instance nature and quantity of the materials used; ▪ An estimate, by type and quantity, of expected residues and emissions (water, air and soil pollution, noise, vibration, light, heat, radiation, etc.) resulting from the operation of the proposed project.	3
2	An outline of the main alternatives studied by the applicant and an indication of the main reasons for his choice, taking into account the environmental effects.	2.2
3	A description of the aspects of the environment likely to be significantly affected by the proposed project including, in particular, population, fauna, flora, soil, water, air, climatic factors, material assets, including the architectural and archaeological heritage, landscape and the inter-relationship between the above factors.	6-10
4	A description of the likely significant effects of the proposed project on the environment, which should cover the direct effects and any indirect, secondary, cumulative, short, medium and long term, permanent and temporary, positive and negative effects of the project, resulting from: ▪ The existence of the project; ▪ The use of natural resources; and ▪ The emission of pollutants, the creation of nuisances and the elimination of waste, and a description by the applicant of the forecasting methods used to assess the effects on the environment.	6-10
5	A description of the measures envisaged to prevent, reduce and where possible offset any significant adverse effects on the environment.	6-10, 11
6	A non-technical summary of the information provided under paragraphs 1 to 5 of this Part.	Before contents page
7	An indication of any difficulties (technical deficiencies or lack of know-how) encountered by the applicant in compiling the required information.	6-10 (conclusions/ confidence)

ARUN DISTRICT COUNCIL P/93/25/PL

Table 4.2 ES requirements according to the Marine Works (EIA) Regulations

Regulations Paragraph	Requirements For ES	ES Section
1	A description of the project and of the regulated activity, including details of the following matters: ▪ The location, size and nature of the project and the regulated activity; ▪ The quantity and nature and source of the materials to be used in the course of the project and the regulated activity; ▪ The quantity, nature and source of any items or materials to be deposited in the sea in the course of the project and the regulated activity; and ▪ The working methods to be used in the course of the project and the regulated activity.	3
2	A description of the aspects of the environment likely to be significantly affected by the project and the regulated activity, including: ▪ Human beings, fauna and flora; ▪ Soil, water, air, climate and the landscape; ▪ Material assets and the cultural heritage; and ▪ The interaction between any two or more of the things mentioned in the preceding subparagraphs.	6-10
3	A description of the direct and indirect effects, secondary effects, cumulative effects, short, medium and long term effects, permanent and temporary effects and positive and negative effects of the project and the regulated activity on the environment, resulting from: ▪ The nature of the activities to be carried out and the manner in which they are to be carried out; ▪ The use of natural resources; ▪ The emission of pollutants; ▪ The creation of nuisances; and ▪ The elimination of waste.	6-10
4	The forecasting methods used by the applicant to assess the main effects that the project and the regulated activity are likely to have on the environment.	6-10
5	A description of the measures envisaged to prevent, reduce and offset any significant adverse effects of the project and the regulated activity on the environment.	6-10, 11
6	An outline of the main alternatives studied by the applicant and an indication of the main reasons for the applicant's choice, taking into account the environmental effects of those alternatives and the project as proposed.	2.2
7	A non-technical summary of the information provided under paragraphs 1 to 6.	Before contents page
8	Any difficulties, such as technical deficiencies or lack of knowledge, encountered in compiling any information of a kind specified in paragraphs 1 to 6.	6-10 (conclusions/ confidence)

ARUN DISTRICT COUNCIL P/93/25/PL

4.4 Habitats Regulations Appraisal

Where a development project is located close to, or within, a classified Special Area of Protection (SAC) and/or Special Protection Area (SPA) under the Birds and Habitats Directives (referred to as European sites), the requirements of Regulation 61 of the Conservation of Habitats and Species Regulations 2010 apply (hereafter referred to as the "Habitat Regulations"). Paragraph 118 of the NPPF extends this requirement to the consideration of potential SPAs, possible SACs, listed or proposed Ramsar sites, and any site identified as being necessary to compensate for adverse impacts on classified, potential or possible SPAs, SACs and Ramsar sites. These sites are referred to in this assessment as European/Ramsar sites. The proposed project overlaps with Pagham Harbour SPA and Ramsar site. It is also located approximately 4km from the Medmerry Managed Realignment Site.

Regulation 61 of the Habitats Regulations requires the Competent Authority, in this case both CDC and ADC, to determine whether the proposed works have a likely significant effect (LSE) on a European/Ramsar site and, if so, to undertake an Appropriate Assessment (AA) of the implications of the proposal in the light of the site's Conservation Objectives. The process for undertaking LSE screening and an AA are together referred to as the Habitats Regulations Assessment (HRA).

The AA needs to take account of the in-combination effects of the proposal with other relevant projects and plans. As noted in Sections 2.1.1 and 2.2.1.3, where it cannot be demonstrated that a project will not have an adverse effect on site integrity (AEOI) either alone or in-combination with other plans or project, the project can only proceed if it can be demonstrated that there are no more suitable (less damaging) alternatives and that there are Imperative Reasons of Over-riding Public Interest (IROPI) sufficient to justify the project. In certain circumstances, the Secretary of State may be required to ensure that adequate compensation, usually in the form of replacement land, mudflat etc., has been provided to protect the overall coherence of the Natura 2000 network.

Further details about the nature conservation sites within the area that are relevant to this assessment is presented in Appendix F. All the necessary information for CDC and ADC to evaluate the impacts to European/Ramsar sites as a result of the proposed project and produce an AA is provided in Appendix C.

4.5 Marine Conservation Zone Assessment

The UK has signed up to international agreements that aim to establish an 'ecologically coherent network of Marine Protected Areas (MPAs)' by 2012. This network will be made up of current MPAs as well as a new type of MPA called a Marine Conservation Zone (MCZ). The development of MCZs in the area of the proposed project was coordinated by the Balanced Seas project. Ecological Network Guidance (ENG) was used to identify potential MCZs and ensure that the network would be ecologically coherent (JNCC and Natural England, 2010). The ENG identifies broad-scale habitats and Features of Conservation Importance (FOCI) which need to be protected through the network.

ARUN DISTRICT COUNCIL P/93/25/PL

In 2011, a number of recommended MCZs (rMCZs) and recommended Reference Areas (rRAs) were identified by the Balanced Seas project (Balanced Seas, 2011). The first tranche of MCZs were designated in 2013. For the first tranche, a total of 27 sites from the Regional MCZ Project recommendations were designated, of which Pagham Harbour MCZ falls within the footprint of the proposed project. In January 2015, Defra opened the consultation on a second tranche of MCZs with the aim of designating sites in 2016 (Defra, 2015b). For the second tranche, 23 sites from the Regional MCZ Project recommendations were identified as suitable candidates for consideration (proposed MCZ (pMCZs)), none of which occur in the vicinity of the proposed project.

An assessment of the potential impacts on the Pagham Harbour MCZ is provided in Appendix G.

4.6 Water Framework Directive Compliance Assessment

The WFD establishes a framework for the management and protection of Europe's water resources. It is implemented in England and Wales through the Water Environment (WFD) (England and Wales) Regulations 2003 (the Water Framework Regulations). The aim of the WFD is to achieve "good ecological and good chemical status" in all inland and coastal waters by 2015 unless alternative objectives are set or there are grounds for derogation.

Ecological status is an expression of the quality of the structure and functioning of surface water ecosystems as indicated by the condition of a number of "quality elements". These include hydro-morphological, chemical and biological indicators (including benthic invertebrates, macroalgae, fish, phytoplankton and angiosperms).

Programmes of measures have been developed through a process of river basin management planning and are set out in a number of regionally based River Basin Management Plans (RBMPs) formally published in December 2009. The proposed project falls within the area covered by the South East River Basin Management Plan and within the South East River Basin District.

Under the Regulations, the Environment Agency is the Competent Authority for implementation of the Directive in England and Wales. Proposed developments which have the potential to affect WFD water bodies are subject to WFD Compliance Assessments.

All the necessary information for the WFD Compliance Assessment is provided in Appendix H of this ES.

4.7 Other Approvals

A range of other appropriate consents and permissions for this proposed project are required from other regulators. Further permissions will be required including: a Marine Management Organisation (MMO) marine licence; Environment Agency Consent under the Coast Protection Act, Permissions under the Wildlife and Countryside Act, and application of Governmental funding under Flood Defence Grand in Aid (FDGiA).

ARUN DISTRICT COUNCIL P/93/15/PL

5. Impact Assessment Approach

An EIA is a process for systematically predicting and evaluating the impacts and effects of a development/activity on the environment, which can includes a number of different stages. The key stages applicable to this EIA are outlined in the sections below.

5.1 Consultation

Rather than a phase of the EIA, consultation is a fundamental part of the process that should be viewed as taking place throughout the period of the EIA from scoping through to preparation of ES and submission of the planning application. For the proposed project, there have been a number of meetings to discuss issues with relevant stakeholders, including CDC, ADC, Natural England, the Environment Agency and the Royal Society for the Protection of Birds (RSPB). These meetings have taken place from original project identification (i.e. even before the commencement of the EIA process) and then during the assessment process as follows:

- Meeting with ADC, Natural England and the Environment Agency on 12 January 2015;
- Meeting with ADC and CDC on 27 January 2015;
- Meeting with Natural England on 11 March 2015;
- Meeting with the Environment Agency on 11 March 2015;
- Site visit and meeting with the RSPB on 26 May 2015;
- Meeting with Natural England on 16 June 2015;
- Meeting with ADC Engineering Services Manager on 10 July 2015;
- Teleconference with RSPB on 15 July 2015; and
- Meeting with the local MP, ADC and the Environment Agency on 17 July 2015.

5.2 Scoping

Scoping involves determining the extent of issues to be considered in the assessment and reported in the ES. The applicant requests the local planning authority's opinion on what information needs to be included (which is called a 'Scoping Opinion'). A Scoping Report for the proposed community project at Pagham was submitted to both CDC and ADC (as the relevant planning authorities) in 14 April 2015 (ABPmer, 2015b) and the Scoping Opinion was provided on 28 May 2015. The comments that were submitted by statutory consultees and which formed the basis of the Scoping Opinion are provided in Appendix B. Actions and/or responses arising from each of these comments, and signposting to the relevant section of the ES, where relevant, are also provided in Appendix B.

5.3 Preparation of an Environmental Statement (ES)

In summary, the ES includes a description of the project, the main alternatives and reasons for the project, a baseline description of each of the receptors that are likely to be significantly affected by the project, an assessment of the effects of the project, and any proposed mitigation measures to prevent, reduce or possibly offset significant effects (see Section 4.3). The ES for the proposed project has been supported by: a large evidence base (including an extensive resource of literature and survey data) that describes the baseline environmental

ARUN DISTRICT COUNCIL P/93/25/PL

conditions. It has also been informed by a numerical modelling study of hydrodynamic/physical processes and expert analysis of the collated evidence. For this proposed project, the ES also includes the necessary information for CDC and ADC (as Competent Authorities) to produce an Appropriate Assessment under the Habitats Regulations (Appendix C). In addition, a range of additional specific studies, including an MCZ Assessment, a WFD Compliance Assessment and Transport Statement have been completed and are provided in Appendix G, H and I respectively.

5.4 Submission of the Planning Application

Once complete, the ES and the planning application for the proposed project is submitted to the planning authority, in this case both CDC and ADC. At the same time, the ES is publicised. The statutory consultees and the public are then given the opportunity to provide their views about the proposed project and the ES.

5.5 Scoping Phase

5.5.1 Impact Assessment Scope

Based on the findings of the scoping phase, including the consultations that have been undertaken as part of this EIA, the main environmental topics in this ES are as follows:

- Physical Environment and Coastal Protection (Section 6)[10];
- Water and Sediment Quality (Section 7);
- Nature Conservation and Ecology (Section 8); and
- Marine Recreation (Section 9).

Each section includes a review of the baseline environmental conditions and an assessment of the 'impact pathways' by which receptors could be affected by the proposed community project during both the construction and operational phases of the work. These impact pathways are provided in Table 5.1.

The cumulative and in-combination effects of the proposed project with other plans, project and activities are assessed in Section 10. This has involved an initial scoping exercise to determine those plans, projects and activities that have potential connectivity with the proposed project. An assessment has then been undertaken of the potential cumulative and in-combination effects on each of the receptors that have been scoped into the EIA.

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10 This topic encompasses issues/impacts associated with coastal hydrology and coastal flood protection. It addresses the changes to the physical environment which are not typically viewed as an EIA impact topic pathway in their own right (but rather part of the description of the baseline environment). However for marine EIAs, and for this project particularly, it is important to fully understand the physical changes and the site's potential physical evolution in the future (and to understand the significance of these) in order to understand the effects across all the other relevant topic areas.

ARUN DISTRICT COUNCIL P/93/25/PL

Table 5.1 Environmental topics and impact pathways that have been scoped into the assessment

Topic (Section)	Receptors	Impact Pathway	
		Construction Phase (Section)	Operational Phase (Section)
Physical Environment and Coastal Protection (6)	▪ Tidal heights ▪ Volumes of tidal exchange ▪ Tidal characteristics ▪ Waves ▪ Sediment transport ▪ Coastal erosion and flood protection	-	1. Effects of Changing Spit Morphology on Coastal Processes (6.2.1)
			2. Effects of Changing Spit Morphology on Hydrodynamic Regime in Pagham Harbour (6.2.2)
			3. Effects of, and Need for, Breach Maintenance (6.2.3)
			4. Effects on Tidal, Wave and Sedimentary Dynamics in Pagham Harbour (6.2.4)
			5. Effects on Coastal Protection in Pagham Harbour and Along Pagham Beach (6.2.5)
Water and Sediment Quality (7)	▪ Temperature ▪ Salinity ▪ Dissolved oxygen ▪ Nutrients ▪ Suspended solids ▪ Contaminants ▪ Radioactivity ▪ Microbiology ▪ WFD waterbodies	6. Effects on Suspended Sediment and Water Quality During Construction (7.2.1)	8. Effects on Status of Water Bodies During Operational Phase (7.2.3)
		7. Effects on Water Quality of Spillages (e.g. Fuel) During Construction (7.2.2)	-
Nature Conservation and Ecology (8)	▪ Saline lagoons ▪ Saltmarsh ▪ Mudflat ▪ Seagrass beds ▪ Spits and beaches ▪ Vegetated shingle ▪ Coastal subtidal environment ▪ DeFolin's lagoon snail ▪ Other benthic	9. Effects of Loss/Change of Shingle Habitat during Construction (8.2.1)	15. Effects of Loss/Change of Shingle Habitat During Operational Phase (8.2.7)
		10. Effects of Loss/Change of Little Tern Breeding Habitat During Construction (8.2.2)	16. Effects of Loss/Change of Little Tern Breeding Habitat During Operational Phase (8.2.8)
		11. Effects of Loss/Change of Habitat for DeFolin's Lagoon Snail During Construction (8.2.3)	17. Effects on Ecology in Pagham Harbour During Operational Phase (8.2.9)
		12. Effects of Loss/Change of Shingle Habitat Outside Development Footprint During Construction (8.2.4)	18. Effects from any Increased Bird Disturbance During the Operational Phase (8.2.10)
		13. Effects on Ecology in Pagham Harbour During Construction Phase (8.2.5)	19. Effects from Potential Closure of Breach (During Operational phase) (8.2.11)

ARUN DISTRICT COUNCIL P/93/25/PL

Topic (Section)	Receptors	Impact Pathway	
		Construction Phase (Section)	Operational Phase (Section)
	invertebrates ▪ Ornithology ▪ Other protected species (water voles) ▪ Coastal geomorphology ▪ Geology	14. Effects from Any Increased Disturbance on Overwintering Birds Due to Construction Work (8.2.6)	-
Marine Recreation (9)	▪ Watersports ▪ Angling	-	20. Effects of Changing Spit Morphology on Marine Recreational Activities (9.2.1)

ARUN DISTRICT COUNCIL P/93/25/PL

5.5.2 Scoped-Out Issues

A number of environmental topics have been scoped out of the assessment because there is no potential for them to be significantly affected by the proposed project. These 'scoped out' topics which have not been considered within the EIA are presented in Table 5.2. This list of topics is derived from the wider list of details to be considered within an EIA as presented in Schedule 4 of the Town and Country Planning (EIA) Regulations 2011 and Schedule 3 of the Marine Works (EIA) Regulations (Amendment) 2011.

Table 5.2 Environmental topics scoped out of the assessment

Topic	Rationale
Buildings, Land Use or Changes in Population	No significant effects on buildings or population changes will arise from the proposed project or the consequential environmental changes. However, it is recognised that this project is important for improving coastal protection levels to existing properties which are considered under the 'Physical/Hydrodynamic Environment and Coastal Protection' topic (Section 6).
Visual and Landscape	The proposed change to the spit morphology will alter the existing appearance of the shoreline and its 'seascape' and then allow natural processes to continue reshaping it. In the context of the dynamic nature of this environment, and the continual landscape changes which are typical of it, this adjustment is not considered to be significant. The geological changes will be considered separately within 'Nature Conservation and Ecology' topic (Section 8).
Noise Emissions	The proposed project will not cause significant changes to airborne noise levels. There will be some noise emissions from plant during the excavation but these are remote from properties, of a small scale and temporary in nature. Changes to underwater noise levels are considered below under the Fish and Fisheries and Marine Mammal topics.
Road Transport	There will be no significant effects on road transport from the proposed project. There will only be 'one-off' effects from plant mobilisation/demobilisation and temporary small-scale effects from staff access during construction. The main route of access is from the Pagham side of the site, in an area where plant regularly need to access the beach for restoration works. A Transport Statement is provided in Appendix I.
Air Quality Emissions or Odours	The proposed project will not cause significant changes to air quality. There will be some air quality emissions from plant during the excavation but these will be remote from properties, of a small scale and temporary in nature.
Human Health	There will be no adverse effects on public health and the issue of the site's value for amenity and recreation, and the beneficial human health effects of the proposed project, will be addressed under the 'Marine Recreation' topic (Section 9).
Public Access	No effects on public access (i.e. Public Rights of Way, Access Land, Coastal Access and National Trails) are anticipated. No new footpaths are proposed to be created as part of the project and existing footpaths are planned to be used by a small number of staff accessing the site daily during construction (Section 3.2). The main access route to the site will be from the east on the Pagham side of the harbour with some daily pedestrian access via the west from Church Norton or via East Beach, Selsey. Post construction, visitor numbers are anticipated to remain the same and within the range of existing seasonal variability as no additional facilities (e.g. car park) will be developed that would attract further visitors from outside the area. The use of existing footpaths will therefore remain the same post construction.

ARUN DISTRICT COUNCIL P/93/25/PL

Topic	Rationale
Utilities	No infrastructure or associated utilities will be affected/introduced as part of the proposed project. Relevant issues of drainage and flood protection to coastal properties and infrastructure will be considered under the 'Physical/Hydrodynamic Environment and Coastal Protection' topic (Section 6).
Light Pollution	There will be no significant change to the existing lighting regime aside from some temporary lighting that may be needed at the site compound and construction site during the excavation and infill works.
Fish and Fisheries	No significant effects on fish or shellfish species are expected from this proposed project because there is no major commercial activity in the harbour and the coastal waters will not be adversely affected. A temporary access 'causeway' will be created across the channel at the north eastern extent of the proposed infilled channel during construction (Section 3.2, Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes"). This will involve driving sheet piles using a vibratory hammer. The use of a vibratory hammer will ensure that the level of noise exposure will be negligible and the potential effects of noise on marine fauna are insignificant. Issues associated with marine angling will be considered under the 'Marine Recreation' assessment.
Marine Mammals	No significant effects on marine mammals are expected because the harbour is not a key foraging ground and cetacean sightings are rare in the south coast. The temporary access 'causeway' that will be created across the channel at the north eastern extent of the proposed infilled channel during construction (Section 3.2, Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes") will involve driving sheet piles. The use of a vibratory hammer will ensure that the level of noise exposure will be negligible and the potential effects of noise on marine fauna are insignificant.
Archaeology	The project will not cause significant changes to features of archaeological or cultural heritage value because the spit is a recently formed morphological feature and the breach will be created in an area where the tidal inlet entrance was previously positioned (in 2003).

5.6 Assessment Methodology

To facilitate the impact assessment process a standard analysis methodology has been applied. This framework was developed from a range of sources, including statutory guidance, consultations and ABPmer's previous (extensive) EIA project experience. The key guidance and regulations that have been drawn upon include:

1) The criteria listed in Annex III of the EC Environmental Assessment Directive (85/337 EEC as amended by 97/11/EC);
2) The assessment process developed by statutory conservation agencies to provide advice on operations within European Marine Sites (English Nature, 1998);
3) An Environmental Risk Assessment approach developed by ABP Research (ABP Research, 1997); and
4) Institute of Ecology and Environmental Management's (IEEM) Guidelines for Ecological Impact Assessment in the UK (IEEM, 2006) and Guidance on Impact Assessment in Marine and Coastal Environments (IEEM, 2010).

All environmental topics have been divided into distinct 'receiving environments' or 'receptors'. The effect of the proposed project on each of these has been assessed by describing in turn: the baseline environmental conditions of each receptor; the 'impact pathways' by which the

ARUN DISTRICT COUNCIL P/93/25/PL

receptors could be affected; the significance of the impacts occurring and the measures proposed to mitigate significant adverse impacts where these are predicted.

This impact assessment framework, which is presented in the following sections, is designed to incorporate the key criteria and considerations without being overly prescriptive.

5.6.1 Stage 1 - Identify Receptors and Changes

The first stage involves identifying the potential environmental changes resulting from the proposed project and the receptors that are likely to be affected (which are together referred to as the impact pathway). The impact pathways that are considered relevant to this EIA are provided in Table 5.1 (Section 5.1.1). This aspect of the assessment was developed in consultation with key stakeholders.

5.6.2 Stage 2 - Understand Change and Sensitivity

The second stage involves understanding the nature of the environmental changes to provide a benchmark against which the changes and levels of exposure can be compared. The scale of the impacts via the impact pathways depends upon a range of factors, including the following:

- Spatial extent (small/large scale);
- Duration (intermediate/short/medium/long term);
- Frequency (continuous/intermittent/temporary);
- Reversibility;
- Probability of occurrence;
- Confidence, or certainty, in the impact prediction;
- The margins by which set values are exceeded (e.g. water quality standards);
- The importance of the receptor (e.g. designated habitats and protected species);
- The sensitivity of the receptor (resistance/adaptability/recoverability);
- The baseline conditions of the system; and
- Existing long term trends and natural variability.

5.6.3 Stage 3 - Impact Assessment

The likelihood of a receptor being vulnerable to an impact pathway is then evaluated as a basis for assessing the level of the impact and its significance. The tables and matrices below have been used to help assess significance.

The key significance levels for either beneficial or adverse impacts are described as follows:

- Insignificant: Neutral change not having a discernible effect;
- Minor: Effects that are discernible but tolerable;
- Moderate: Effects that are of a local to regional nature, of medium to long term duration and/or where effects are anticipated to potentially be above accepted guidelines/standards. Where these changes are adverse they may require mitigation; or

ARUN DISTRICT COUNCIL P/93/25/PL

- Major: Acute effect on a national or international scale, of long term or permanent duration, and clearly above accepted guidelines or standards (or indeed against best practice policy, or even illegal in nature). Where these changes are adverse they will require mitigation.

5.6.3.1 Impact assessment guidance tables

The matrices in Tables 5.3 to 5.7 have been used to help assess significance (see below).

Identification and Estimation of Exposure to Change

Whether a receiving environment can be exposed to an impact or change depends on there being a route or pathway. The first step in order to determine the exposure to change is to consider the magnitude of change and the probability of occurrence.

The magnitude of change and its ability to affect a receptor in the context of the background environmental conditions in the study area depends on the following:

- Spatial extent - the spatial extent of a change is referred to using the terms 'immediate' (i.e. development footprint), 'local' and 'wide'; and
- Duration - the length of time a change operates can be described as being either an immediate or longer-term change. Immediate changes are more likely to occur as a result of activities during the construction phase (which are temporary in nature), whilst longer-term changes are more likely to be relevant to the operational period.

Table 5.3 sets out the basic criteria which can be used to help determine the magnitude of an impact for the purposes of an impact assessment. Whilst these are basic criteria, not all changes can be defined. Expert judgement based on an understanding of the overall system is therefore required to moderate the assessment and ensure consistency across receptors.

Table 5.3 Basic criteria for defining magnitude of change

Magnitude	Definition
Large	Large spatial extent with scale of change greater than the natural variability with a continuous signal extending into the long term.
Medium	Local spatial extent with scale of impact within the same order as the natural variability, frequently occurring in the long term. OR Immediate spatial extent (development footprint) with scale of change greater than the natural variability, occurring frequently over a short timescale.
Small	Local spatial extent with scale of impact smaller than the natural variability, frequently occurring over a short/temporary timescale.
Negligible	Immediate spatial extent (development footprint), with scale of impact smaller than the natural variability, occurring infrequently over a short/temporary timescale.

The probability of occurrence is related to the likelihood of the impact occurring (i.e. the likely connectivity between a receptor and the source of the change).

ARUN DISTRICT COUNCIL P/93/25/PL

The magnitude and probability of occurrence is combined to arrive at an exposure score which is then used in the next step of the assessment (Table 5.4). For example, an impact pathway with a medium magnitude of change and a high probability of occurrence would result in a medium exposure to change.

Table 5.4 Exposure to change, combining magnitude and probability of occurrence

Probability of Occurrence	Magnitude of Change			
	Large	Medium	Small	Negligible
High	High	Medium	Low	Negligible
Medium	Medium	Medium/Low	Low /Negligible	Negligible
Low	Low	Low /Negligible	Negligible	Negligible
Negligible	Negligible	Negligible	Negligible	Negligible

Vulnerability of Receptor

Whether a receiving environment is vulnerable to an impact or change depends on the sensitivity of the receptor and the exposure to change (determined in the preceding step). This step essentially provides a benchmark against which the exposure to change can be compared.

An effect can only occur if a receptor is exposed to a change to which it is sensitive. Sensitivity can be described as the intolerance of a receptor to readily accept the levels of predicted environmental change to which they are exposed and essentially considers the response characteristics of the receptor. In this assessment sensitivity is considered to be the degree of perturbation a receptor can tolerate in response to the predicted changes to which they are exposed. Thus, if a single or combination of environmental changes is likely to elicit a response then the receptor under assessment is considered to be sensitive. In some cases it may be applicable to compare the anticipated exposure to change against either baseline conditions or other relevant thresholds such as quality criteria (i.e. for water, light or noise).

The sensitivity and exposure to change is combined to arrive at a vulnerability score which is then used in the next step of the assessment (Table 5.5). For example, if the impact pathway previously assessed with a medium exposure to change acted on a receptor which had a high sensitivity, this would result in a high vulnerability score. Where the receptor is not sensitive to any given exposure to change, then the vulnerability is scored as none. Similarly, where a negligible exposure is identified during an impact assessment, vulnerability will always be none, no matter how sensitive the receptor is.

Table 5.5 Estimation of vulnerability based on sensitivity and exposure to change

Sensitivity of Receptor	Exposure to Change			
	High	Medium	Low	Negligible
High	High	High	Moderate	None
Moderate	High	Moderate	Low	None
Low	Moderate	Low	Low	None
None	None	None	None	None

ARUN DISTRICT COUNCIL P/93/25/PL

Significance of Impact

The significance of an impact depends on the importance of the receptor and its vulnerability (determined in the preceding step). A receiving environment may have a high or a low vulnerability, but whether the potential effect is 'significant' will depend on its relative 'importance'. The importance of a receptor is based on its value and rarity (e.g. to either ecosystem or economy), such as the levels of protection it is afforded. For this step, Table 5.6 provides basic definitions for determining the importance of the receptor being assessed.

Table 5.6 Definition of receptor importance

Receptor Importance	Definition
High	Receptor internationally designated and/or of international importance. Likely to be rare with minimal potential for substitution or unable to tolerate change. May also be of high or very high socioeconomic importance.
Moderate	Receptor nationally designated and/or of national importance and/or some ability to tolerate change and recover in the medium term. Likely to be relatively rare. May also be of high socioeconomic importance.
Low	Receptor not designated but of local to regional importance and able to tolerate the effect to a large extent, with relatively rapid rate of recovery or not designated/ of local importance but not tolerant to change.
Negligible	Receptor only of local importance with a high tolerance to change.

The vulnerability is then combined with the importance of the receptor using Table 5.6 to determine an initial level of significance. For example, a receptor with a high vulnerability and low importance would have an initial level of significance of minor. Estimating and categorising the significance of an effect, however, can also involve a degree of subjectivity and expert judgement.

Table 5.7 Estimation of significance based on vulnerability and importance

Importance of Receptor	Vulnerability of Receptor to Impact			
	High	Moderate	Low	None
High	Major	Moderate	Minor	Insignificant
Moderate	Moderate	Moderate/Minor	Minor/Insignificant	Insignificant
Low	Minor	Minor/Insignificant	Insignificant	Insignificant
None	Insignificant	Insignificant	Insignificant	Insignificant

5.6.4 Stage 4 - Impact Management

The final stage is to identify any impacts that are found to be of moderate and/or major adverse significance and are considered to require mitigation measures to avoid or reduce residual impacts to environmentally acceptable levels, as far as possible. The range of mitigation measures that are considered necessary to avoid and minimise significant impacts are set out in Section 11. Within the assessment procedure, the use of mitigation measures will alter the risk of exposure and hence will require significance to be re-assessed and thus the residual impact identified.

ARUN DISTRICT COUNCIL P/93/25/PL

5.6.5 Stage 5 - Confidence Assessment

Following the significance assessment, a confidence assessment is undertaken which recognises the degree of interpretation and expert judgement applied. This is presented in the summary table contained within the conclusions section of each impact assessment section (i.e. for each environmental topic). Confidence was assessed on a scale incorporating three values: low, medium and high.

5.6.6 Cumulative Impact and In-Combination Assessment

Under the Town and Country Planning (EIA) Regulations 2011 (as amended) and the Marine Works (EIA) Regulations (Amendment) 2011 it is necessary to assess the potential cumulative impacts of a proposed project on all environmental receptors together with other known developments in the area. Under the Conservation of Habitats and Species Regulations 2010 (as amended) ('Habitats Regulations'), it is also necessary to consider the in-combination effects of a development proposal specifically on the designated features of European Sites.

Cumulative effects are those that accrue over time and space from a number of developments. The effects of the proposed project have been considered in conjunction with the potential effects from other plans, projects or activities that are both reasonably foreseeable in terms of delivery (e.g. have planning consent) and are located within a spatiotemporal scope where environmental impacts could act together to create a more (or less) significant overall effect.

The combination of predicted environmental impacts resulting from a single development on any one receptor that may collectively cause a greater (or lesser) effect is referred to as 'combined'. An example could be the combination of habitat loss, changes in water quality and introduction of non-native species impacting upon receptors together to cause a combined effect that is different to that when each impact is considered in isolation.

Where cumulative and combined effects are assessed to result in a different effect to that of their component parts, they may be described as:

- Synergistic, whereby the interaction of two or more impacts results in a cumulative or combined effect that is greater than their individual component effects; or
- Antagonistic, whereby the cumulative or combined effect is less than the component individual effects, for example as a result of different impacts acting to neutralise or counteract the effects of one another.

Cumulative impacts associated with the construction, operation and decommissioning of the proposed project with other plans, projects or activities have been considered in Section 10. There is no standard prescriptive method for assessing cumulative and in-combination impacts and therefore the assessment is primarily based on professional judgement. Impacts are quantified where possible but where environmental assessment information regarding other plans, projects and activities is not available or uncertain, the assessment is necessarily qualitative.

ARUN DISTRICT COUNCIL P/93/25/PL

5.7 Study Area

The study area encompasses all 'impact pathways' or routes by which the receptors could be affected. The 'study area' is thus defined as the area over which the potential direct and indirect impacts of the proposed project are predicted to occur. The main study area for the proposed project covers the tidal extent of Pagham Harbour, the entire length of Church Norton Spit, the adjacent Pagham Beach and nearshore area of the coast.

A wider area is covered for mobile bird features and therefore the study area for these receptors takes account of neighbouring areas (e.g. Dark-bellied Brent Geese have been recorded in adjacent grassland and nearby fields). Furthermore, for the purpose of the WFD assessment, waterbodies within 5km of the proposed project have been included within the study area.

5.8 Study Duration

This community project seeks to address immediate problems and anticipate future issues over short, medium and long term periods up to around 20 years, while recognising that these issues will be subject to varying degrees of certainty over this period. Over time it becomes increasingly difficult to forecast issues because the system will continue to be dynamic. Therefore, the shoreline's evolution will be subject to increasing uncertainty towards and beyond this two-decade period. This assessment, therefore, focusses on forecasting effects and anticipating benefits over the following broad periods:

- Immediate days/weeks;
- Short term: weeks/months to a year;
- Medium term: years; and
- Long term: decadal 10 to 20 years.

As the proposed project seeks to address existing and anticipated coastal erosion problems over a period of 20 years (because making predictions beyond this timeframe is not feasible) longer-term issues associated with climate change and sea level rise have not been reviewed in detail. These issues will instead need to be considered on an ongoing basis as part of the continuing process of adaptive management.

ARUN DISTRICT COUNCIL P/93/25/PL

6. Physical Environment and Coastal Protection

6.1 Introduction

This section of the ES considers how the proposed project will influence the existing physical environment along the shoreline and in Pagham Harbour. It reviews the historic changes observed at this site; the current baseline conditions; the anticipated physical consequences of the proposed project and the changes that are likely to occur without the project taking place.

This review is critical to understanding how the project will achieve its desired objectives which are to adjust the coastline towards a more sustainable morphology and address the severe coastal erosion problems that are being experienced on the Pagham Beach. This review of the effects on the physical environment is also vital for understanding the potential effects of the proposal on other receptors (e.g. the habitats and species using the site). Therefore, the information presented in this section has been used to underpin the conclusions reached in subsequent chapters of this ES about the significance of the effects (both beneficial and adverse) that are likely to occur.

In advance of this review, it should be noted that a large amount of previous analysis has been undertaken along the Pagham Harbour/Beach shoreline that is valuable for understanding the physical processes that are taking place. This previous, and also ongoing, work has been carried out by a range of coastal managers and other specialists and includes:

- Extensive topographic, bathymetric and other surveys (as listed in Section 6.1.1); scientific research work (e.g. Cundy *et al.*, 2002),
- Strategic evaluations of morphological changes (e.g. Barcock and Collins, 1991; Bray *et al.*, 2004; Royal Haskoning, 2009; Orford, 2009; 2013; 2014) and
- Reviews of previously considered proposed intervention proposals on the Church Norton Spit (e.g. Royal Haskoning, 2014a; b)).

This existing evidence base and available literature has been reviewed for this assessment. To add to this previous work ABPmer, working with Prof Ian Townend, has undertaken further literature review and coastal process analyses to help evaluate the project. These analyses have been undertaken as a series of technical steps to initially verify the feasibility of the project and then develop the design and understand how the introduced breach is likely to function (see Section 1.2 for a description of this process).

This preceding ABPmer work has included hydrodynamic and topographic field surveys and the application of numerical models to understand how the proposed scheme will function. The results of these studies were presented in the preceding Breach Design Report (ABPmer, 2015c) and the key findings outputs from that work are referred to in this chapter, where relevant. This preceding report is presented in full as Appendix A of this ES.

This physical processes review chapter now builds on this past work, but also includes additional analyses that have been required to underpin this assessment (see next section) in the light, especially, of the scoping process. This additional work includes bespoke studies that

ARUN DISTRICT COUNCIL P/93/15/PL

have been undertaken to explore the processes acting on the shoreline and to understand the sediment fluxes that are taking place at present, and those which are likely to take place after the proposed breach.

6.1.1 Data Sources

As noted in the previous section, a large evidence base is available for the Pagham Harbour site that can be used to help understand both the functioning of this section of the coast and the implications of the proposed intervention. This information includes an extensive amount of available data collated under, or held by: Environment Agency, Southeast Strategic Regional Coastal Monitoring Programme, Adur and Worthing Council and the Channel Coastal Observatory (CCO).

A list of key datasets collated for this project, along with details of the key supporting documents, is provided within Section 2 of the Breach Design Report (ABPmer 2015c; as presented in Appendix A). A summary of this available information is as follows:

- A total of 51 datasets describing the past and present topography and bathymetry of the area, including:
  - Light Detection and Ranging (LiDAR) Data (2001 to 2014);
  - Topographic Real Time Kinematic (RTK) GPS Data (2007 to 2009);
  - Topographic All-Terrain Vehicle (ATV) Laser Scan Data (2012 to 2015);
  - Photogrammetric Data (2003 to 2007); and
  - Bathymetric Survey Data (2006 and 2014).
- Further data describing the historical and baseline hydrodynamic conditions including:
  - Rustington Wave Buoy Data (2003 to 2015);
  - Bracklesham Wave Buoy Data (2013) to fill gap in information at Rustington;
  - Pagham Outfall Tide Gauge Data (2002 to 2015);
  - Aerial Photographs of the site (1944 to 2105); and
  - A large set of historical charts, maps and drawings (1587 to present).
- Further data collation and analysis work undertaken specifically for the assessment of the proposed intervention measure including:
  - Extra flow speed data recording for the area within the main internal channel (adjacent to the training wall) collected March 2015;
  - Extra topographic data recording for the area within both the main internal channel and the adjacent secondary channel collected March 2015;
  - The creation of a Digital Terrain Model (DTM) of Pagham Harbour and foreshore using latest available topographic and bathymetric data from a range of sources to support the development of environment measurements (e.g. tidal prism or habitat area calculations) and the application of a number of modelling techniques;
  - The development of a Mike 21 FM numerical model to describe tidal behaviour within Pagham Harbour and through the tidal channel (under baseline conditions and with a breach introduced into the spit);
  - The inclusion of surge tide scenario to consider flood risk conditions;
  - The application of Geographic Information System (GIS)-based analysis of historical land elevation datasets (mapped to a common projection to allow direct inter-comparison) in order to describe the historical morphological

ARUN DISTRICT COUNCIL P/93/15/PL

changes that have occurred to the spit and beach over time as well as the spatial patterns of spit-ebb delta migration that have been observed;
- Transformation of Rustington Wave Buoy Data (2003 to 2015) to describe the inshore wave climate (by Prof Ian Townend);
- The development and application of a novel morphological tool (ASMITA[11] model) to describe the functioning of the spit feature (by Prof Ian Townend); and
- Analyses of tidal channel meanders from past and present morphologies (by Prof Ian Townend).

6.2 Baseline Review

6.2.1 Introduction

The review of the baseline environment considers the physical conditions that exist within Pagham Harbour, Pagham Beach and, where relevant, along the wider coastline. From the areas defined within the SMP, it encompasses the Eastern side of Policy Unit 4D24 (Aldwick to Pagham) and all of 4D25 (Pagham Harbour & Church Norton) as well as Unit 4D26 Church Norton to Selsey East Beach where relevant (SMP 2006).

This review describes the physical environment before considering the historical and recent changes that have been observed. Finally, the changes that may happen in the future are described. In summary, the topics covered in this chapter (along with relevant section numbers) are as follows:

- General Site description (Section 6.2.2)
- Hydrodynamic Regime (Section 6.2.3)
  - Tidal Heights and Volumes of Tidal Exchange
  - Tidal Characteristics
  - Wave Regime
- Sediment Transport Characteristics (Section 6.2.4)
  - Main Directions and Patterns of Sediment Transport
  - Spit-Delta Migration Interactions
  - Sediment Transport Sources
  - Sediment Transport Rates
  - Sedimentation (siltation) with Pagham Harbour
- Characterising the Spit-Delta Migration Patterns (Section 6.2.5)
- Historical Changes and Recent Developments (Section 6.2.6)
  - Historic Situation (1587 to 2003)
  - Recent Evolution (2003 to 2014)
  - Coastal Protection Works (2013/2014)
  - Current Condition of the Spit and Delta (2015)
- Changes Occurring on Pagham Beach (Section 6.2.7)
- Future Development of the Spit and Beach without intervention (Section 6.2.8)

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11 Aggregated Scale Morphological Interaction between Tidal basin and Adjacent Coast.

ARUN DISTRICT COUNCIL P/93/15/PL

6.2.2 General Site Description

Pagham Harbour is situated to the north-east of Selsey Bill, in West Sussex (see Figure 1.1). The harbour is characterised by a tidal inlet channel fronted by a dynamic shingle beach and spit complex, which provides shelter from open-coast wave activity. The spit, foreshore and beach are predominantly coarse-grained shingle. The harbour is predominantly characterised by silt, although the main channel bed (i.e. to the rear of the spit and adjacent to the training wall) is characterised by gravel with sand in low energy areas An overview of the key geomorphological features in this area (that are referred to this chapter) is provided in Figure 1.2.

The Pagham shoreline is east-southeast facing with a relatively shallow lower foreshore due to extensive offshore sand and shingle bank (Inner Owers) (SRCMP, 2014a). Notwithstanding this, the physical environment is constantly changing from spit to bay-bar to spit again (see also Section 8.17) in response to movements of sediment along the shoreline (predominantly in a north-easterly direction).

Due to this dynamic condition, the spit features, harbour inlet channel and beach have been subject to considerable change with time and such change is continuing to take place (see Section 6.2.6 for further detail). The major, and certainly most visible physical, change that has been observed over recent years is the growth of the Church Norton Spit which has prograded some 1 km over the last 12 years (Figure 6.1). This growth has made a substantial change to the shoreline morphology and the alignment of the inlet channel draining Pagham Harbour.

In its present alignment, the tidal inlet channel to the harbour is now predominantly orientated parallel to the coastline (i.e. in a north-east to south-west direction). In this position it is funnelled by the spit to run in front of Pagham Beach (see Figure 6.1 and Image 6.1). The outermost (north-eastern) section of this tidal channel changes direction to the south-east when it becomes constrained by the rock groynes on Pagham Beach (see Image 6.1).



(Source: John Akerman, 27 February 2015)

Image 6.1 Church Norton Spit, Pagham Harbour and south-western Pagham Beach

ARUN DISTRICT COUNCIL P/93/15/PL

Seaward of the spit complex, the nearshore area has typically been dominated by the ebb tidal delta[12] of the inlet. This is an area of shallow, mobile shingle bars and shoals overlying a hard packed shingle pavement. This feature occurs as response to the ebb dominant nature of the tidal cycle in the harbour (see Section 6.2.3) and it moves and adjusts as the tidal inlet changes position. The area to the east and west of the delta was described by Barcock and Collins, (1991) as sloping gently from the toe of the beach and comprising of a mixture of shingle, gravel and sand. The ebb delta plays a very important role in the evolution of the Church Norton Spit not least because it provides the main platform upon which the spit can grow.

The shoreline in front of the Church Norton Spit also has a distinct sequence of transiting shingle 'spurs' or 'fingers' which extend out perpendicular to the shoreline at several locations between Selsey and Pagham (but excluding the ebb delta in front of Pagham Harbour). It has been concluded that offshore shingle is transported ashore via these features (Barcock and Collins, 1991). These spurs migrate slowly along the shore (18 m/year on average) in the direction of the prevailing north-easterly sediment drift. The rate is variable depending upon climatic conditions but their movement (and possible changes in associated onshore transport pathways) can lead to fluctuations in the supply of shingle at any given location.

6.2.3 Hydrodynamic Regime

6.2.3.1 Tidal heights and volumes of tidal exchange

The tides at Pagham Harbour are macro-tidal in nature, experiencing a mean spring and neap tidal range of approximately 4.85 m and 2.40 m, respectively. These values are an average of the standard tidal levels presented for Selsey Bill and Pagham in Table 6.1, the locations of which are further along the coast to the south-west and north-east of the harbour respectively. The tidal elevations outside the inlet tend to be slightly higher than those measured inside, suggesting that the tidal inlet channel is restricting tidal flows into Pagham Harbour (Royal Haskoning, 2013).

Table 6.1 Standard tidal levels

Tidal Level		Selsey Bill (ME2A) (mODN)	Pagham (ME2A) (mODN)	Pagham Harbour (mODN)
Highest Astronomical Tide	HAT	2.80	3.05	2.93
Mean High Water Springs	MHWS	2.30	2.55	2.43
Mean High Water	MHW	1.75	1.90	1.83
Mean High Water Neaps	MHWN	1.20	1.25	1.23
Mean Sea Level	MSL	0.00	-0.50	-0.25
Mean Low Water Neaps	MLWN	-1.10	-1.25	-1.18
Mean Low Water	MLW	-1.70	-1.90	-1.80
Mean Low Water Springs	MLWS	-2.30	-2.55	-2.43
Mean Spring Tidal Range (MHWS – MLWS)		4.60	5.10	4.85
Mean Neap Tidal Range (MHWN – MLWN)		2.30	2.50	2.40
Note: The tidal levels presented for Pagham Harbour are an average of those for Selsey Bill and Pagham.				

(Source: UKHO, 2014)

[12] The accumulation of sand/shingle formed at the seaward mouth of tidal inlet as a result of interaction between tidal currents and waves.

ARUN DISTRICT COUNCIL P/93/15/PL

The volume of water that can, in theory, be exchanged between the harbour and coast[13] ranges from 2.8 million m³ on a mean high water spring (MHWS) tide to 1.4 million m³ on an average tide down to 0.59 million m³ (590,000 m³) on a mean high water neap (MHWN). These volumes are based on the updated DTM that was developed for this study. As this DTM may slightly under-estimate the full depths of the internal harbour channels the actual tidal prism may be marginally higher than values quoted here.

As the harbour sits mainly above MSL (-0.25 mODN), the majority of water exchange occurs above this level. Indeed the volume below MSL only accounts for approximately 0.5% of the total volume at MHWS. This volume will be limited to the deeper internal harbour channels, with the majority of the harbour drying out towards low water.

6.2.3.2 Tidal characteristics

As originally described by Barcock and Collins, (1991) (when the tidal inlet was in front of Pagham Harbour (see Section 6.2.6)) flow into the inlet channel on the flood tide tended to be from all directions in order to fill the harbour as the tide rose. In contrast, tidal flows through the inlet on the ebb tide, which tend to be stronger than on a flood, were more characteristic of a 'jet', created by a gradient difference between the water levels inside and outside the harbour. This flow pattern is characteristic of ebb deltas and so is also observed around the delta as it migrates along the coast.

The substantial, and more focused, flows that typically occur on the ebb tide remove sand and shingle material from within the inlet channel that was originally transported into the channel by flood tidal currents and wave activity. That material that is exported in this manner then feeds a well-developed ebb tidal delta (Barcock and Collins, 1991). The outflow from the harbour maintains a channel through these ebb tidal deposits, with secondary channels also occurring.

The ebb delta will also be fed by longshore transport of shingle from the southwest. Barcock and Collins (1991) described how the delta was decreasing in volume prior to 1982 but increased subsequently as an anticipated function of littoral drift changes. In the same study it was noted that over a short period, the harbour's inlet channel migrated in a north-east direction until it became unstable and then shifted to a shorter and straighter alignment in front of the harbour inlet. This model of channel cycling might explain the relative stability of the inlet location through much of the latter part of the 20th century. However, this stability did not persist and instead was replaced by a more progressive process of north-easterly migration as seen since 2003.

At present, there continues to be a very well-developed ebb delta and, in general, the tidal flow conditions observed today are likely to be similar to those observed historically, albeit with a clear spatial shift in the location of the inlet. However, the presence of an elongated spit and xtended tidal channel running along the shoreline is likely to be having some influence on the

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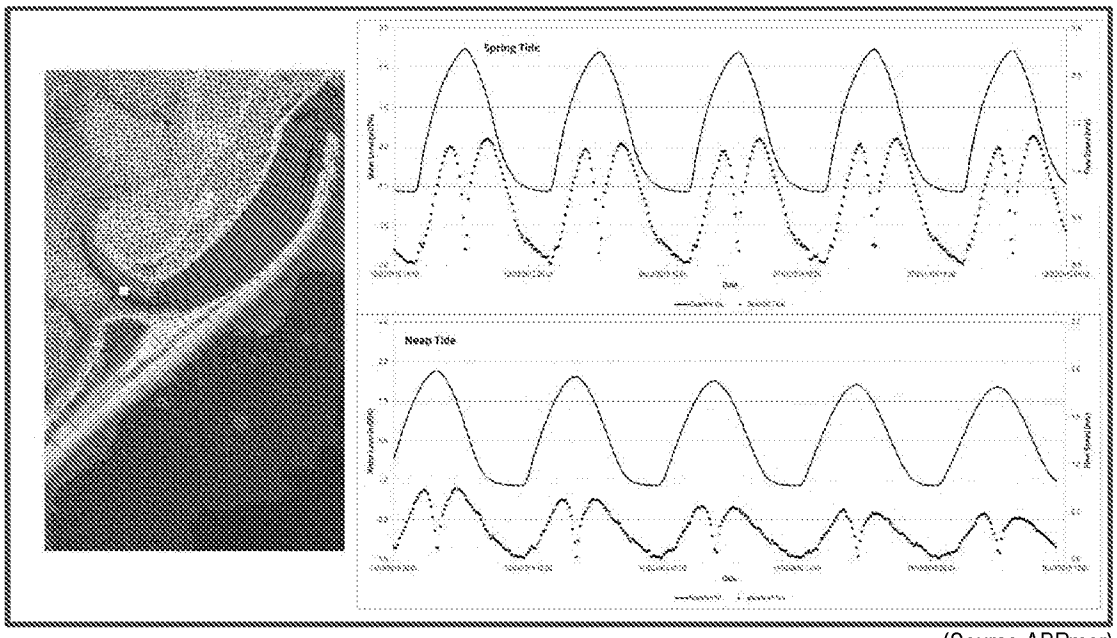
[13] This volume (also termed the 'tidal prism' value) excludes water that lies within the extended inlet channel along the Pagham Beach frontage as that volume will not be material to understanding the functioning of the harbour, the breach and the spit after the proposed managed breach is introduced.

ARUN DISTRICT COUNCIL P/93/25/PL

tidal range and water levels within the harbour. In particular, it appears, from numerical modelling and on-site observations that the harbour is draining slightly less efficiently as a result. This is as evidenced by the fact that it is 'storing water' in the inlet channel at low water.

The behaviour of the tides (water levels) and the depth-averaged flow speeds within the harbour (and through the tidal channel that has formed as the spit has extended) were described using numerical modelling work undertaken specifically for this EIA. This numerical modelling depicts how the harbour floods gradually through the tide, with the majority of the site inundated an hour before HW. Water levels at HW on a mean spring tide tend to be fairly uniform across the harbour, reaching between 2.4 and 2.5 mODN at the six modelling points interrogated for the interpretation (see Figure 5 of the Breach Design Report (ABPmer, 2015c); as presented Appendix A, and modelling results described in Section 6.3.2). Towards the back of the harbour, some 2.2 km from the harbour mouth, HW is reached approximately 30 minutes after it is observed at the mouth (i.e. the distal end of Church Norton Spit) (see Figure 5 of the Breach Design).

The majority of the site remains inundated until one hour after HW, thereafter, intertidal areas become present. For approximately two hours around LW, shallower features of a delta at the end of the spit can be observed along the offshore (eastward) part of the spit. The draining of the harbour then occurs through the ebb delta via the primary tidal channel and two or three secondary channels.



(Source ABPmer)

Image 6.2 Baseline neap and spring water levels and flow speeds at location (white square on map) inside the harbour near proposed managed breach

The modelling work, as well on-site observations made during survey work (March 2015), show that under the existing conditions, the seaward end of the harbour does not fully drain on the larger spring tides and that the extended inlet channel provides some additional storage capacity. This can be seen in Image 6.2, which shows baseline water levels at a position at the

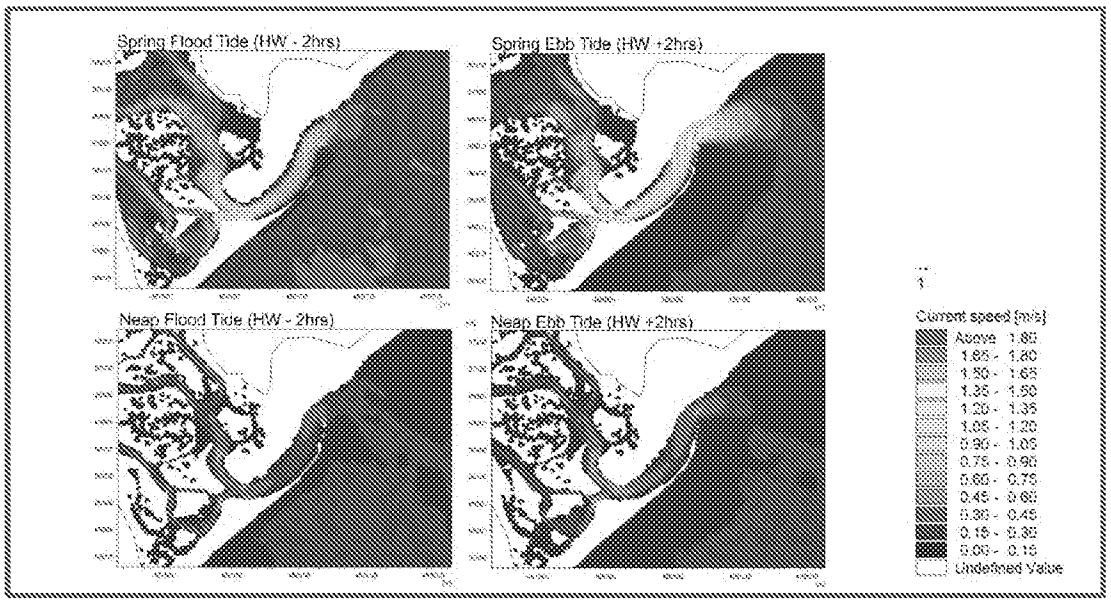
ARUN DISTRICT COUNCIL P/93/15/PL

centre of the internal channel (approximately half way along the training wall). On a mean spring tide, the low water level stabilises at around -1.1 mODN (i.e. is at that level at around six hours before and after high tide). This is 1.3 m above the level of MLWS (see Table 6.1). The tides also drop to around -1.1 mODN on a mean neap tide (Image 6.2) which is close to the anticipated MLWN elevation (see Table 6.1).

As all the bed elevations in the harbour and the channel are typically above this MLWS level, both the channel and the harbour should in theory fully drain. However, they do not have enough time to do so during spring tides due to the increased volumes of water, as well as the distances, involved. This results in a pooling effect within the inlet at the mouth of the harbour that is visible on site and is also described within a sequence of modelling outputs that are described further in Section 6.3.2. The harbour is then 'topped up' on subsequent tides, and reaching higher water levels, especially during consecutive, rising, tides around spring tides.

In the past, when the harbour inlet was much shorter, the harbour would probably have drained more efficiently (i.e. the water levels would have dropped more quickly to lower elevations at low water (LW) in the outer harbour especially). Depending upon the nature of the inlet, i.e. the width and depth over time, the HW within the harbour would have also been subject to small changes (although this is likely to be within a 0.1m range).

As indicated above, the tidal patterns in Pagham Harbour have a characteristic ebb dominance pattern with stronger flows experienced on the ebb than on the flood during spring tide periods. This is the process influences the creation of the ebb tidal delta. This behaviour is represented by the modelling as shown in Image 6.3. The dominance of the ebb flow speeds are inherently more in evidence during the spring tidal periods because of the larger volumes that need to be exchanged. This difference is not as clearly observed during the smaller neap tides (see Image 6.3).



(Source: ABPmer Numerical Modelling)

Image 6.3 Modelled flow speeds (depth averaged) on spring and neap ebb and flood tides

ARUN DISTRICT COUNCIL P/93/25/PL

This ebb dominance was identified in past studies (Royal Haskoning, 2009). When the spit is breached (i.e. when the project is implemented) and a new inlet channel formed, this characteristic means that any material moved into the channel via littoral drift will be subject to 'flushing' over the ebb tide, thus facilitating the formation of a significant ebb tidal delta (as described above). The flows generated by this tidal exchange are then effective in interrupting littoral drift at the harbour entrance (Royal Haskoning, 2009), particularly during spring tides.

Flow speeds, are shown to be at their highest at the distal end of the spit and also in the narrow section of the channel, close to the training wall, before the divergence of the two channels into Pagham Harbour. The highest flow speeds are typically seen between two and three hours after HW on the ebb tide, and especially on the ebbing spring tide (see Figures A1 to A3 of Annex A in the Breach Design Report (ABPmer, 2015c); as presented Appendix A). At the distal end of the spit, peak speeds of between 1.5 and 1.6 m/s are observed at this time on a spring tide.

Faster flows also to be found at the bottom end of the 1963-constructed training wall where flows of over 1.8m/s were modelled and are shown in Figures A1 to A3 of Annex A in the Breach Design Report (ABPmer, 2015c); as presented Appendix A). On spring tides, the peak flood flow speeds at the same locations, which would occur around one hour before HW, are significantly lower at around 1.35 to 1.5 m/s at the training wall and between 1.05 and 1.2 m/s on at the distal end of Church Norton Spit.

It is worth noting that significantly higher peak flows can be seen (particularly locally around the rock groynes) and values of 14 knots (i.e. 7.2 m/s) have been quoted by several residents (see Section 9.1). Such visibly higher peak surface flow speeds are to be expected when compared to the depth averaged values expressed in the model and may well be reached for brief periods around the rock groynes.

6.2.3.3 Wave regime

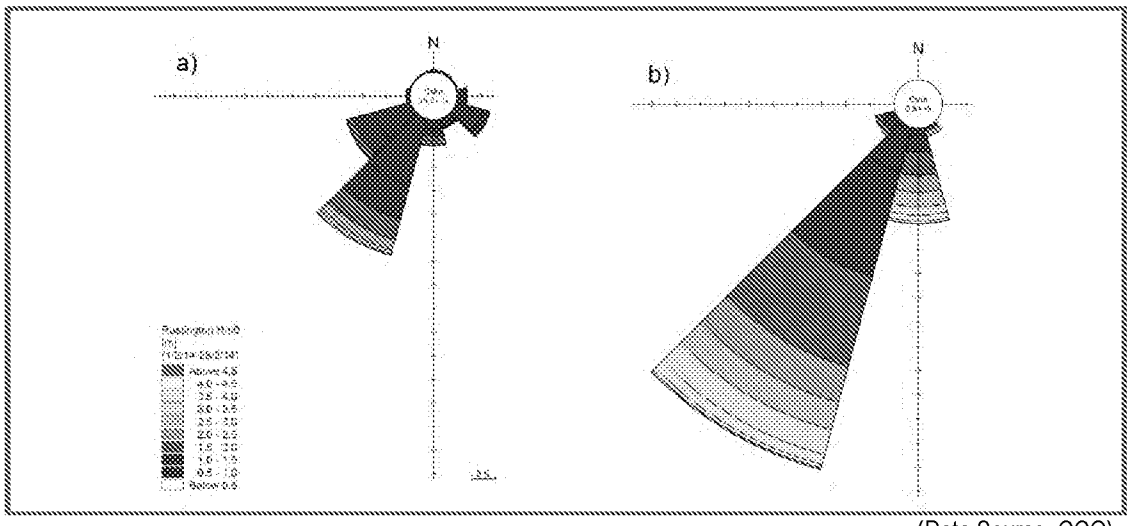
The Pagham coastline is exposed to a moderate to high-energy wave climate from English Channel wind generated waves from the south-east, south and south-west as well as swell waves propagating up the Channel from the west that become diffracted around the Isle of Wight (Royal Haskoning, 2009). However, the narrow nature of the English Channel also leads to a fetch-limited condition over most of the Pagham frontage. As a consequence, only waves incident from south of 225°N have sufficient fetch to produce fully developed seas (Barcock and Collins, 1991).

The offshore wave climate for areas outside Pagham Harbour can be characterised by the wave buoy data for Rustington (obtained from CCO). This buoy is located to the south-east of Bognor Regis in a water depth of approximately 10m (about 13m to mean tide level (MTL)). The data obtained from this source covers the years 2003-2014 and includes the first two months of 2015, with a gap in 2013 for which there is no data. The data from this buoy shows that the predominant offshore wave are from the south-west although there are some events

ARUN DISTRICT COUNCIL P/93/15/PL

from the south and south-east (see Image 6.4). This wave activity drives the net north-easterly movement of shingle that occurs along this coastline.

Over the period from 2003 to 2015, the dominant direction was from the south west at 195-225°N. This was also the primary direction during the sequence of large storm events that occurred in February 2014 (see Image 6.4) which is indicative of some of the conditions experienced during the 2013/14 winter. That winter was the most severe storm period recorded at this buoy and during this period wave heights (H_s) were recorded at 5.46m (or a return period of greater than 50 years) (SRCMP, 2014a). Typically the peak wave heights in any given year typically reach 3 to 4m (and occasionally 5m).



(Data Source, CCO)

Image 6.4 Wave outputs for Rustington Buoy a) average July 2003 to February 2015 (but excl., 2013) b) average February 2014 only

This offshore wave climate, and the transformation that then takes place into inshore waters, occurs as a function of complex interactions between shoreline bathymetry and hydrodynamics. For this study, a transformation exercise was undertaken to convert the measured offshore wave height values to predicted inshore wave conditions. This was valuable for seeking to understand the interactions between these inshore wave conditions and the prevailing shingle transport patterns. Further details about the outcome of this shingle transport analysis are presented in Section 6.2.5.2 but, in summary the findings were in keeping with past estimates by HR Wallingford (1993) who calculated a mean significant wave height of 1 m, and a maximum of 4.5 m, at Pagham Harbour entrance (as quoted by Royal Haskoning, 2009). HR Wallingford (1995) report maximum significant wave height (Hs) to be 3.94 m at the Pagham Harbour entrance.

Under present conditions waves will not be propagating into the harbour because of the shielding effects of the large spit feature. Therefore, waves within the site will be restricted to internally generated wind waves, with a maximum fetch of 1.6 km during high spring HW.

ARUN DISTRICT COUNCIL P/93/25/PL

The key consideration for this study is that the dominating south-westerly waves are playing a key role in driving the northerly longshore transport of shingle along this south-east facing shoreline. The resulting effects in terms of the observed patterns of shingle movement forming a distinct swash-aligned coast are discussed in the following sections.

6.2.4 Sediment Transport Characteristics

6.2.4.1 Directions of sediment transport

The nature of the inshore wave climate (including the wave heights, and incident angle at which they approach the coast) influences the rates of longshore sediment transport and the spatial variations in those patterns that are observed. As a consequence of the shoreline orientation and the dominant south-westerly wave directions there is a classic drift aligned shoreline from Selsey Bill to Pagham Harbour (Royal Haskoning, 2009, 2013; Bray et al., 2004).

Considerable longshore sediment transport has been observed along this coastline in a net north-easterly direction (both presently and historically). The transport pathways and mechanism are illustrated in Image 6.5 from the result of the SCOPAC study (Bray et al., 2004). Longshore transport of shingle feeds the shoreline to the south of Pagham Harbour, and promotes the development of the Church Norton Spit. Continued supply to the spit drives its north-easterly migration towards the northern part of the harbour frontage (i.e. towards Pagham Spit/Beach) a process which has been observed to occur rapidly both historical and over the past 10 years. At the same time, this migratory procession of the spit is linked to the northward migration of the harbour inlet (and associated channel).

In front of Pagham Harbour there is an interaction between the development of the Church Norton Spit and the development of the ebb tidal channel which together influence the position of the inlet channel. Royal Haskoning (2009) highlight how, as the ebb delta matures, it provides an elevated bed surface upon which the spit can develop. This interrelationship between the ebb delta 'platform' and the spit growth is considered in greater detail in Section 6.2.5. The dynamics of the spit also indicates cannibalisation phases, where the spit uses its own shingle to continue growing because the source supply of shingle is intermittently occurring rather than happening at a uniform continuous rate (Orford, 2013).

The presence of the harbour inlet and the resultant ebb tidal delta (particularly towards the northern side of the harbour) causes a major disruption to longshore drift along the coastline. As a result, material arriving from up-drift (i.e. from the south west) will no longer naturally bypass the harbour inlet, but rather will be stored in the ebb tidal delta and contribute to accretion (and migration) of the Church Norton Spit.

On the north-eastern side of the harbour, an area of drift divergence has previously been described (Barcock and Collins, 1991; Bray et al., 2004), as shown in Images 6.5 and 6.6). In this region there is a local reversal of the predominant direction of transport towards the inlet. This has been described as providing 5,000 m³/year westwards to the inlet over a 500-700 m long frontage. This material then enters a reverse circulation into the ebb delta at the harbour entrance.

ARUN DISTRICT COUNCIL P/93/25/PL

Material transported into the tidal channel by flood tidal flows and wave activity will have a 'choking' effect, restricting flow through the channel. In order to regain stability, the channel will move this material (via ebb tidal currents) towards the ebb delta. The size of the ebb delta will, therefore, be dependent upon the ability of the system to move this material seawards and the rate of littoral drift (Royal Haskoning, 2009).



(Source, Bray et al., 2004)

Image 6.5 Net sediment transport pathways around Selsey Peninsula

Due to shingle being transported through a northerly littoral process, the migration of the inlet channel has historically occurred in the direction of this predominant drift (i.e. north-east). According to the Geodata Institute (1994), net seaward discharge (that generates accretion of sediment/shingle within the ebb tidal delta at Pagham entrance) is in the order of 16,000 m³/year, representing the balance estimated between landwards (flood tide and wave-driven) and seawards transport. Flushing processes and the ebb tidal delta sediment budget will be highly variable between years and will have, undoubtedly, changed historically, due to a reduction in the harbour tidal prism as a consequence of siltation and land reclamation (i.e. margins of the harbour have been isolated behind roads).

ARUN DISTRICT COUNCIL P/93/25/PL



(Source: Bray et al., 2004 using Cambridge University CAP infrared image)

Image 6.6 Sediment transport directions around Pagham Harbour inlet (dated 2000)

6.2.5 Spit-Delta Interactions

For this assessment, the pattern of the Church Norton Spit migration, and its relationship to the ebb delta position, has been subject to further, more detailed, analysis using the latest topographic data for this area. This involved using GIS analysis to identify contour outlines for the spit and ebb delta since 2001 and calculate the sediment volumes within the areas defined by these contours over time. Three different elevation contours were selected for this analysis (+3 m ODN, 0 mODN and -0.5 m ODN) which captured the extent of the spit crest and the ebb tide delta. The position of the ebb delta and the distal end of the spit was also mapped for the 2001 to 2015 period to describe the horizontal progression of these features.

The results of this analysis describe the inter-relationship between development/migration of the spit and that of ebb delta. Essentially, there is a relatively longer period of time during which the ebb delta matures and grows at a location in front of, and some distance away, from the end of the spit. Then over a shorter space of time (especially influenced by storm events), the crest of the spit grows and fills in the 'accommodation space' between them to catch up. Therefore, the position of the spit follows the location of the leading ebb delta once that ebb delta has provided a sufficient platform.

The spatial inter-relationship between the spit and the delta is illustrated in Image 6.7 which shows lines joining the distal point of the spit (at the 0m contour) and the ebb delta at each time interval from 2001 to 2015. On this plot, the dashed black line shows the track of the spit and the dashed red ovals show the position of the delta, grouping the points when the delta remained in approximately the same place over several time intervals.

This close coupling between the spit crest and the ebb delta is consistent with the observed approximate shore parallel migration. The lower part of the spit (at and below mean tide level) follows a similar track but with more variability. This probably reflects changes in accommodation space and/or temporal variations in sediment supply. Overall though, the

ARUN DISTRICT COUNCIL P/93/25/PL

system has tracked approximately shore parallel at a relative standard rate (since 2003) of 80m/year. The intertidal and sub-tidal part of the spit has moved at a faster rate of some 100m/year because of the additional distance involved in forming the channel meander.

This analysis confirms that the position of the ebb delta provides a good indication of the future direction of spit migration over the short term. However, the future direction of the ebb delta, whilst typically shore parallel, is strongly influenced by constraints, such as accommodation space, sediment supply and coastal structures, which may alter the harbour channel alignment (even if only temporarily) and so alter the ebb delta location.

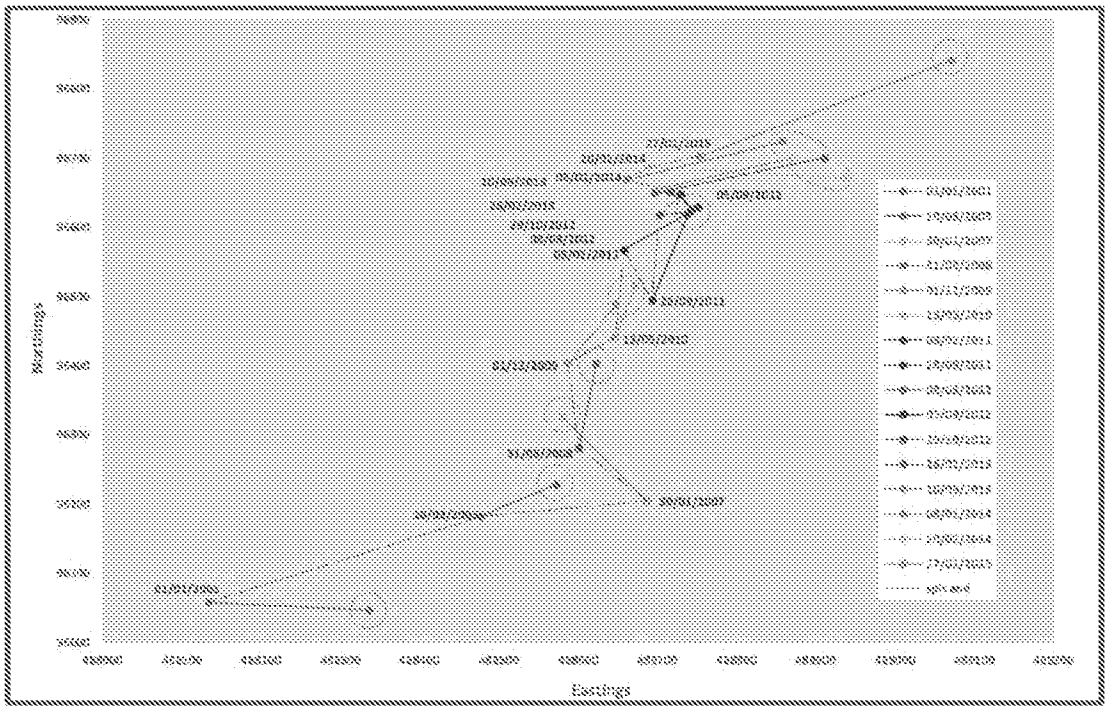


Image 6.7 Spatial relationship between ebb delta (red circles/ovals) and the track of distal end of the spit (black dashed lines)

Further analysis has also been carried out to understand the volumes of material within the spit and the ebb delta features over the course of its recent development. For this work, the section of coast throughout the length of the spit was divided into 10 cross-shore cells and the changes in volumes of sediment within each feature (spit and delta) and for each cell were calculated. What this analysis shows is that the majority of the volume and the majority of the change occurs below the 0 m ODN (MSL) elevation. Indeed the main change in total volumes above 0 mODN is a substantial increase in the volume at the root of the spit to the south of the area that is proposed for the managed breach. This analysis has also shown that the spit has grown at a rate which is consistent with the estimated volumes of littoral drift. If estimates of the rate of sediment supply are correct, this implies that there continues to be little bypassing of sediment from the spit to the Pagham foreshore to the north-east leading to a reduced supply to Pagham Beach.

ARUN DISTRICT COUNCIL P/93/25/PL

6.2.5.1 Sediment transport sources

The sediment which supplies the Pagham Harbour entrance is predominantly derived from the south-west of the harbour (i.e. the up-drift beaches). Ultimately, the majority of this transported material (predominantly shingle) is, in turn, evidently derived from offshore sources, e.g. Kirk Arrow Spit (a mobile gravel bank), and from the series of mobile nearshore shingle banks located at the Inner Owers. The shallow bathymetry of these offshore features subjects them to intense wave action which provides a mechanism by which shingle can be transported onshore.

The ability of these offshore features to supply material in the future is relatively unclear. The nature and volume of shingle transported to date would suggest that these sources (i.e. Kirk Arrow Spit and Inner Owers) are presently 'healthy'. Certainly, Dornbusch, (2014) identified several morphological indicators (spit shape, up-drift beach volumes, ebb delta movement, nearshore bank alignment and intertidal vegetation) which indicate that the supply of shingle to the spit is not reducing.

Material is also supplied from erosion of the cliffs and beaches at Selsey Bill, although the building of a sea wall in 1960 evidently reduced this erosion (Robinson and Williams, 1983). However, even prior to this, Barcock and Collins (1991) estimated that the proportion of material originating from the cliffs that reached the Pagham frontage was only between approximately 10 and 30%, indicating that material is primarily from offshore sources.

It has also been concluded that shingle is transported ashore (at a rate of 42,000 m³/year) via the spur features which extend out from the shoreline at several points along the Selsey to Pagham coast (Barcock and Collins, 1991). These features also migrate along the shore at around 18 m/year (see Image 6.8) (as noted in Section 6.2.2) but individually they do not necessarily hold large volumes of shingle (around 1,000 m³ for the single feature illustrated in Image 6.8).

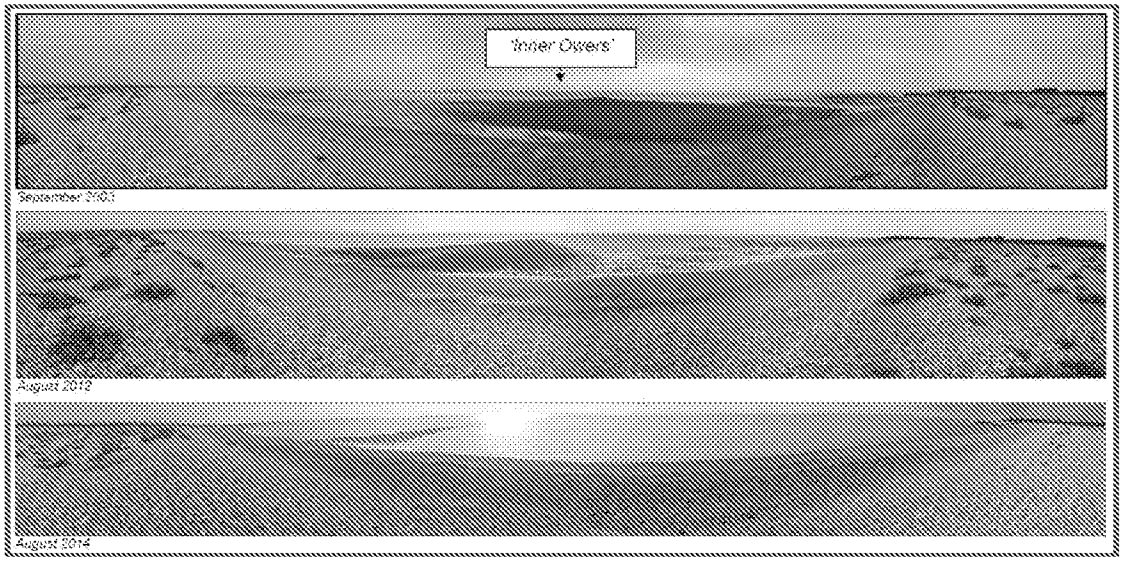
While the majority of the shingle that migrates along the eastern side of Selsey is evidently derived from offshore sources, previous coastal intervention measures along this shoreline will also influence observed changes. For example, in late 1999, the Kirk Arrow Spit offshore from Selsey Bill was 'cut' to alleviate flood risk (30 m wide, average 3 m deep with the base at or slightly above MLW, see Image 6.9) and this released a volume of shingle into the prevailing drift. This was done because this spit had begun to move closer to the shore at Hillfield Road (around 600 m to west of Selsey Bill) causing beach erosion[14].

This cutting of the spit allowed the separated distal (southern) end of the spit to move onto the beach and over subsequent years move slowly around the Bill and then more rapidly north-eastwards towards Pagham. It is likely that this pulse of shingle (estimated about 75,000m³ over two years) contributed to the accelerated growth of Church Norton Spit probably from about 2006-7 onwards (David Lowsley, Senior Engineer CDC, Pers. Comm.).

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[14] By December 1999 the landward end of the spit had nearly reached the shore and although it was thought that this would have sealed naturally, the risk was considered too great to leave the channel open over the two week Christmas break.

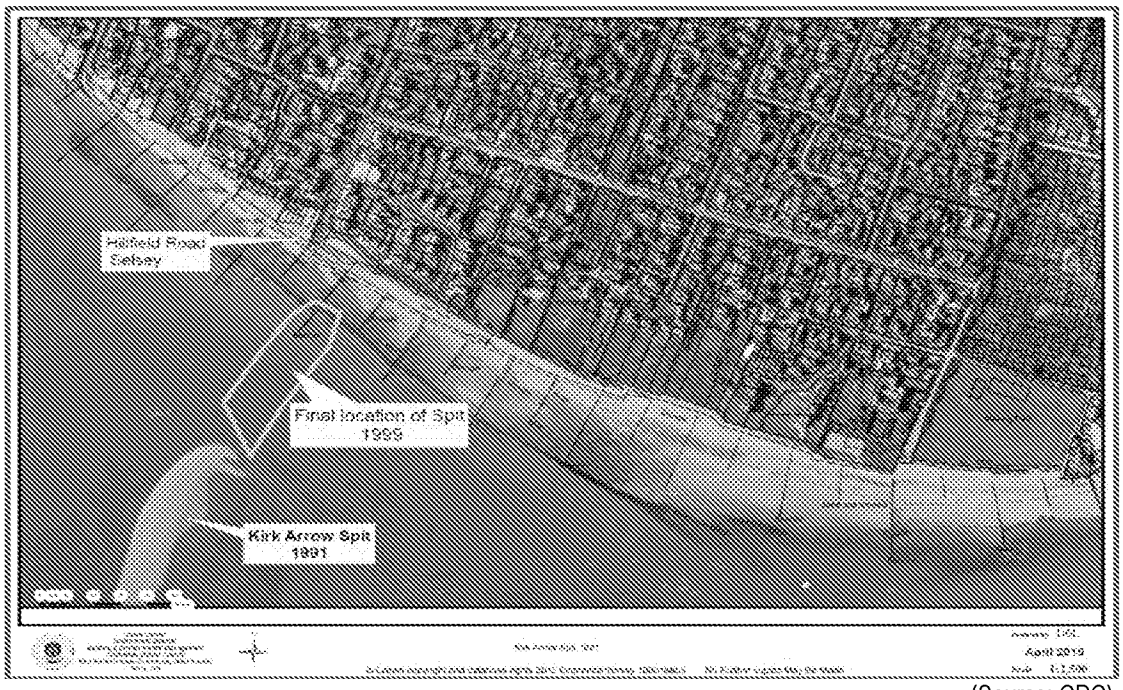
ARUN DISTRICT COUNCIL P/93/25/PL



(Source: SRCMP 2014a)

Image 6.8 Example of spur progression along shoreline to southwest of Pagham harbour

It would also appear that occasional beach nourishment work to the west of Selsey (undertaken for the CDC beach management plan) has contributed to intermittent pulses of material coming ashore. This nourishment will contribute to the supply of shingle on the eastern shoreline. There have been past nourishments (including around 45,000 tonnes in 2010/11, and 65,000 in 2014) placed across the drift divide and from experience it is expected that half moves to the west while the other half moves east (David Lowsley, Senior Engineer CDC, Pers. Comm.). There have also been small scale nourishment works back in 1992 and 1995 on the East Beach of Selsey, which generally requires much less intervention.



(Source: CDC)

Image 6.9 Approximate location of Kirk Arrow Spit (in 1991 and 1999)

ARUN DISTRICT COUNCIL P/93/15/PL

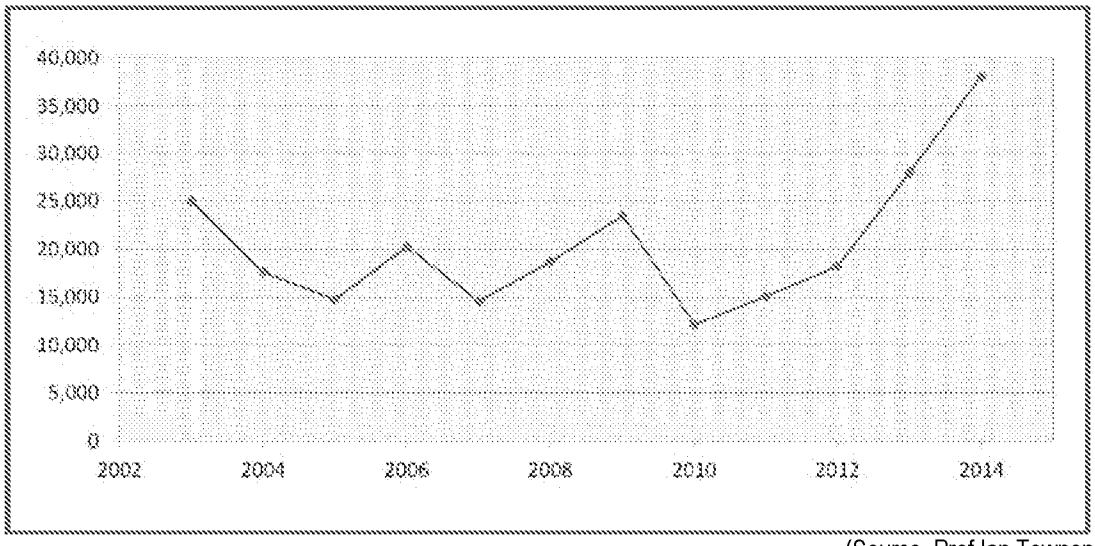
6.2.5.2 Sediment transport rates

Various studies over the years have estimated the rates of sediment transport along this coastline. The resulting values have typically ranged from 24,000 m³/year (Lewis and Duvivier, 1976) to 42,000 m³/year (Wallace, 1988), with a maximum rate of 76,000 m³/year reported for 1962 (Wallace, 1988).

For this assessment, two further analyses of the transport rates were undertaken. The first analysis was based on interpretations of the inshore wave climate and of the patterns of littoral drift that can be expected as a consequence. The accuracy of these interpretations were verified by testing them against the measurable rates of transport experienced by one of the local spur features as it migrates along the foreshore (further details about this spur analysis is presented later in this section). This analysis indicates that, over the past 11 years (2004 to 2014), the transport rates have ranged between 12,075 m³ (2010) and 38,068 m³ (2014), with the average rate being 20,064 m³.

The results of this analysis for each year between 2003 and 2014 are plotted within Image 6.10 and this shows the degree inter-annual variability that exists with respect to predicted transport rates. This variability will be linked to climate conditions, as a primary driver, but is also likely to be influenced by the movement of spurs features (if they are cross-shore transport conduits) as they migrate towards, and integrate into, the spit. It is notable that the highest rates of transport (approximately 40,000 m³/year) in this period were calculated for the most recent two years (28,000 m³ in 2013 and 38,000 m³ in 2014) which included the severe storm phases during the 2013/14 winter.

The consequences of these recent high transport periods were clearly observed in the form of the substantial growth of the Church Norton Spit that took place at this time and also by the increased erosion of the frontage due to wave activity that was seen during this recent period. These storms also accelerated the rates of littoral drift and beach erosion on Pagham Beach as described further below.



(Source, Prof Ian Townend)

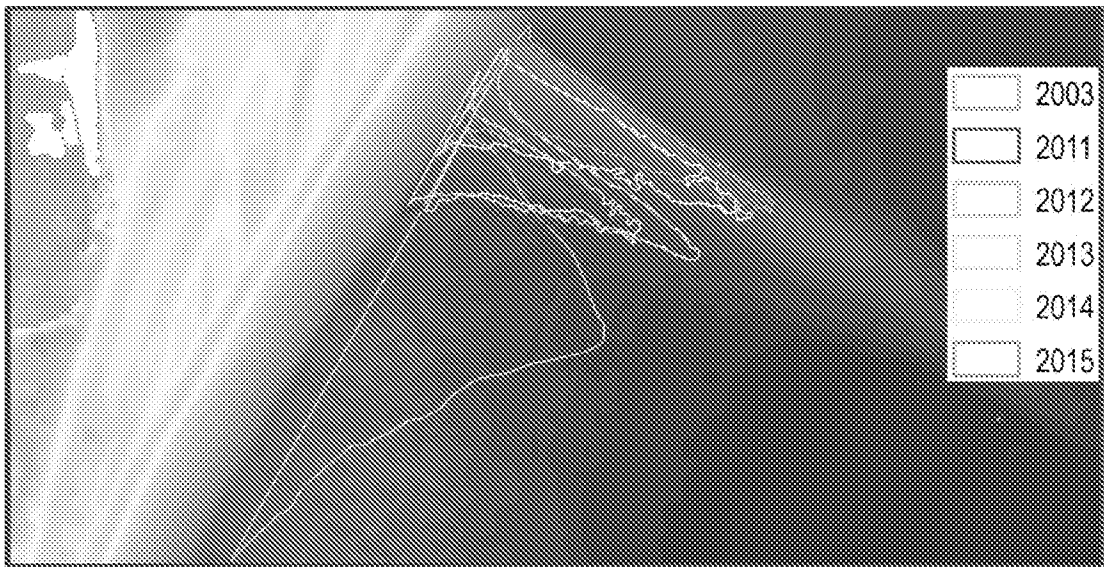
Image 6.10 Annual littoral drift potential (in m³/year) for the Pagham Harbour frontage (based on the inshore wave climate), 2003 to 2014

ARUN DISTRICT COUNCIL P/93/25/PL

The second analysis of drift rates undertaken (which was used to verify the initial quantification) involved an analysis of the overall rates of littoral drift along the spit using latest topographic data. For this work, GIS-based measurements of the plan and volume areas of one of the spur features were made as based on its progression along the spit in recent years (see Image 6.11). This spur is located immediately to the south west of Pagham Harbour and has retained its shape while also transiting in a clear northerly direction (with the longshore sediment transport pathway) over the period 2012 to 2015 (see Image 6.11).

This analysis of the spur transit indicated that the overall drift rate over these last three years has been 16,234 m³ (2012-2013), 40,519 m³ (2013-2014) and 20,563 m³ (2014-2015). These measured values closely match the values of drift volumes estimated separately using calculations based on the interpolated inshore wave climate and methods for calculating littoral drift (Soulsby, 1997) as described previously in this section. This similarity between observed and predicted outcomes provides confidence in the effectiveness of the interpolations made about the inshore wave climate and littoral drift rates (as presented above, see Image 6.10).

In summary, the work undertaken for this assessment indicates that the typical rate of drift is between 15,000 and 20,000 m³/year, while higher values approaching double this range can be experienced during years with more frequent storms. The high transport periods will be strongly influenced by climatic conditions but also other factors such as the arrival of spur features that move along the shoreline. These rates are generally in keeping with the range of values that were quoted by preceding studies (Lewis and Duvivier, 1976; Wallace, 1988). They are also considered to offer an improvement (greater level of confidence) regarding the values since they are based on greater and more resolved field data and use latest available methods.



(Source, ABPmer using Environment Agency data)

Image 6.11 Spur progression along shoreline to southwest of Pagham Harbour

ARUN DISTRICT COUNCIL P/93/25/PL

6.2.5.3 Sedimentation (siltation) with Pagham Harbour

In addition to the sediment processes that occur along the coast (especially the physical and visually dominant movement of coarse shingle), it is valuable also to recognise that these processes influence the rates of fine sediment accretion within the harbour. In particular, the presence of a tidal inlet allows a net process of sedimentation to occur within the harbour. This is because the imported fine sediment is mainly derived from marine sources rather than from the freshwater rife systems that drain into the harbour (Cundy et al., 2002; Royal Haskoning, 2009).

The marine import of fine sediment was analysed by Cundy et al., (2002) who described the rate of sedimentation in the northern harbour area following the natural storm-induced breach that occurred in 1910. They used stratigraphic and radiometric evidence (including depositions of 137Cs from the Chernobyl event in 1986) to consider this issue and identified a relatively constant rate of sedimentation with no prolonged large-scale variations in accretion. From this work the inner harbour was found to have accreted by between 400 mm and 700 mm since 1910 which equates to between 4.7 and 8.3 mm/year (similar to rates observed on Spartina dominated marshes in this part of southern England).

Further stratigraphic (sediment layering) analysis of intertidal sediment has also indicated that sediment has rates of 4 to 8 mm/year (Royal Haskoning, 2009). It has been found that accretion is spatially variable across the harbour and has been low in areas close to the inlet but relatively high on the western side of the harbour. Also, there has been no evidence of a decline in the accretion rates over the marshes (Royal Haskoning, 2009). In general however, this accretion is exceeding the rate of relative sea level rise so that the harbour is generally considered to be exhibiting a bed elevation rise leading to a net reduction in the intertidal area.

6.2.6 Historical Changes and Recent Developments

6.2.6.1 Historic situation (1587 to 2003)

The morphology of the Pagham shoreline has historically been strongly related to the position and stability of the Pagham Harbour spit features, harbour inlet, inlet channel and ebb tidal delta. As noted previously, these features are inter-related, are highly dynamic and in a continually evolving state, which has resulted in a considerable change. The evolution of these coastal features for the period 1587 to 2015 is schematically illustrated in Figures 6.2 and 6.3 which show 14 schematic charts drawing upon those collated in previous reviews (Robinson and Williams, 1983; Barcock and Collins, 1991) along with extra maps obtained for this assessment. Based on these maps, and previous reviews, the key historic changes are set out below.

Earliest reliable mapping of the Pagham coastline, drawn in 1587, identifies the presence of two separate shingle spits projecting part way across the mouth of the harbour; one situated to the north-east of the southern shore (Pagham Spit) and the other south-west of the northern shore (Church Norton Spit). At this time (see Figure 6.2) the harbour was more like a river estuary and the existing freshwater drainage 'rifes' flowing into it were then tidal (Environment Agency, ADC, CDC, undated).

ARUN DISTRICT COUNCIL P/93/25/PL

During the 1700s, the southern spit extended north-eastward and little remained of the northern (Pagham) spit. Previous analysis of historical charts indicates that between 1672 and 1785 the southern (Church Norton) spit had formed and grown by 90 m up to 1724 (Royal Haskoning, 2009) followed by rapid growth of a further 900m until 1874 (see Figure 6.2).

The harbour itself looked similar to today by around 1778 to 1785 with areas of reclaimed land behind and defences and sluices built to protect the drained land. However, at this point, the 'Ferry area' was still tidal. By 1825, the Ferry causeway had been constructed to restrict tidal exchange in this area (Environment Agency, ADC, CDC, undated).

In 1874 the spit exhibited a similar morphology to the present condition but lying further landward. Then, in 1876, the inlet that existed on the northern side of the harbour was artificially closed after an Act of Parliament to prevent ongoing erosion to the northern shore (Barcock and Collins, 1991). The old outlet channel was transformed into a lagoon and controlled by sluices, and the mudflats within the harbour reclaimed for pasture land (Robinson and Williams, 1983).

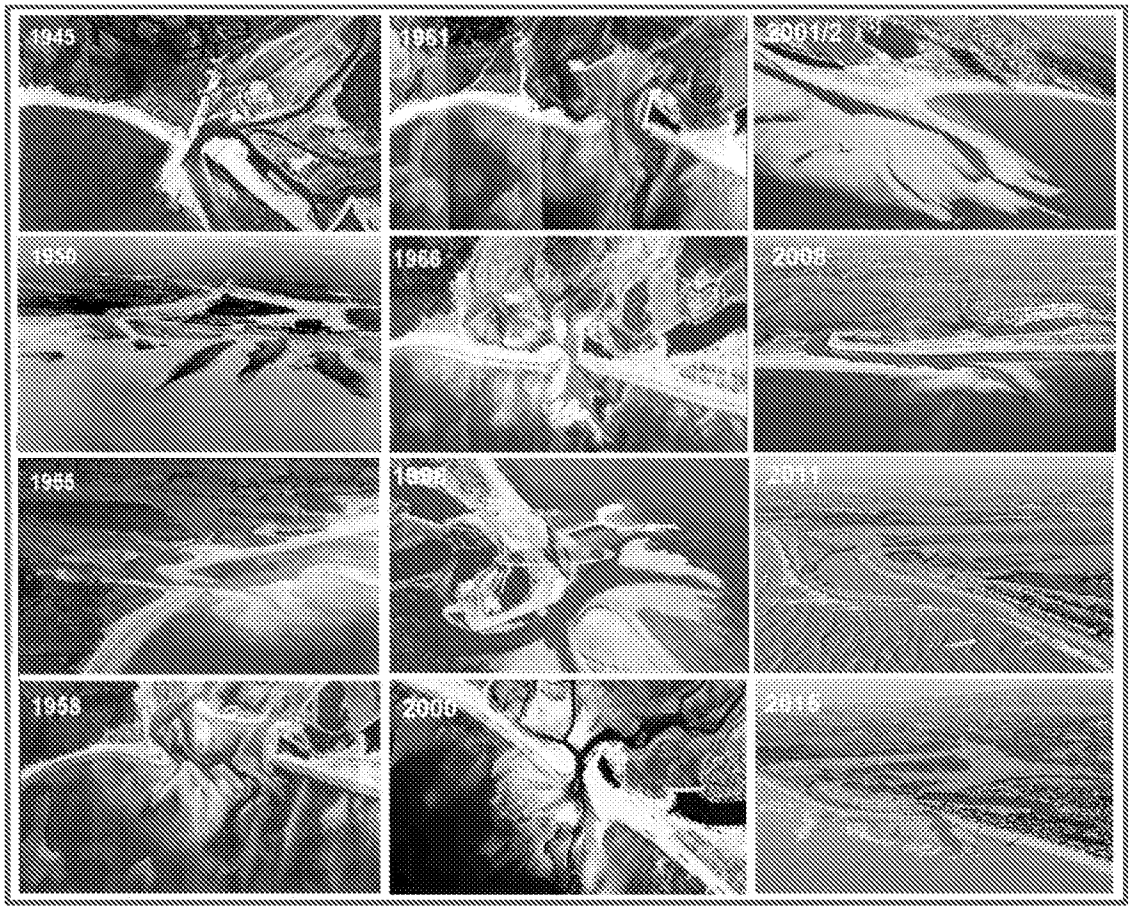
Over the next 34 years (1876 to 1910) the beach at Pagham extended seawards as the ebb delta deposits were eroded and moved onshore leading to a build-up of the foreshore (Royal Haskoning, 2009). In 1910, however the shingle ridge was breached by a large storm towards the southern Church Norton side of the harbour (see map in 1911 – Figure 6.2). This allowed the sea to flow again across the low-lying land into Pagham Harbour and through an inner harbour sea wall also (Cundy et al., 2002; May, 2007).

In the years following, the position and size of the inlet continued to change greatly in response to anthropogenic and natural factors (see Figures 6.2 and 6.3). Pagham Beach also continued to grow in the early 1990s and by the 1930s construction of properties began to take place (Dornbusch, 2014). Between 1910 and 1934, the spit again grew in a northerly direction by some 700-800 m (towards Pagham Beach) and deflected the tidal inlet in that direction (Royal Haskoning, 2009). By 1934, two separate shingle spits extended from each side of the harbour frontage with the intertidal gravels diverting the outflow towards the north-east.

Subsequent attempts to stabilise the inlet were unsuccessful and the southern spit again grew north-eastward. This necessitated the man-made creation of a new breach entrance in the south, near Church Norton in 1937 (near where the natural breach occurred in 1910) to prevent erosion of Pagham Beach (Royal Haskoning, 2009) (see map in 1944 – see Figure 6.2).

After this new breach was introduced at the southern end of the harbour, the pre-1937 entrance (middle of the harbour) gradually closed becoming marked by a low gravel berm. By 1944, the old mid-point entrance had become encapsulated within the spit, forming a small lagoon (see Figure 6.2) which is still present today at the end of the Pagham Beach/Spit (called 'Little Lagoon'). In the same year (1944), concrete and sheet piles were introduced to the southerly breach to try and stabilise it. However, in 1955 the spit was once again breached over a wide front by a storm. This subsequently rolled back a portion of the spit into the harbour by approximately 800 m, leaving a wide southern entrance (Robinson and Williams, 1983) (see Figure 6.3 and Image 6.12).

ARUN DISTRICT COUNCIL P/93/25/PL



(Sources Various: Bray et al., 2004, John Akerman, Gary Crossley, Save Pagham Beach Website)

Image 6.12 Changing configurations of the spit, inlet and delta complex

Rapid littoral drift thereafter led to a further extension of the Church Norton spit across the inlet narrowing it to 250 m by 1961 (Royal Haskoning, 2009). Between the 1950s and 1969 the inlet had migrated by 900 m to the north. Following continued inlet narrowing a training wall was introduced on the distal end of the Pagham Spit to stabilise the entrance. This was completed in 1963, and this situation was largely maintained subsequently (Bray et al., 2004). Whilst this piled training wall provided stability to the harbour entrance, it also assisted in fixing the position of the north-eastern Pagham Spit more seawards than previously had been the case historically.

By 1978, the harbour entrance had gradually reduced to a narrow gap in the centre of the two shingle spits, largely kept open by the steel sheet training wall (Royal Haskoning, 2013). Since 1978, the inlet has been showing increasing similarity to the 1874 and 1934 situations, in which the Church Norton Spit once again began extending in a north-eastward direction towards the northern shore. The steel sheet training wall at the southern end of the Pagham spit was reconstructed in the mid to late 1980s following its major collapse.

Over the period from 1969 to 1997 the area generally remained relatively 'stable' (i.e. when compared to past conditions) (Royal Haskoning, 2009; Dornbusch, 2014). Through the 1990s and into the early 2000s, the Church Norton Spit and ebb delta were subject to regular annual

ARUN DISTRICT COUNCIL P/93/25/PL

intervention by the National Rivers Authority (NRA) until 1996 and then the Environment Agency. This involved taking approximately 15,000 m³/year sediment on average from the harbour mouth nearshore banks and ebb delta and then using it to rebuild and reshape the beach fronting the Church Norton spit following winter storms (Bray et al., 2004). This work was not required after 2004 when it was clear that the Church Norton spit was accreting naturally and was self-maintaining.

6.2.6.2 Recent evolution (2003 to 2014)

Since 2003, there has been considerable visible change to the morphology of the Church Norton Spit reminiscent of historical changes described in the preceding section. In particular, Church Norton Spit has grown rapidly in a north-easterly direction mirroring trends observed over the last 300 years. The recent morphological change, particularly with respect to the extent of the spit, has been captured by a sequence of digital terrain models (DTMs); compiled from various types of data for the period March 2003 to January 2015. Changes in the characteristics of the spit, inlet channel and ebb tidal delta are illustrated in Figure 6.3.

Comparison of the DTMs show that between 2003 and 2005 the Church Norton Spit was fairly static. During this time, a single inlet channel was located to the south-west of Pagham Beach and the ebb-tidal delta was well developed. After 2005, the Church Norton Spit began to rapidly grow in a north-easterly direction. Between April 2005 and January 2009, this spit extension was fairly linear, running parallel to the adjacent Pagham Beach shoreline and across the pre-existing ebb-tidal delta surface. During this time, the section of beach fronting the residential properties at the western end of Pagham Beach was stable (Royal Haskoning, 2013).

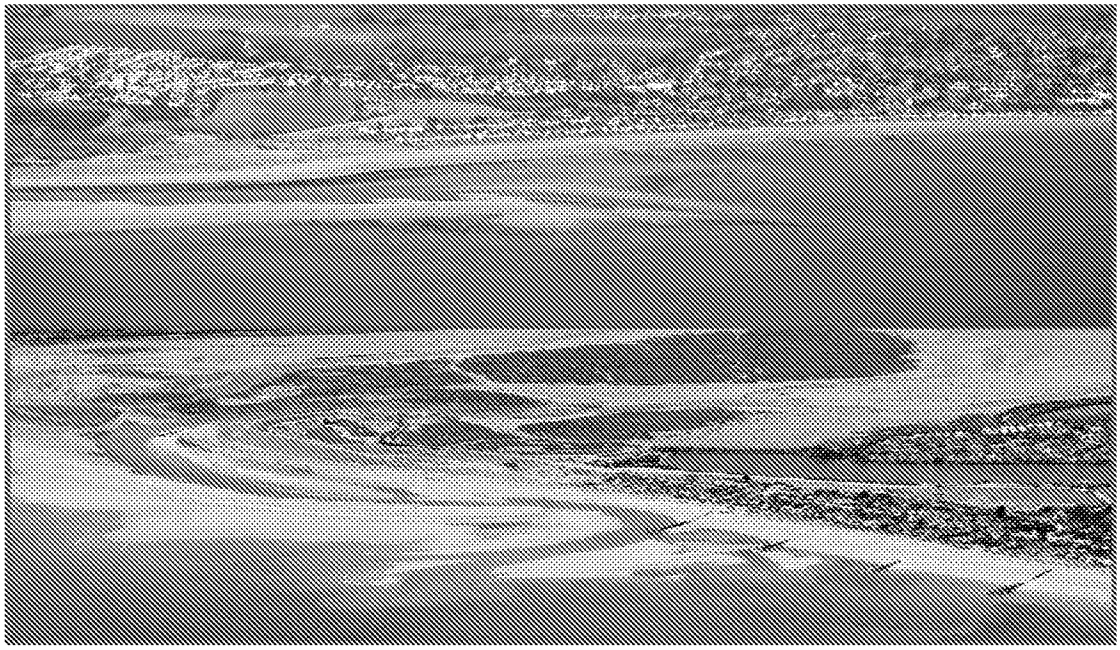
Between January 2009 and December 2009, a large change to the spit extension took place. The direction of the distal end of the spit extension ceased to be linear and turned towards the southern section of Pagham Beach in the form of a re-curve[15]. This re-curve extension migrated more than 100 m north over this short period, with the main channel flows migrating closer towards the Pagham Beach. The northerly change in direction of the spit is likely to be due the bathymetry (intertidal elevation at the tip) of the shoreline (Orford, 2013) as well as the interactions between bathymetry, sediment availability and tide/wave interactions (Dornbusch 2014).

Between 2009 and 2013, the Church Norton Spit continued to migrate north, forcing the harbour inlet channel closer to the Pagham Beach (see Image 6.13). The accretion within the spit occurred at a rate of 38,300 m³/year accumulating 228,300 m³ of material over a period from March 2003 to February 2014 (SRCMP, 2014a). Royal Haskoning (2014a) estimated that the Church Norton Spit had grown over 700 m in a north-eastward direction since 2001. This recalls situations in the 1800s and 1960s when the Church Norton Spit had grown in a similar direction by several hundred metres.

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15 The hook at the tip of a coastal spit.

ARUN DISTRICT COUNCIL P/93/15/PL



(Source: John Akerman, 22 October 2008 and 3 May 2013)

Image 6.13 Positon of Church Norton Spit relative to Pagham Beach in 2008 (top) and 2013 (bottom)

During the 2012/13 winter period, three separate storm incidences (on spring tides) severely eroded the Pagham Beach coastline between the end of the Church Norton Spit and the first of four groynes located to the north of the harbour entrance. Before these storms, there was approximately 25 m of beach fronting the residential properties, however, each successive storm reduced the width of the beach front leaving only 16 m protecting the properties (i.e. a reduction of approximately 40%). Between each storm, Arun District Council (ADC) recycled beach material in the area to try and increase the width of the defence, although this material was lost to each subsequent storm (Royal Haskoning, 2013).

Between 2012 and 2014, the distance between the spit and delta also increased and the delta moved offshore relative to the spit. This is almost certainly a consequence of the influence of the recent rock revetment works on Pagham shore in the vicinity of Groyne 4 (see next section). These defences initially forced the harbour channel to make a sharp turn alongside this groyne and the delta responded by moving offshore. However, the groyne was not resilient to this tidal pressure and this caused it to fail in January 2104. Once the channel had breached the groyne, the ebb delta was able to move back to the new alignment of the ebb-flood channel occupying a position relative to the shoreline that is more typical of earlier years.

During the summer of 2014, the tip of the spit retreated by around 30 m, and the landward facing side moved approximately 15 m seawards. This is most likely a consequence of a lack of wave driven transport towards the tip of the spit, combined with high spring tides in August and September 2014, which would have led to an increased tidal flow eroding the landward edge (Dornbusch, 2014). Therefore this is likely to be a short term inter-annual adjustment and not a long term trend. The likelihood remains that the spit will continue over the ebb delta when conditions allow.

ARUN DISTRICT COUNCIL P/93/15/PL

6.2.6.3 Coastal protection works (2013/2014)

In order to prevent a repeat of this erosion occurring again during the winter of 2013/14, whilst also reducing the reliance on beach recycling efforts, ADC sought to find a longer-term solution to the problem. A local rock armour revetment was constructed along the most significantly eroding part of Pagham Beach between November and December 2013 to protect the residential properties from coastal erosion and subsequent flooding (Royal Haskoning, 2013). The rock revetment was placed along the shore and joined the western edge of the southern-most groyne in this area.

The rock revetment and adjacent groyne were undermined through scour over the 2013/14 winter with some loss of material to their rear. Urgent remedial works were undertaken in early January 2014 to stabilise the revetment as a short term repair, with additional rock imported to bolster the revetment and adjacent groyne in November 2014. Image 6.14 shows the beach frontage and rock revetment works in December 2014. Further maintenance and beach shingle recycling work was then also undertaken in February 2015.



(Source: ABPmer, December 2014)

Image 6.14 Protection works at Pagham Beach viewed from south-west (top) and north-east (bottom)

The rock revetment and beach recycling work that has been undertaken to date was urgently required and has afforded protection to the worst affected section of the beach and the most threatened properties. However, it also demonstrates how difficult and costly it can be to try and fix a section of shoreline along this coast.

Over the last three winter periods these measures have cost around £900,000, including £500,000 for the 2012/13 revetment and £360,000 for later remedial/improvement measures. In the years preceding, there were fees incurred for shingle beach nourishment in 2010 (£600,000) and beach shingle recycling in 2009 (£43,000).

ARUN DISTRICT COUNCIL P/93/15/PL

Therefore over £1.5 million has been spent over the last 6 winters with the sum being incurred increasing over time with the growth of the Church Norton Spit. The continuation of such reactive measures, on an emergency need basis, throughout the beach length is not considered to be the most suitable long term solution to the continuing coastal erosion and flood risk along this part of the coast (see Section 2.2).

6.2.6.4 Current condition of the Beach, Spit and Delta (2015)

As described previously, the tidal inlet channel from the harbour has grown and extended alongside the migrating Church Norton Spit. The northern end of this channel now runs alongside and into the front of the south-western side of the Pagham Beach foreshore (Image 6.15). This is resulting in an ongoing erosion and flood risk to residential properties on this side of the beach which are currently being afforded some protection by the recent rock revetment work (Section 6.2.6.3). This revetment will however continue to be vulnerable to further failure. In the near future, the spit and channel are also likely to outflank the existing structures on the shoreline (revetment and groynes) to further exacerbate erosion along the central part of the beach further to the east.

The central part of the Pagham Beach area is in an eroding/deteriorating condition, and in this present state has a substantially reduced amenity and reactional value. This is because not enough shingle is being allowed to move north-eastward through normal long-shore sediment transport pathways into this part of the beach. Instead, the shingle is largely being stored or 'locked up' within the spit and ebb delta is not being moved ashore in large part because of the strong flows that occur through the elongated tidal inlet channel. This reduction in the shingle supply is exacerbating beach erosion problems along Pagham Beach and increasing flooding risk to residential properties.



(Source: John Akerman, 27 February 2015)

Image 6.15 Tidal inlet and coastal protection works at south-western Pagham Beach

ARUN DISTRICT COUNCIL P/93/15/PL

Man-made features along the shore also influence this evolution of the spit, harbour entrance and inlet channel and, in recent years, are also partly responsible for the erosion issue presently experienced along Pagham Beach. For instance, while the migration of the Church Norton Spit and channel appear to be relatively natural processes predominantly controlled by the influence of longshore drift supply (albeit that supply is itself influenced by updrift anthropogenic activities) the channel has become artificially impinged by the training wall at the end of the Pagham Beach/Spit[16]. Without the training wall, the channel would have been able to erode the distal end of the northern (Pagham) spit in order to follow a more natural sinusoidal (meandering) shape, possibly taking it away from the properties situated along Pagham Beach.

The groynes in place on Pagham Beach also have a key influence. They are designed to slow the drift rate and stabilise the beach (especially during periods of erosion) and were constructed in the 1960s, re-profiled and raised in 1985/86 and extended in 1991/92 to manage coastal processes and enhance the stability of Pagham Beach. The installation in the 1960s clearly indicates that there was an erosion concern at that time (Dornbusch 2014). Recently, however, they have constrained the inlet channel, which has migrated northwards towards Pagham Beach as the migrating Church Norton Spit advances. This is inherently complicating and aggravating the local erosive pressure at this part of the beach.

During 2015 the conditions, as described above, have remained relatively stable and there appear to have been no significant change in the position of the inlet channel since February 2015[17]. However, from a site visit undertaken by ABPmer in May 2015 there appears to be increased volumes of material in the ebb delta in proximity to Groynes 1 and 2. The implications of this for the future evolution of the spit and delta are reviewed in Section 6.2.8.

6.2.7 Changes Occurring on Pagham Beach

In addition to the identified changes to the Pagham Harbour spit complex and inlet channel, both historically and more recently, the beach fronting Pagham has also been subject to considerable change. Royal Haskoning (2009) undertook historical trend analysis of beach change along Pagham Beach (between Groynes 3 and 4) and further to the north-east (adjacent to East Front Road), for the period 1938 to 2008. Results from this analysis indicate that the beach typically experienced accretion prior to 1969, with respect to the position of the berm crest, followed by a prolonged period of stability until around 1997. Since this time, the beach was subject to ongoing erosion, however, erosion rates were determined to have incrementally decreased with time at the locations analysed.

In the last few years, however, the presence of an extensive Church Norton Spit is causing increasing erosion of the beach and flooding risk to the residential properties at the Pagham Beach (as is clearly evident now). This erosion can be attributed to a number of factors, including:

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16 The training wall that was constructed in 1963 to provide stability to the harbour entrance and rebuilt in the 1980s (see Figure 6.3)

17 A new Lidar survey data was carried out by the Environment Agency on 17 May 2015. This is not yet available but it will clarify any changes that may have taken place in the first half of the year

ARUN DISTRICT COUNCIL P/93/15/PL

- Tidal scour caused by the extended inlet channel meandering towards the shoreline, before cutting seawards around the distal end of the spit. Recent beach defence works have sought to minimise the impact of this erosion through the placement of a rock revetment, geobags and shingle recycling;
- The refraction of waves around the end of Church Norton Spit as they approach the shoreline;
- Shelter provided by the spit and ebb-tidal delta from waves approaching from the south-west possibly resulting in a localised reversal of sediment transport direction (i.e. longshore drift is towards the south-west immediate north of the harbour along Pagham Beach); and
- The beach immediately down-drift of the spit (to the east) is also being starved of material supply from the south-west, with this material being largely trapped within the spit and the ebb delta.

Further along the coast (i.e. well beyond the end of East Front Road and towards Aldwick), the beach has been accreting in recent years. This suggests that there is still an active sediment supply in this area. However, this will probably come mainly from the transport of shingle along the shoreline from eroding sections of the beach to the west (with these areas to the west not then receiving an up-drift supply to address the imbalance). There will possibly also be some offshore-onshore source as well as some minor by-passing of the spit feature (although that is expected to be very limited).

The changes taking place on the beach are subject to detailed annual assessment under the Southeast Strategic Regional Coastal Monitoring Programme (SRCMP). The latest report (SRCMP, 2014b) provides a particularly detailed overview of beach and cliff changes throughout Coastal Process Sub-Cell 4d (Beachy Head to Selsey Bill) between 2003 and spring 2014. This Sub-Cell 4d is split into a number of survey units, which are, in turn, separated into a number of smaller areas in which volume calculations can be undertaken. These smaller areas typically include groyne bays (where possible) or areas between interim profile lines.

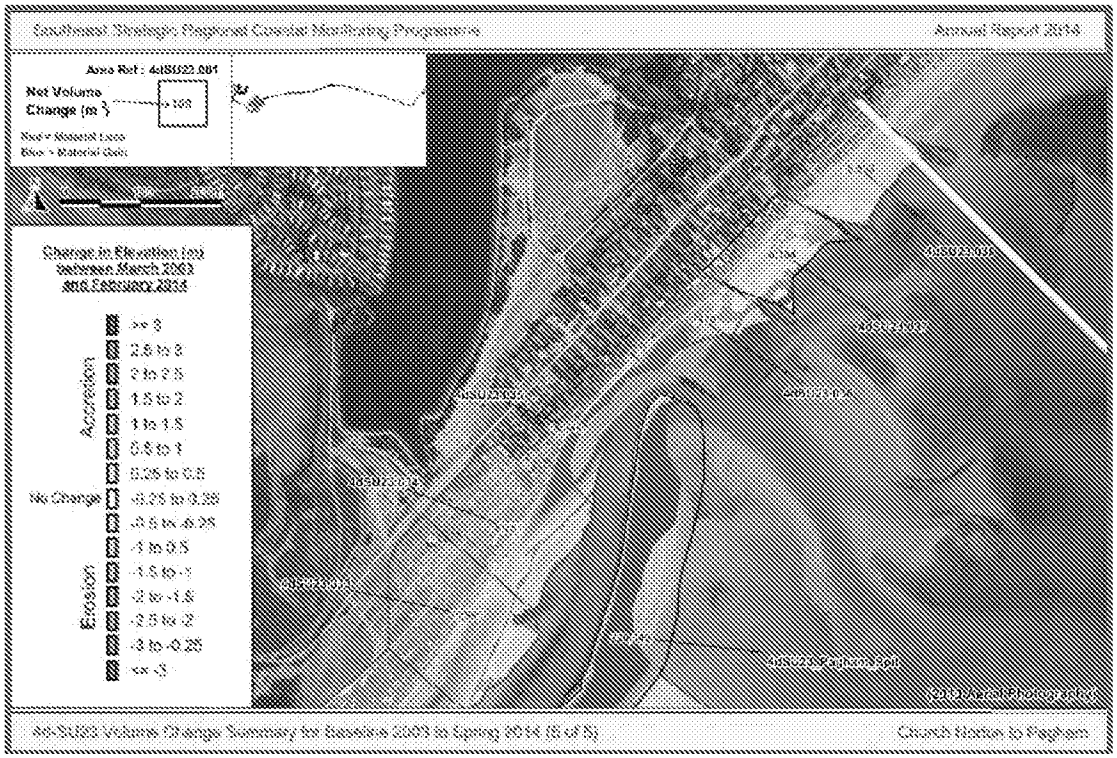
For each area, the volume of beach material above a fixed datum (-1.0 mODN) is calculated from the survey data, which is then compared against a baseline (Spring 2003). For the latest survey report (SRCMP, 2014b), the survey work is undertaken using mobile laser scanning in addition to cross-sectional beach profiles that has previously been used. In the future, laser scanning only will be reported as this data is able to support the most complete understanding about beach volume changes.

For this survey work, parts of units 4dSU23 and 4dSU22 cover the Pagham Beach foreshore and the Pagham Harbour frontage. The results from the analysis of these sections describe the net changes in beach elevation (whether accreting or eroding) for the period from spring 2003 to spring 2014. The results of this work for the areas that are specifically relevant to this proposal are illustrated in Images 6.16 and 6.17.

ARUN DISTRICT COUNCIL P/93/15/PL

Image 6.16 describes the conditions along the south-western part of Pagham Beach. This analysis illustrates the complex changes, substantial spit growth and shoreline erosion that have been experienced in this area over the last decade due to tidal currents created as the inlet channel migrates into the beach. The substantial erosion caused by the tidal inlet and areas of Pagham spit to the west is clearly shown. There is also a small amount of net accretion between Groynes 2 and 3 which may be influenced by artificial recharge and net erosion between Groynes 1 and 2.

Image 6.16 also shows that there is 228,349 m³ more material in the shingle spit. The SRCMP (2014b) report also records that across the whole of 4dSU23 (from northern part of Selsey East beach to western part of Pagham Beach and including the Pagham Harbour frontage, including this spit) there has been a net increase of 267,000 m³ of sediment over the period from 2003 to 2014.



(Source: SRCMP 2014b)

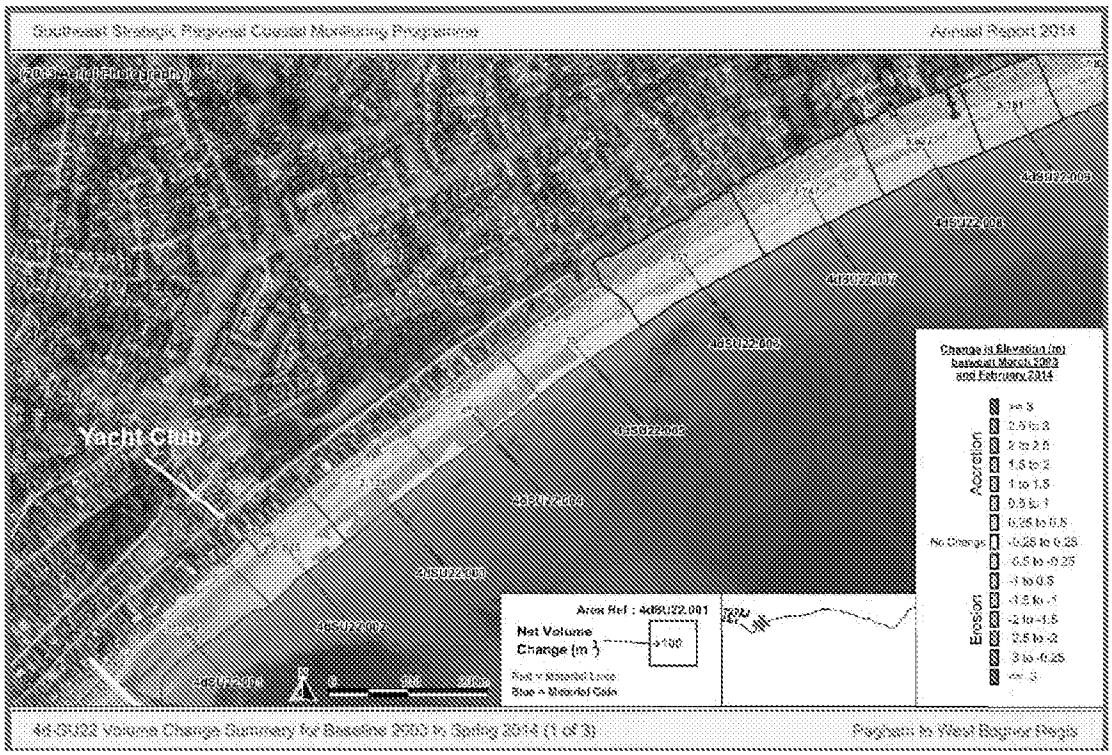
Image 6.16 Beach volume changes (2003 to 2014) along Pagham Beach (centre and east, 4dSU23)

Further along the beach (i.e. adjacent to West Front Road and between Groynes 1 and 2), erosion is also occurring but is driven by a lessened sediment supply (due to the spit and ebb delta). This leaves this frontage vulnerable to large waves and the risk of local volume losses and height reductions.

The Pagham Harbour Beach Management Plan Report (SRCMP, 2014a) has examined this western beach area in greater detail and confirms that it has been subject to scour and berm width reductions since 2009. The management of Pagham Beach is driven by the need to

ARUN DISTRICT COUNCIL P/93/25/PL

consider critical trigger levels with 'emergency' status being when the berm width[18] reaches 10 m and the berm height is 4.9 mODN (SRCMP, 2014a) ('warning' levels are 20 m berm width, 5.3 m berm height and 'action' levels are 15 m berm width, 5.1 m berm height). The 2014 report confirmed that the western part of the beach was below the emergency level and close to the emergency width based on data up to February 2014. During 2014, ADC therefore carried out substantial emergency works using a combination of rock, rip-rap, geobags and shingle recycling to address this issue in the short term (SRCMP, 2014a).



(Source: SRCMP 2014b)

Image 6.17 Beach volume changes (2003 to 2014) along Pagham Beach (west, 4dSU22)

Image 6.17 shows how there has also been net erosion along the north-east part of the beach in the area in front of East Front Road. From 2003 to 2104, the beach volume in the five management units that lie to the west of Groyne 1 has reduced by 35,154 m³. From spring 2013 to 2014 it has reduced by 13,314 m³ with the highest rate of loss having occurred since 2013. There is also a very clear pattern of decreasing erosion leading towards increased accretion in a north-easterly direction as shingle is transported in that direction moved along the beach from the south-west. Consistent accretion is then prevalent across the Aldwick frontage because this transport is not interrupted by any structures along this open beach. The SRCMP (2014b) records that there has been an overall net increase of 40,500 m³ of sediment over the period from 2003 to 2014 across the whole of the 4dSU22 (the Pagham and Aldwick frontages combined).

18 The berm width is the distance from houses to the beach crest

ARUN DISTRICT COUNCIL P/93/25/PL

The net erosional changes on Pagham Beach (while areas to the east have accreted) has occurred despite two major shingle recharges that were undertaken by ADC along the area fronting the Yacht Club area in 2009 and 2010. In 2009, 10,000 m³ of shingle was relocated to this area from the distal end of the spit while in 2010, 20,000 m³ were imported to the beach and placed using SOSPAN dredger. There has also been a further 22,000 m³ of shingle translocation (up to February 2014) in smaller amounts of between 1,000 m³ and 4,000 m³ over 9 campaigns since October 2012. This smaller scale work has been conducted within the area of the groynes (SRCMP, 2014b). More recycling was also carried out in February 2015. Therefore, while the SRCMP (2014b) report indicates a loss of 35,154 m³ from this part of the beach the net loss should really be closer to 60-80,000 m³ when both the import and movement of shingle is accounted for.

A substantial amount of the erosion that has been experienced along the eastern part of the foreshore occurred during the 2013/14 winter storms. However, it is evident that this beach is also subject to a more progressive reduction in volumes over time. Also, the berm crest is retreating in many areas, as is illustrated in Figure 6.4. These plots show the alignment of the 4.9 mODN elevation along the beach from available LiDAR data, as collected in 2001, 2003, 2012, 2103, 2014 and 2015. This elevation is used as one of the emergency criteria for the management of the beach (along with berm width) and so has been used in this plot to indicate the comparative levels of erosion risk along the foreshore. These plot show how there has been large retreat (around 30 m) in this berm position to the west of the beach (as caused by tidal channel) as well as the high levels of retreat (around 16 m) at the centre of the beach up to the Yacht Club area.

Further to the east there is less retreat (just a few metres) as the beach is more stable in this area. This greater stability is probably because this frontage is presently being supplied by sufficient shingle from the west to offset a greater level of retreat (Image 6.17). The reduced rate erosion in this region will also have been moderated by shingle supply from the two recent recharge campaigns. However, most of the up-drift supply is locked away within the spit or in the ebb delta (as described previously). As a consequence of the present limited shingle supply, ongoing wave activity and down-drift shingle transport is continuing to cause a net erosion of the local beach.

As a summary of the issues facing Pagham Beach, Figure 2.1 identifies the key factors that are influencing the presently observed erosion patterns.

6.2.8 Future Development of Spit and Beach (Without Intervention)

The preceding sections have presented a review of the past and present physical conditions along the Pagham Harbour and Pagham Beach frontages. To inform the impact assessment of this project, and other alternatives, it is also necessary to understand what might happen in the future without the introduction of a managed breach in order to further clarify the rational for, and the benefit:cost ratio of, this proposal. In large part, this topic has already been considered under Section 2 which reviewed the alternatives that exist in order to clarify why the proposed approach is the most appropriate options. However, the particular way in which the site is likely to change in the future warrants further consideration.

ARUN DISTRICT COUNCIL P/93/15/PL

Given the dynamic nature of the local physical environment, it is clear that the spit and ebb delta features in front of Pagham Beach, as well as the beach itself, will always be subject to change into the future. We have a good understanding about these features and their relationships as well as the processes influencing their morphology although it is recognised that precisely predicting future changes due to future processes is difficult. It is however possible to broadly anticipate the scope and nature of future change based on existing information and understanding. An outline of future change was developed towards the end of last year by the Environment Agency (Dornbusch, 2014) in their review for Arun District Council. This work has been further considered within this assessment using any new information that is available.

The Environment Agency study provided a high-level review of available information which again recognised the inherent uncertainties associated with making predictions at this site. The study clarified that the main drivers for change will be the wave/storm effects as well as the influence of the tidal channel alignment and existing (and any future) revetment works. It also clearly concluded that there were no signs that the supply of shingle is reducing at this time based on multiple observations of the beach volumes on Selsey East Beach, the development of nearshore bank (Inner Owers) and the morphology and dynamics of the spit feature and ebb tide delta.

In the Environment Agency study the change in alignment of the tidal channel that had occurred following the break-up of Groyne 4 was noted and it was considered likely that the spit would extend along the shore into the next groyne bay(s) (causing beach erosive pressure). Overall, it was concluded that the spit could take one of several paths from its 2014 position within an envelope of two key extremes (as illustrated in Figure 6.5) Under one scenario it could progress into the beach at the other it could run parallel to the shore. It was also noted that it could move in a seaward direction.

The location where the spit and channel could progress into the beach would depend upon whether there was a failure of the existing rock revetment or if the spit moved into unprotected sections of the beach. Based on past experience (both from the 1874 morphology and recent development), further erosion of the beach was considered likely if the spit progresses in this manner. There would then possibly need to be improved revetment works between Groynes 4 and 3 and then an extension to these revetments into the subsequent two bays between Groynes 3 and 1 over time.

The issue of how the spit might progress has also been considered further for this assessment. The conclusions reached agree in large part with the preceding Environment Agency study, not least because the key observation underpinning both studies is that the shoreline is essentially 'seeking to return' to the morphology previously observed in the late 19th century, in which the spit was located where the eastern part of Pagham is now present. However, coastal defence protection works (groynes, revetments and shingle translocation measures) are clearly altering the spit's present course. In particular, the presence of the essential new revetment at the western end of the beach (west of Groyne 4) has halted the north-eastern progress of the spit and is now directing it to move along the shore.

ARUN DISTRICT COUNCIL P/93/15/PL

These studies have highlighted how the morphology of the spit, and especially the tidal channel, has in the past (in both 1876 or in 1978) exhibited an inherent meander form. The shape (amplitude and wavelength) of this meander is linked to the tidal prism of the harbour but is also influenced by the shifting position of the tidal channel. A similar shape is evidently being replicated under the present conditions with all these meander lengths typically being around 1,800 m long which are in keeping with separate empirical estimates based on estuarine meanders (Murray and Pethick, 1999).

In all likelihood this meandering will continue although in this case the groynes and revetment work will force a flattening in its amplitude and wavelength. The spit is also not expected to progress seawards because of the effects of wave and tides and because in deeper waters much more sediment will be required (i.e. more sediment is needed to fill the 'accommodation space' and build the ebb delta, platform and spit).

Based on a projection of the likely meander (which is shown in Image 6.18, and compared against the predicted range highlighted by Dornbusch (2014)), there is likely to be continued pressure on the beach in and around the area where the groynes are currently present. Then, depending on future foreshore intervention, the spit may move seaward slightly before then turning towards the foreshore 5-600 m to the east. However, while we have a good understanding about the factors driving these processes, these longer-term projections about the spit morphology in such an extended form are inherently uncertain. They also assume that spit itself will not breach naturally at some point along its length (although there is currently no indication that that will happen in the short term given the existing spit morphology and the lack of any sign of reducing sediment supply[19]).

The short term future direction of the spit will be dependent in large part on the fate of Groyne 3. If this groyne stays in place the spit may move offshore but if it fails (as Groyne 4 has done) then the spit is likely to move inshore, pass the end of Groyne 2 and contribute to erosion in the vicinity of Gropes 1 and 2. In early 2015, there were signs of increasing pressure being placed on Groyne 3 with a clear 'weiring' of the ebbing tidal current over this structure. In response, ADC carried out further work to bolster this structure.

Overall, the most likely outcome based on present understanding, is that the spit will continue to exert erosive pressure on the beach in the vicinity of the groyne bays and areas immediately to the east. In the short term, that will be at Groynes 3 and 4 (in the areas protected by revetments) but in the near future, and especially following storm periods, the spit may well progress around to the bay between Groynes 1 and 2. This is because the ebb delta appears to be maturing and exhibiting the clearest accretion (see Image 6.18) in this area.

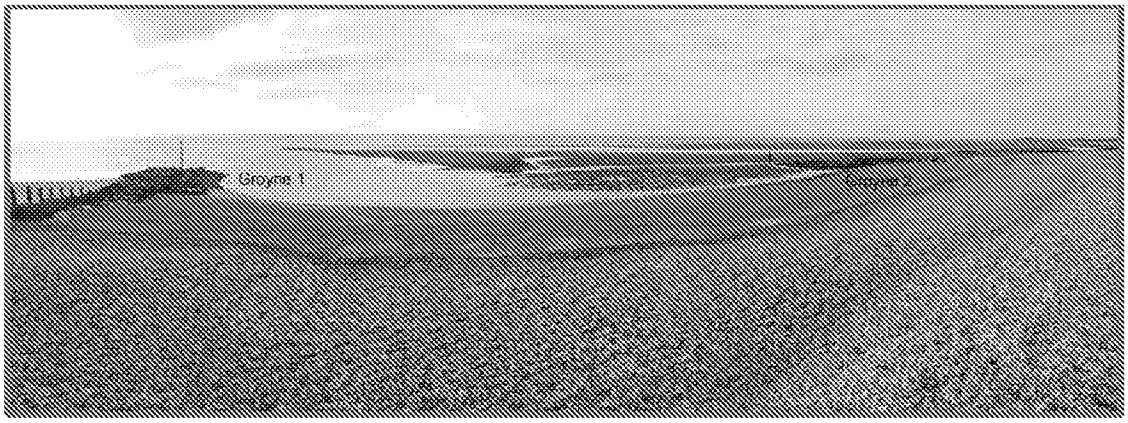
As described above, the developing ebb delta position provides an early indication of the location to which the spit will move. Currently, there is no expectation that the shingle will

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19 In 2011 there was an overtopping event on the spit (due to the possible due to drawdown of sediment) which could have presaged a future breach formation but in the subsequent summer the spit was then raised in elevation. Currently, there is no expectation that the spit will breach naturally within the medium term (within next decade) and were it to do so there is no guarantee as to its location or the level of benefit to Pagham Beach in terms of improved shingle supply.

ARUN DISTRICT COUNCIL P/93/15/PL

begin to bypass the ebb delta and begin to resupply the beach to the east. Therefore, the problems of ongoing down-drift shingle starvation are expected to continue and may accelerate as beach volumes deplete.



(Source: ABPmer, 22 May 2015)

Image 6.18 Pagham foreshore showing area of accretion between Groynes 1 and 2

6.3 Impact Assessment

6.3.1 Impact Pathway 1: Effects of Changing Spit Morphology on Coastal Processes

6.3.1.1 Introduction

As described previously, the proposed project is 'soft engineering' initiative (i.e. considerate to working with natural processes and aiming to achieve coastal protection and other benefits). It is designed to adjust the morphology of the shoreline and work with, but not then interrupt, the coastal processes acting along the front of the harbour and across the beach. After implementation, natural processes will, therefore, continue being the dominant forcing factor on the coast but recommencing from a new shoreline configuration rather that the existing one. This new configuration seeks to mimic what would happen in the event of natural breach of the spit while deliberately placing it in the most suitable position (at the northern end of the harbour) in a location that the harbour inlet occupied some 10 years ago and throughout much of the latter half of the 20th century.

As natural processes will continue to be the primary forcing influence, the way in which the foreshore fully evolves after the breach has been excavated will, inherently, be subject to a number of uncertainties (although remaining within an envelope of possible outcomes). These uncertainties relate to the speed of change and the rate at which the separated end of the spit will decline on the Pagham side and the rate and extent of new spit formation at the Church Norton side. However, the envelope of possible outcomes likely to occur from the breach, and then naturally thereafter, would be within the very broad range of different coastal morphology morphologies that have been experienced at the site historically (see Figures 6.2 and 6.3).

Although there are inherent uncertainties about future change, a high level of confidence exists about the broad character of the changes and the benefits arising. In particular that there will be a rapid cessation of tidal erosion pressure to the eastern part of Pagham Beach and the

ARUN DISTRICT COUNCIL P/93/15/PL

transport of larger volumes of shingle into the down-drift beach as the separated part of the spit and ebb delta integrates into the shoreline.

In a national context this project is considered to be a comparatively novel (and also foresighted) undertaking to meet particular local issues in the context of the site-specific process acting on this shoreline[20]. It is designed to meet both present immediate needs, and anticipated future requirements over the short, medium and long term. This section reviews the changes that are expected to take place after the breach to inform other aspects of this EIA.

6.3.1.2 Post breach changes to existing spit features

Once the breach has been introduced and the former tidal channel infilled with excavated shingle, the new morphology will be relatively novel initially with technically two spits being present, each extending in a north-easterly direction. This is simply illustrated in Image 6.19 which shows the before and after shoreline morphologies as used within the numeral modelling work (ABPmer, 2015c, Appendix A).

Within a relatively short space of time (weeks/months depending on south-east wave activity) after the breaching however, the separated end of the spit (on the Pagham side) and its fronting ebb delta are expected to increasingly grade into the Pagham Beach foreshore. This will occur relatively rapidly because there will no longer be a significant flow pathway along the existing inlet channel[21]. This will remove the high erosional pressure along the western beach frontage and will ultimately stop the development of this part of the ebb tidal delta, thus freeing up this material for ongoing transport also.

As the separated 'Pagham side' of the spit then winnows into, and integrates with, Pagham Beach there will be a return to a condition with essentially two facing spit features on either side of an inlet directly fronting Pagham Harbour (i.e. a "double spit" system). However, for a few years the spit on the Pagham side will include a new lagoonal feature (i.e. the existing tidal channel but with tidal exchange stopped at the western harbour entrance side due to the intervention and with much reduced tidal exchange on its eastern, Pagham side).

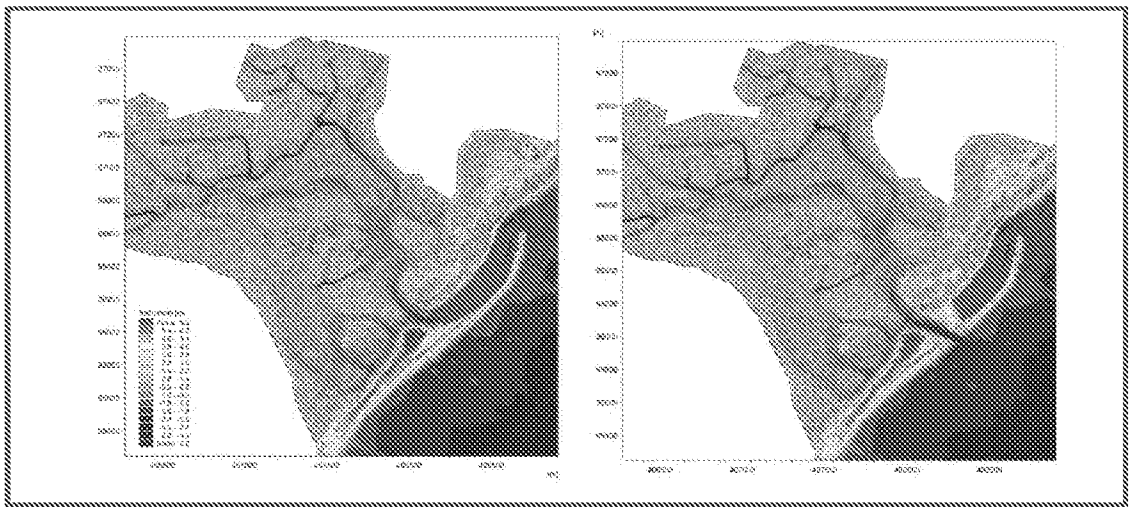
It is notable that the existing 'Little Lagoon' at the end of Pagham Spit formed following the deliberate 1937 breach and closure of the inlet on the Pagham side of the harbour. The later installation of the training wall in 1963 then helped stabilise the end of Pagham Spit so that this lagoon remains in place today (see Figure 6.3).

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20 It is also novel in the context of local history when it is borne in mind that many of the past and present influences acting on this shoreline, as with many other locations, are a function of man-made interventions (i.e. hard engineering) to try and fix the shoreline in place (including through breach closure (1876), historic land reclamation, breach relocation (1937), training wall installations at two different inlets, shingle recharge, groyne installation and rock revetment work).

21 This process may also be facilitated by the fact that a small 'causeway' of shingle may have to be introduced at the distal end of the spit to allow plant to initially access the site for the works (see Section 3.2.1) albeit that much of a good proportion shingle is likely to be exported during the subsequent excavation period and before the channel is closed.

ARUN DISTRICT COUNCIL P/93/15/PL



(Source: ABPmer, 2015c)

Image 6.19 Indicative description of the shoreline morphologies before and after breach (based on bathymetry used for numerical modelling work)

Over a longer time (probably 2 to 3 years), this conversion of the strong flowing tidal channel to a slower flowing lagoon will allow the fronting section of the spit and the ebb delta in this location to increasingly migrate shoreward. The main changes will occur during periods of high wave activity (from the south-west) during the winter months which will push available material within the separated end of the spit landwards towards the beach as well as driving littoral drift across the front of the severed spit into the beach to the east. Over these first few years, therefore, there will also be a gradual narrowing of the lagoon as the separated spit is likely to relax to landwards.

6.3.1.3 Short term breach and ebb delta evolution

After excavation, the breach will also undergo intentional morphological changes initially (i.e. over a few weeks and within around two months) in order to adjust to the new flow regime. The precise nature of this adjustment will be dependent upon the localised flow regime but is expected to involve local deepening of the channel base during periods of strong (spring tide) flows. This is in keeping with breaches in some managed realignments which have a high water exchange relative to their designed breach sizes. In such a condition, erosion stress is typically placed on the central section causing local channel deepening to occur (Symonds, 2006, Nikolaou 2012).

The deepening of the excavated breach would also be in keeping with the morphology of the existing inlet where slightly greater depths (lower than -2 mODN) are experienced due to the higher flows speeds. There is also anticipated to be an anti-clockwise turn in its alignment of the newly introduced channel in response to the pattern of flows emanating from the harbour (and influenced by the curvature of the harbour channel and the presence of the inner training wall).

The new breach and inlet channel would then result in the maturing of an ebb delta seaward of the new inlet position (over the short term) which will continue to grow with time (over the medium to long months/years). Following an inlet stability assessment (see Section 7.1 of the

ARUN DISTRICT COUNCIL P/93/25/PL

Breach Design report (ABPmer, 2015c) in Appendix A) it was concluded that the breach is likely to remain stable especially under typical littoral drift conditions of around 20,000 m³/year (the typical rate for this coastline has been identified as 15,000 to 20,000 m³/year in this assessment and is in keeping with past studies). However, there will clearly be self-adjustment of the breach shape after it has been excavated.

6.3.1.4 Medium/long term evolution of down-drift Pagham Spit and Delta

Over the medium to long term the evolution of the shoreline morphology will be a function of various factors including, especially, the frequency, severity and nature of storm events. The spit on the Pagham side will gradually decline in size as shingle is transported into Pagham Beach. The rate at which it will do this is not known precisely and will be strongly influenced by climatic conditions. However, the eastern end of the spit that would be separated by the proposed breach holds up to 230,000 m³ of material (a local store) above the 0 m ODN level (from GIS analysis of the topographic survey data from 27 January 2015). Given that the rate of longshore shingle transport is typically around 15-20,000 m³/year then, in simple terms, it is likely to take 8 to 12 years for this feature to disperse on this evidence alone. In the unlikely event that rates of longshore shingle transport were to remain consistent, and atypically, high (at 40,000 m³/year) then this period of spit dispersion might reduce to 5 years.

Although, the net trend is likely to be one of wave-dominated northerly transport leading to this separated section of the spit gradually feeding the beach in this manner, in reality, the process of shingle re-supply to the beach will be more complex than a simple reduction in the volume of the spit over time through progressive longshore transport. There are likely to be local physical influences on the pattern of sediment movement from the maturation of the ebb delta in front of the new inlet position.

Also the volume of available shingle is not just in the spit feature. While the exposed spit is expected to be more mobile than the underlying platform on which it is lying, there is also a large volume of sediment locked within this platform and in the ebb delta fronting this section of the spit (i.e. in front of the inlet in its current location) that needs to be considered. Much of this volume of material is expected to move into the beach and contribute to beach growth and also leave the separated spit more exposed and then help to accelerate shingle transport and its decline. The process of ebb delta migration into the beach is one that would mirror what happened after the breach closure in 1876 which ultimately prompted the formation of the existing Pagham Beach (Royal Haskoning, 2009).

To further examine the issue of how the separated end of the spit might decline and at what rate an ASMITA model (Stive et al., 1998) was used to describe the fluxes of sediment along the Pagham Harbour and Pagham Beach foreshore areas. ASMITA modelling is used to understand the long term behaviour of estuaries and tidal inlets. ASMITA considers the long term balance between morphological units but also introduces various assumptions and simplifications to do this.

The model was developed by dividing the shoreline into sections and inputting details for each section about the tidal flats, channel, spit and delta morphology as well as the shoreface profiles (see Image 6.20). The model was then used to evaluate how changes to the

ARUN DISTRICT COUNCIL P/93/15/PL

morphology in one coastal section could have implications for others and was used to make projections about future morphological evolution.

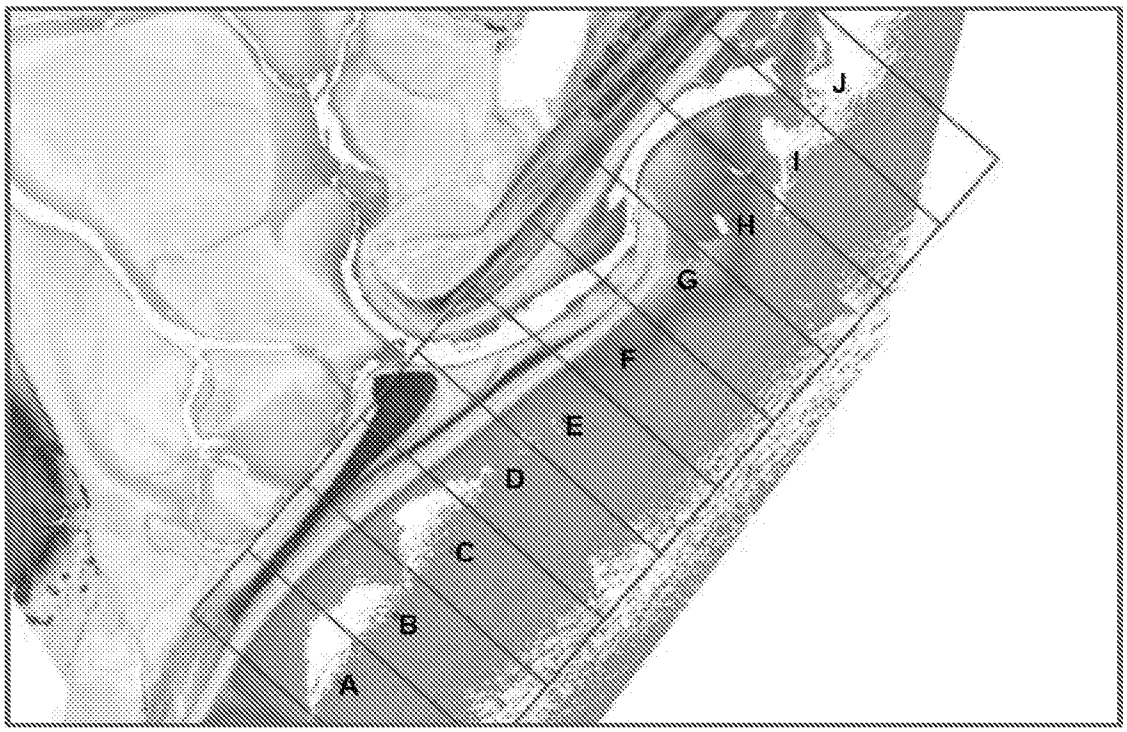


Image 6.20 Coastal sections used for the ASMITA analysis

To further examine the issue of how the separated end of the spit might decline and at what rate, an ASMITA model (Stive et al., 1998) was used to describe the fluxes of sediment along the Pagham Harbour and Pagham Beach foreshore areas. This modelling work was undertaken to complement the findings from the other conceptual review and short-term modelling work. In particular, ASMITA was developed to examine the longer term behaviours of the primary morphological features and examine the sensitivities that exist in terms of the physical linkages between these features.

ASMITA modelling is used to understand the long-term behaviour of estuaries and tidal inlets. ASMITA considers the long-term balance between morphological units but also introduces various assumptions and simplifications to do this. The model was developed by dividing the shoreline into sections and inputting details for each section about the tidal flats, channel, spit and delta morphology as well as the shoreface profiles (see Image 6.20). The model was then used to evaluate how changes to the morphology in one coastal section could have implications for others and was used to try and make projections about future morphological evolution.

The ASMITA model proved to be effective at representing the existing environment and the historical changes that have taken place in recent years. However, when using it to make future projections about the conditions after the breach it proved to be very sensitive to the criteria that were included for spit volumes and shingle drift which meant that the results do not provide projections that are more realistic those presented previously. This sensitivity in the

ARUN DISTRICT COUNCIL P/93/25/PL

model will be due to the complexity of representing (in a modelled environment) interactions between the spit/delta formation and degradation processes. As one example, the model probably does not readily represent the role that the ebb delta in front of the new inlet location will play in providing wave protection to the down-drift spit on the Pagham side. This function will help slow the rate at which the spit's decline will occur.

The outputs of the ASMITA modelling do however indicate that the separated (relict) spit could be removed by the prevailing littoral drift in a few years (it predicts it to occur faster than the 8 to 12 years cited above but without considering the role of the ebb delta as noted above). The model then suggests that the Church Norton Spit will reform (as described further in Section 6.3.1.5) and develop in a manner similar to the recent spit development. The timescale for an advance to a condition similar to the present day is some 20 years or more (this is somewhat slower than the 10-15 years cited in the following section). The model has therefore helped to verify the predictions made above about how the separated Pagham spit will decline and how the Church Norton Spit is likely to regrow (albeit that the timescales for these processes are uncertain within this model).

6.3.1.5 Medium/long term evolution of up-drift Church Norton Spit

The rate at which the spit on the Pagham side declines and the speed with which a new ebb delta matures in front of the new inlet will influence how, where and when the Church Norton spit will reform. If, as expected, the removal of shingle from the (separated) Pagham Spit is a gradual process that takes around a decade, then any spit formation at the Church Norton side will take an equivalent number of years thereafter.

Under this scenario, any spit formation at Church Norton during the initial years would only be able to occur seawards (over a platform made by the maturing ebb delta in front of the new inlet). Such an offshore movement into deeper water will require much greater volumes of shingle (than for the spit on its present alignment), that will probably need to be delivered over longer periods of time, to fill the accommodation space (i.e. water depth) and allow the spit to form and then, over time, to prograde.

If an extended Church Norton spit did prograde to seaward in this manner then it is likely to follow a very similar shore parallel path to that taken by the spit from 2001 to 2015. It could then effectively overlap the Pagham Spit. Under this circumstance the material on the shore side (in the Pagham Spit) will then only be moved back to the beach, possibly more rapidly, by the effects of the tidal inlet channel between the two spits. A tidal channel erosion of the Pagham Spit would then mimic the effects that the tidal channel has had on Pagham Beach over the last few years. In this overlapping configuration, there will no wave-induced transport along Pagham Spit because the extending Church Norton Spit would be providing a local wave shielding effect to the adjacent downdrift beach.

Based upon the time taken for the existing spit to have grown, it is assumed that it would take around 10 years or more for it to approach it current size. The rate and pattern of the spit's growth would be closely linked to the rate pattern of ebb delta maturation as that is needed to form the platform on which the prograding spit develops.

ARUN DISTRICT COUNCIL P/93/25/PL

If the spit on the Pagham side (the northern section separated by the managed breach) declines more rapidly than the predicted 8 to 12 years, any spit formation at the Church Norton side will probably follow the existing spit alignment. This would, therefore, lead to a progressive north-easterly migration of the breach and a replication of the condition that has been seen over the last 10 years.

Under either of these two spit decline and regrowth scenarios it is assumed that a new spit will reform in around 10-15 years following the breach. This would be similar to the development that has been seen over the last 12 years and comparable with the rapid rates of north-easterly spit progradation that has been recorded historically.

6.3.1.6 Breach closure changes

It is recognised that a small residual risk exists that the new breach will close at some time in the future which would alter the pattern of morphological change from the range described above. However, following such a process there will be a continued process of uninterrupted north-easterly littoral drift and an expectation that a natural breach will reform within a few years at most. That said, a high level of confidence exists that such a closure will not occur and that the risk is lower with the managed breach than with the existing condition. In large part this confidence is provided by the fact that the inlet has not closed naturally in the past; even in the last 10-15 years when there have been such dynamic changes and interactions with the groyne structures. Also it is proposed, as a contingency, that one intervention is included to allow for a re-opening if required. Such a re-opening may well be easier at the proposed managed breach site than at the existing inlet location.

The new breach/inlet would be at greatest risk of closure if there was large flux of sediment into the site. This is most likely to occur if a large spur moves into the inlet, particularly if it does so over a short period of time during winter (stormy period) and neap tides. The nearest large spur is 750 m away and this is likely to would reach the breach location in over 40 years based upon its current rate of movement (i.e. around 18 m/year).

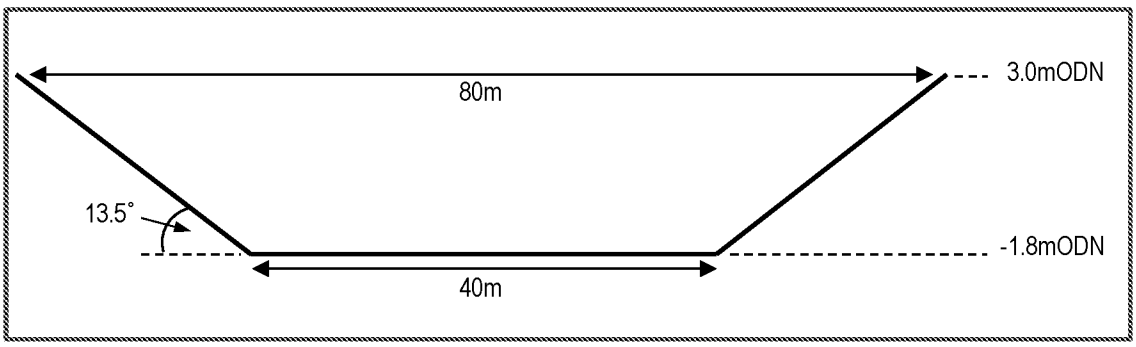
6.3.2 Impact Pathway 2: Effects of Changing Spit Morphology on Hydrodynamic Regime in Pagham Harbour

6.3.2.1 Introduction

Following the proposed breach, there will be a change to the location, direction and size of the harbour's inlet channel. This will cause localised changes to the hydrodynamic conditions in areas that lie immediately inside and outside Pagham Harbour in the vicinity of the new breach. There will also be changes in the west and central Pagham Beach areas where the strong tidal flows currently being experienced will be reduced.

To understand the hydrodynamic changes that will arise from the proposed scheme a Mike 21 FM numerical modelling exercise was undertaken. This was initially run to describe the existing conditions within the harbour and the adjacent coast (see Section 6.2.3) and to then compare these conditions against those that are likely to occur in the future once a breach is introduced. A schematic design of the breach that was used within the model is shown in Image 6.21.

ARUN DISTRICT COUNCIL P/93/25/PL



(Source ABPmer, 2015c, see Appendix A)

Image 6.21 Indicative preferred/proposed breach design (not to scale)

The results of this modelling work were previously outlined in the preceding Breach Design Report (ABPmer 2015c; as presented in Appendix A) and these have been further reviewed and analysed in this section. The key graphic outputs from this work, which compares the pre-scheme and post-scheme condition, are presented within the following locations:

- Figures 5 and 6 in the Breach Design Report (see Appendix A of this ES);
- Figures A1 to A3 in Appendix A of the Breach Design Report (see Appendix A of this ES); and
- In the text below as Images 6.22 to 6.25.

The following sections describe the changes to flow speeds (Section 6.3.2.2), sediment changes at the breach (Section 6.3.2.3) and water levels (Section 6.3.2.4), as informed by this modelling work.

6.3.2.2 Flow speeds

As a result of the proposed change to the harbour inlet position, flow speeds in the immediate nearshore area fronting the new breach location will increase. Peak depth-averaged flows on a mean spring tide in this nearshore area currently reach around 0.35 m/s and are predicted to reach levels of approximately 0.8 and 2.0 m/s on the flood and ebb tide, respectively, thus indicating tidal asymmetry with a strong ebb dominance (see data for Point 1, Figure 6 in Appendix A). Additionally, because of the inlet change, a location that is now essentially coastal (Point 1, Figure 6 in Appendix A) will revert to having distinctive flood and ebb tidal signals (similar to an estuarine/harbour environment) because the harbour will again flood and drain across this area.

These changes in the hydrodynamic conditions that occur of the new inlet position then diminish seawards away from the harbour. The maximum extent of any measureable flow speed change outside the harbour (i.e. above 0.1 m/s) is not expected to occur further than 650 m from the breach. The changes are also expected to also be largest during the period when the breach adjusts and before it deepens (as is expected).

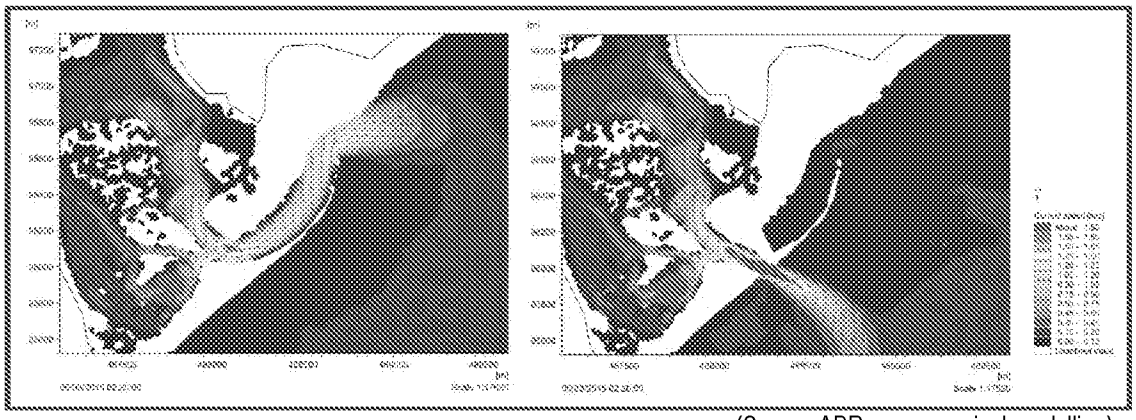
After the breach self-adjustment period, flow speeds are then likely to reduce in this nearshore location although there may well also be periods of breach narrowing and widening (influenced by climate, littoral drift and tidal variability) leading to cycles of change subsequently around this equilibrium. Furthermore, as an ebb tidal delta develops in front of the new harbour mouth

ARUN DISTRICT COUNCIL P/93/15/PL

the flow patterns are likely to become more strongly influenced by the shape of the tidal channels (or along multiple channels) forming through this delta

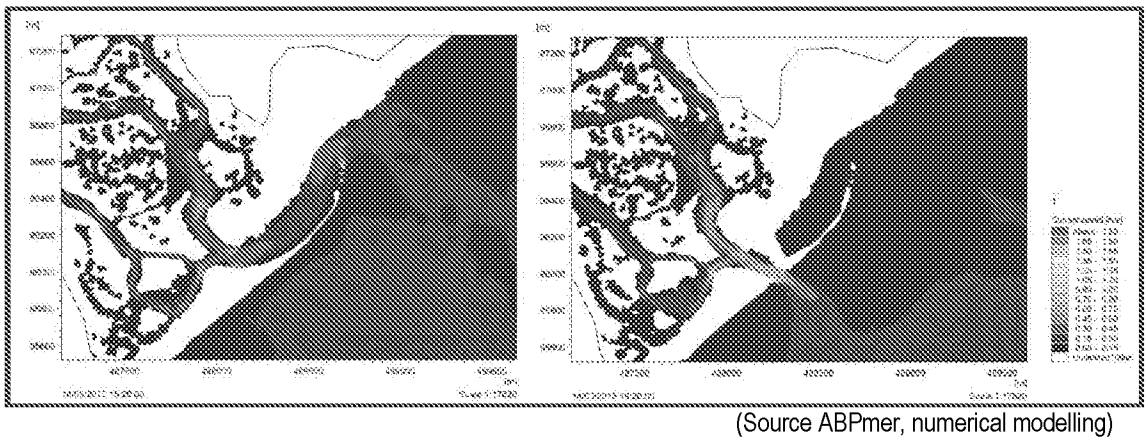
In contrast to the strong spring tidal currents, the depth-averaged neap flow speeds at this nearshore location are not predicted to exceed 0.4 m/s on either the flood or ebb tide (cf. Images 6.22 and 6.23). Due to the lower tidal volumes and reduced flow speeds on a neap tide, any nearshore changes to the hydrodynamic conditions will be more localised to the inlet outflow area (within around 100 m). Also under neap conditions there expected to be little sign of any tidal asymmetry (in respect to both time and speed) based on the modelling work.

Within the centre of the newly introduced breach there is expected to be strongest depth-average flows of 1.75 and 2.3 m/s on the flood and ebb spring tide (again with a clear and strong ebb dominance (see Image 6.22 and the data for Point 2, Figure 6 in Appendix A). The model results further indicate that this ebb dominance is increased in a seaward direction along the breach channel, whilst across the width of the breach channel, flow speeds are considerably reduced over the side slopes. Over neap tides, flow speeds through the centre of the breach channel are typically no greater than 0.7 m/s, with no distinct flood or ebb tidal dominance (see Point 2, Image 6.24).



(Source ABPmer, numerical modelling)

Image 6.22 Spring tide ebb flow speeds at 2 hours after high water before and after scheme implementation (breach as per schematic in Image 6.21)



(Source ABPmer, numerical modelling)

Image 6.23 Neap tide ebb flow speeds at 2 hours after high water before and after scheme implementation (breach as per schematic in Image 6.21)

ARUN DISTRICT COUNCIL P/93/25/PL

Inside Pagham Harbour, the model results for Points 3 to 7 (see Image 6.24 and Figure 6 in Appendix A) illustrate that the proposed breach design will result in only small changes to local flow speeds, compared to the baseline scenario. The changes identified are largely attributed to a small 'phasing difference'[22] in the tide across the harbour and are predominantly characterised by slight reductions on both the flood and ebb tide, with these changes decreasing away from the harbour entrance (largely becoming negligible). The modelling tends to indicate that there is change to tidal asymmetry along the internal channels and across the intertidal areas within the harbour.

At Point 3 (which lies just inside the harbour behind the proposed new breach and near to the training wall) the spring tide flows through the area of the inlet will be slightly stronger than those experienced in the present condition (see Images 6.22 and 6.24). They will also be higher than the baseline levels throughout the duration of the ebbing tide (see data for Point 3 in Image 6.24). This difference from the baseline will be a function of the relatively narrow and shallower breach when compared to the existing channel which will be constraining the spring tides.

Over a short period of time (days/weeks) the breach is expected to adjust and deepen such that flows would be expected to return to speeds experienced at baseline (with subsequent variations about this equilibrium as noted above). A morphological response (channel deepening) may also occur at Point 3. At Point 3 there is also expected to be a reductions to the low water levels as a function of marginally better drainage of the harbour after the breach is introduced (this is described in Section 6.3.2.4).

The neap flow speeds in the area of the inlet (i.e. around Point 3) are not predicted to change greatly from those experienced under baseline conditions (as they will be constrained by the breach in the same way as the larger spring tides). They do not exceed 0.5 m/s on either the flood or ebb tide and as with the baseline condition there is little sign of tidal dominance; in respect to both time and speed (see Images 6.23 and 6.24). These typical neap flows are expected to reduce after breach has self-adjusted.

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22 This refers to slight differences in the timing of the flooding and ebbing tide between the baseline and post-breach conditions which then leads to differences in flow being indicated when the before and after scenarios are compared for the same moment of the tidal cycle.

ARUN DISTRICT COUNCIL P/93/25/PL

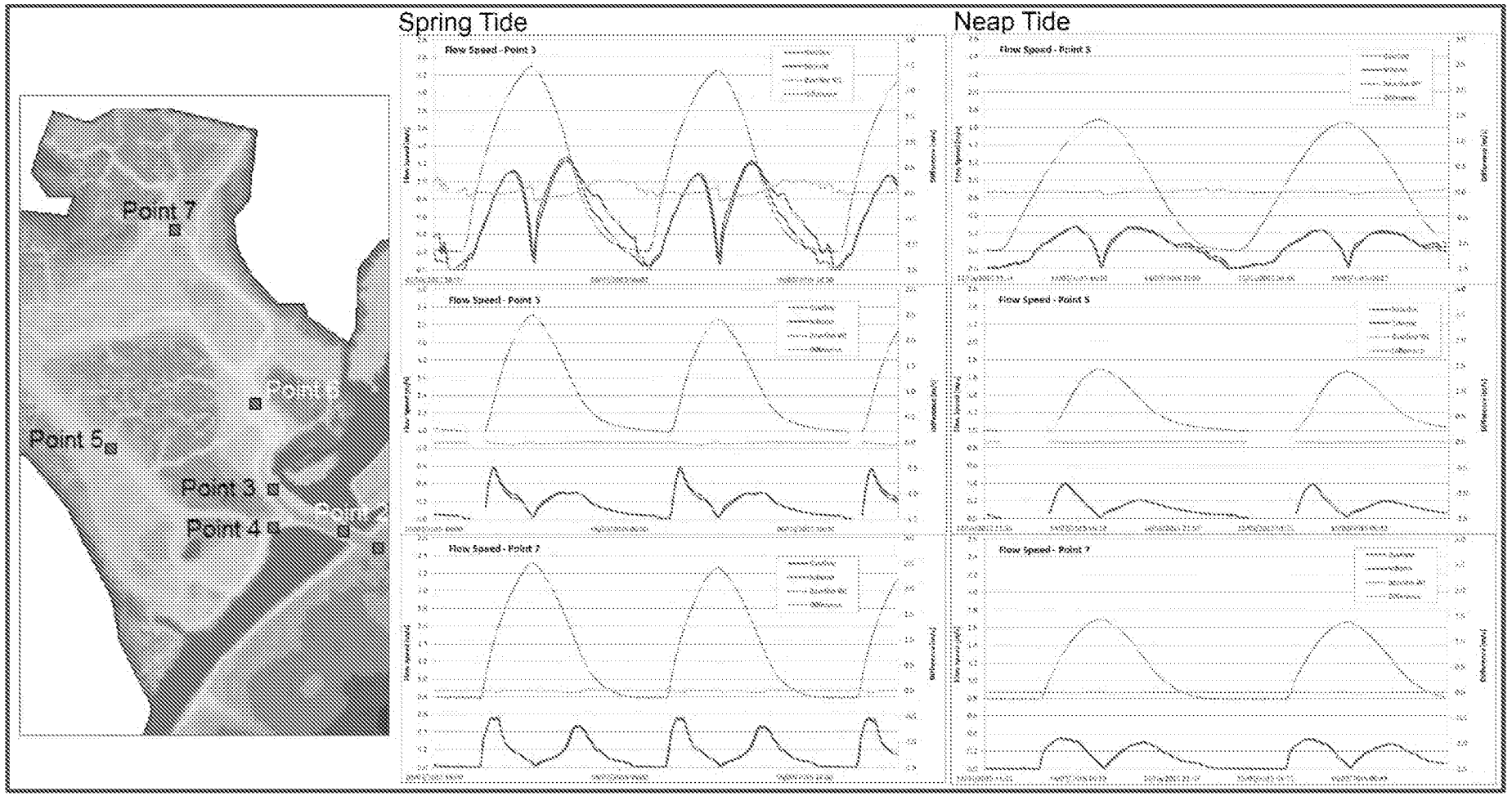


Image 6.24 Time Series plots of flow speeds at 3 points within the harbour before and after scheme implementation (breach as per schematic in Image 6.21)

ARUN DISTRICT COUNCIL P/93/25/PL

6.3.2.3 Sediment changes at breach

The strong flows that will occur within the breach on a spring tide particularly will have an effect on sediment transport in a manner that is equivalent to conditions observed historically at Pagham Harbour inlets. The bed shear stresses resulting from these tidal currents will be sufficiently high to mobilise a range of sediment material types.

The preceding reviews of the flow speeds that will be experienced after the project is implemented, indicates that there is potential for some movement of sand and fine gravel over the flood tide (i.e. into the harbour). However, much of this will be deposited within the breach channel itself or within the internal channel (adjacent to the training wall). This material would then be subject to flushing over the ebb tide, feeding the ebb tidal delta. By contrast, the mobilisation of medium to very coarse gravel fractions will largely be limited to the ebb tide, when flow speeds are greatest. Lower mobility (sediment transport) is also expected across the slopes of the breach channel; thus reducing the likelihood for slope erosion and instability.

Over neap tides, flow speeds through the centre of the breach channel are typically no greater than 0.7 m/s, with no distinct flood or ebb tidal dominance. These reductions in flow through the breach illustrate that sediment mobility, particularly of coarser material (i.e. gravels), will be largely restricted to spring tides.

6.3.2.4 Water levels

After the introduction of the breach, water levels in the nearshore region, seaward of the proposed harbour inlet are not expected to be noticeably affected through the tidal cycle. However, the water draining from the harbour will affect the timing and pattern of the low water levels in this area. Also, the morphology of the environment in front of the breach will be changed through the formation of the ebb delta and local ebb-delta channels. These will visibly influence the timing and spatial pattern of flows at low water.

Within Pagham Harbour there are expected to some minor changes in water levels. During the initial period of breach adjustment there is likely to be a small reduction in high water levels across the harbour, and in the order of 0.05 to 0.06 m (5 to 6 cm) over a mean spring tide (see Image 6.25), but by less than 0.02 m (2 cm) over neap tides. Once the breach has adjusted and enlarged to a new equilibrium these small reductions are not expected to persist, and the high waters are expected to return to baseline conditions. Hence, the small changes on high waters are considered to be short-term and temporary.

As the breach will shorten the inlet channel, the area which used to store water at low tides will no longer influence and hold up low waters on a spring tide at the seaward end of the harbour, and this local area will be able to drain more efficiently. This local reduction is illustrated in Image 6.25 which indicates that at Point 3 (just inside the new inlet) the low water on a spring tide would drop to -1.4 m ODN compared to – 1.1 m ODN under the baseline condition, a change of around 0.30 m. A marginal reduction in the neap low water levels is also indicated for this local area by the modelling. Whilst this effect is only local to the seaward part of the harbour it is likely to last for the longer-term.

ARUN DISTRICT COUNCIL P/93/25/PL

The consideration of a surge tide shows that peak water levels within the harbour have a minor reduction during the period of self-adjustment in breach dimensions, but thereafter the flood risk levels remain unchanged.

The initial self-adjustment of the breach to a new morphological equilibrium is expected to be achieved over the course of a few spring tidal cycles. Any subsequent natural readjustment of the breach and inlet channel is likely to either increase (if the breach widened/deepened to a greater degree) or decrease high water (if it narrowed). Such changes will be in keeping with the range of conditions experienced previously (given the range of morphologies that previously existed at the site) and will continue to be an inherent function of the natural dynamic in the future.

ARUN DISTRICT COUNCIL P/93/25/PL

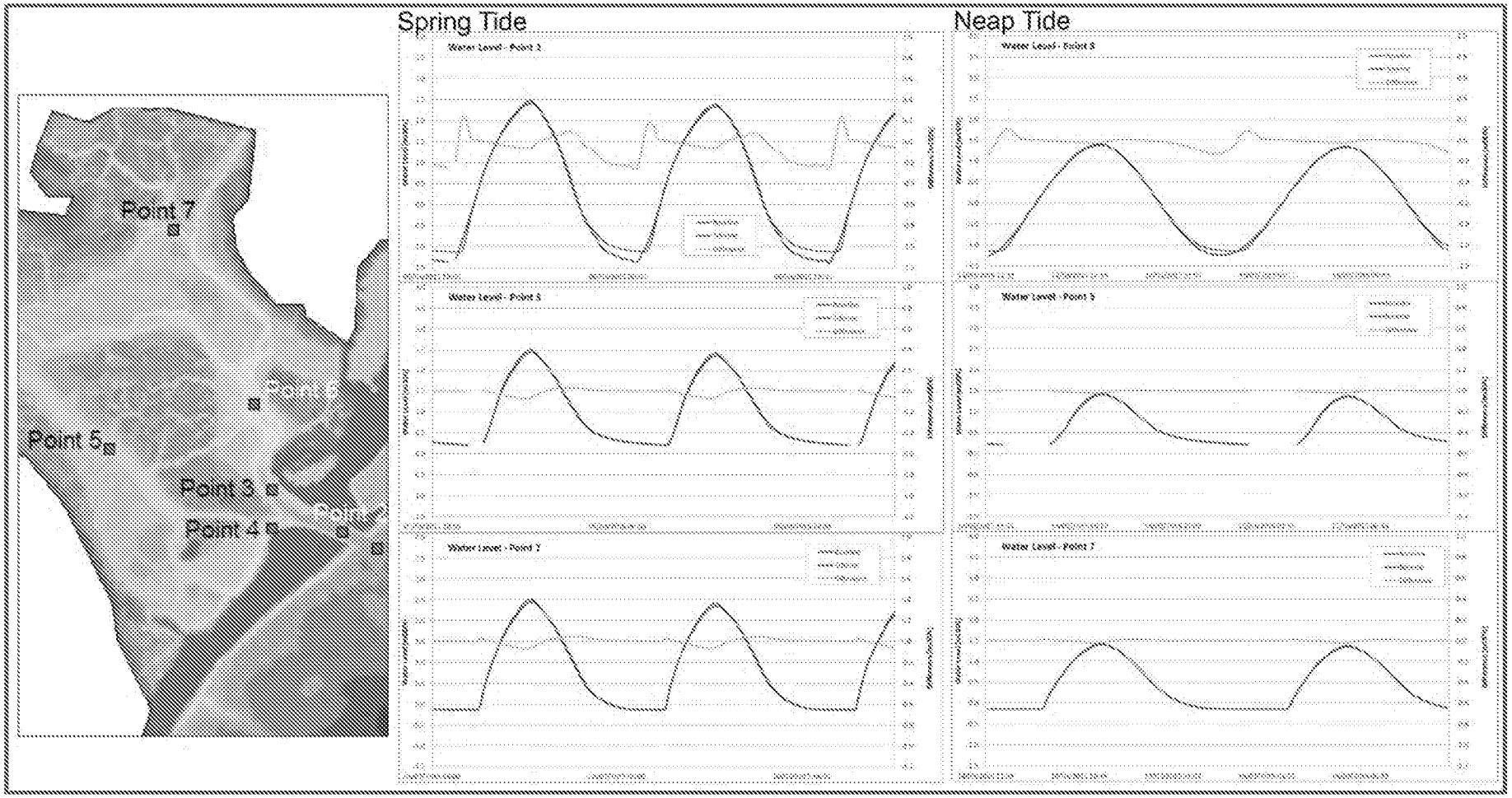


Image 6.25 Time Series plots of water levels at 3 points within the harbour before and after scheme implementation (breach as per schematic in Image 6.21)

ARUN DISTRICT COUNCIL P/93/25/PL

6.3.3 Impact Pathway 3: Effects Of, and Need For, Breach Maintenance

The proposed breach has been deliberately designed so that it works with natural processes (e.g. with no training wall being introduced) to achieve a sustainable solution. Once created, the breach will be allowed to self-adjust and the coastal regime allowed to function in as natural a way as possible. This principle is fundamental to the project's design and rationale, not just because of the need to be sensitive to the natural environment but because to do otherwise is likely to cause shoreline management problems in the longer-term. In particular, the introduction of a training wall might have improved the potential stability of the breach but would probably also have stopped future longshore drift which could cause future problems especially for Pagham Beach under conditions of reduced shingle supply (ABPmer 2014).

The breach has also been positioned/designed to maximise the likelihood of it being self-maintaining, and to minimise the requirement for future intervention (e.g. to address a breach closure). One way of making it as stable as possible in such a dynamic environment (e.g. recognising that the surround spits will be changing/evolving) involved placing it in a location where it can make use of the existing Pagham Spit training wall. This wall was introduced in 1963 after which it helped to maintain a relatively stable breach position for four decades (with the assistance of annual NRA/Environment Agency maintenance through the 1990s) as described in (Section 6.2.6.1). The location chosen is also where the inlet 'gravitated to' during the middle of the last century having initially been opened up on the south side of the harbour in 1937. Further details about the reason for the selection of this position and the design of the breach are set out in the Breach Design Report (ABPmer 2015c; see Appendix A).

Other factors will also help to ensure that the breach can remain stable, including, changing the tidal inlet morphology to a shortened, straightened channel that will allow for greater and more efficient drainage. As described in the preceding section, this new configuration will also allow for more efficient hydraulic tidal exchange and lower volumes of tidal water storage in the harbour at low water. This will also modestly increase the tidal prism volumes.

Following the work undertaken to develop the breach design and on the balance of the evidence and the Inlet Stability Analysis carried out, there can be high level of confidence that the breach will be relatively stable and will not close up. It will be most stable during periods with typical longshore shingle drift rates (i.e. 15,000 to 20,000 m^3/year as discussed in Section 6.2.5.2) but is expected to be less stable during periods of larger drift events when volumes of 40,000 m^3 are observed (like those seen in 2013 and 2014). It will be most susceptible to large fluxes of sediment especially where occurring over short durations during neap tide periods.

Periods of high transport would occur in the future if a sequence of severe storms were experienced (as seen during to the 2013/14 winter period). High rates of shingle transport might also occur at a time when one of the spur features moves into the path of the breach. This might influence the breach not necessarily because of the volume of shingle within it but because it could be a conduit for the focused delivery of greater volumes of shingle from offshore sources (see Section 6.2.2) to the location of the breach (i.e. act as a local trap for additional material).

ARUN DISTRICT COUNCIL P/93/15/PL

The highest confidence that the breach will not close comes from the fact that it has not done so naturally in the past and certainly not over the course of 20th century. Yet, its risk of closing up should have increased over the last 100 years due to the harbour having a lower tidal prism as a consequence of historic land reclamations. That risk of closing has also been especially high over the last few years as the tidal inlet has been pushed up close against the Pagham shoreline and had to work around and ultimately through a solid rock groyne structure (Groyne 4). In early 2015 the channel also put erosive pressure on Groyne 3 leading to a requirement for that structure to be reinforced.

As noted above and within the breach stability work (ABPmer 2015c, Appendix A) the stability of the breach will be highest during spring tide periods. A comparable conclusion was reached following a previous Inlet Stability Analysis by Royal Haskoning (2009). That study also noted that there was a sensitivity to the rates of longshore drift and concluded that the breach was of a low stability in general. However, recent experience has shown that despite the substantial increases in drift rates that have occurred since 2009 (allied to the more complex interactions that have taken place around Pagham Beach, the new revetment and the groyne bays) there has still not been a breach closure.

It is recognised that when the breach is made it will be slightly shallower than the existing breach morphology and will have a predominantly shingle base. This may well make the introduced breach less stable than the existing tidal inlet in the immediate period after the excavation. However, the breach has been designed so that it will then be allowed to self-adjust (deepen into the bed) such that shortly after the excavation (within a few weeks and one or two spring tide periods) it is expected to naturally achieve a more stable configuration than the existing tidal inlet.

Therefore it is concluded that the risk of the introduced breach closing is low and it is not proposed or advised that there is a regular campaign of maintained work at this site. However, regular monitoring is recommended to verify that the breach continues to develop within the expected envelope. The breach will of course change as the spit features on either side of it also change and this natural alteration is an inherent part of the proposal. An indicative description of the changes and the timelines over which they might occur was presented in Section 6.3.1.

For these reasons, maintenance work should not be required and ideally should be avoided (in order to preserve naturalness in the system and also manage cost). However, it is recommended the allowance is made for one future dredging/excavation to be undertaken at the entrance of the inlet (end of the Church Norton Spit) to assist with maintaining a level of breach stability. This intervention is likely to be required if the breach closes during periods of high littoral transport and it will be important that monitoring is undertaken to anticipate the need for such an intervention.

Such a measure should seek to work with natural process as they are acting on the system rather than to seek to preserve a fixed breach position through hard engineering options. In other words, consideration will have to be given to whether and how the breach shape might be changing and to adjust the breach according to that 'natural' configuration.

ARUN DISTRICT COUNCIL P/93/15/PL

The inclusion of only one proposed future management measure does leave a residual risk of breach closure. However, this risk is considered to be very low in the context of the available evidence. It is also recognised that, should closure occur, a natural breach will then take place in time. Such a natural reopening would be expected within the space of weeks/months or, if not, perhaps a few years at most, given past experience at this site.

6.3.4 Impact Pathway 4: Effects on Tidal, Wave and Sedimentary Dynamics in Pagham Harbour

The effects on the hydrodynamic regime within Pagham Harbour were considered under 'Impact Pathways 2' (Section 6.3.2). It was concluded that such effects were small in scale and localised. They included slightly improved drainage of the harbour at low water and also adjustments to the high water levels that relate to the breach shape and width and are expected to be within the range of historical and contemporary changes. In the context of these changes and likely future evolution of the breach, delta and spit features (see Section 6.3.1) potential changes to wave activity and sedimentation are given further consideration here.

The spit features which front Pagham Harbour play an important role in reducing wave activity. There is no indication from the evidence available that these spit feature will be substantially reduced by the proposed breach excavation measure. The supplies of shingle into the immediate future appear to be healthy (see Section 6.2.5.1).

The proposed work will introduce a new tidal inlet channel that will lead to greater penetration of wave activity. As the channel alignment faces south-east it will only be exposed to the wind wave energy (around 5-10% of all waves) that arise from this direction. This proportion is likely to be much lower during storm periods when waves are from south-west, as described in Section 6.2.3.3. However, there will be short term risk (weeks/months) of increased wave penetration into the harbour after the project is implemented but before the ebb delta forms and matures in front of the new inlet. During this time waves may enter the inlet and if there were a storm this could cause some erosion in and around the inlet entrance with the width and level of the breach moderating this.

After the breaching an ebb tidal delta will re-establish and further develop in front to the inlet. This development is likely to follow the typical and historically observed patterns because the harbour is expected to remain in an ebb-dominant condition. This ebb delta will then dissipate much of the wave energy across the inshore waters as well as acting to locally shelter a short up-drift section of the frontage. No adverse effects on the wave climate inside the harbour are therefore expected beyond the short term and any changes that occur will be within the scope of historical variability.

The proposed project is not expected to significantly alter the pattern of sedimentation within the harbour. As described in Section 6.2.5.3, sedimentation occurs within the harbour principally from finer sediment derived from marine sources and there is considered to be limited import from the freshwater rife systems that drain into the harbour (Cundy et al., 2002; Royal Haskoning, 2009). Once the excavated breach has undertaken a brief period of self-adjustment (especially an anticipated period of deepening) it will function as per the historical

ARUN DISTRICT COUNCIL P/93/25/PL

inlet shapes at similar locations and will continue to allow sediment ingress from marine sources.

Compared to the existing morphology, the new inlet will be more open to the south-east (rather than the north-east) and therefore be more exposed to onshore wind waves. There will also be a shorter channel length. These features mean that there is technically a potential for more sediment to be introduced to the harbour following the intervention than is currently the case with the existing inlet. This is only theoretical however because there is no evidence to determine whether the current inlet has altered the rate of sediment import from marine sources when compared to the proposed or previous conditions.

The proposal will result in the harbour having a marginally greater tidal prism, and therefore there is the potential for marginally more sediment to be imported. Conversely, with the new shorter tidal inlet in place and improved drainage at low water there is less potential for sediment settlement at low water and a greater likelihood that sediment in the channel will be exported. Overall the scheme is not expected to have a significant effect on the existing rates and patterns of sedimentation within the harbour.

6.3.5 Impact Pathway 5: Effects on Coastal Protection in Pagham Harbour and Along Pagham Beach

6.3.5.1 Introduction

This section considers the coastal protection effects of the proposed managed breach for the Pagham Beach foreshore and for Pagham Harbour. This has been informed by historical reviews of the harbour conditions alongside estimations and predictions of the future evolution of the beach and spit both with and without the proposed project (as presented above). The review of issues within Pagham Harbour has also been informed by the numerical modelling analysis conducted by ABPmer (see Section 6.3.2 and the Breach Design review report in Appendix A) as well as using expert analysis of the evidence and an understanding about the proposed coastal improvement measures that are underway and proposed within the harbour.

Where the benefits provided to Pagham Beach are considered, these are presented in a way which will allow for informed judgments to be made about the flood defence costs and benefits. This is designed to assist with developing funding calculations using the Government's FDGiA (Flood Defence Grant-in-Aid) cost calculations (Defra, 2011). These calculations are based on an understanding of the proposal costs, the number of properties at risk and the duration of the coastal protection benefits that is afforded by the scheme.

It is recognised that these FDGiA cost metrics are often more easily applied to projects that enhance defined sections of sea walls and thus protect discrete coastal areas for definable periods of time. By contrast, the soft-solution approach that is being adopted for this proposal (which is designed to ensure natural processes have a dominant influence on the foreshore) will benefit properties across a relatively large and unconstrained area over varying timescales. Therefore, there are some inherent uncertainties associated with making predictions about the precise duration and scale of coastal protection benefits.

ARUN DISTRICT COUNCIL P/93/25/PL

The FDGiA process can address these uncertainties as long as the predications remain realistic in the context of the available evidence. Therefore, care has been taken to make realistic but not 'high-end' 'over optimistic' estimates of the duration of future benefits (in general a value of around 8 years has been used)) even though the benefits may well extend over a longer period (predictions for the decline of the separated end of the spit are in the region of 8 to 12 years and the benefits of this in terms of sediment supply to Pagham Beach is likely to have value well beyond this timeframe).

The relatively distinct nature of this project, and its coastal protection benefits, will be recognised in the application of any future detailed cost:benefit analysis, along with a consideration of the wider benefits that the project will have for the amenity value of the beach and the economics of the town as described in Section 9.2. The following section considers the key issues that will be relevant for different sections of the Pagham Beach shoreline as well as Pagham Harbour.

6.3.5.2 Pagham Beach (erosion to the south-west of Groyne 3)

Once implemented, the project will have an immediate coastal protection benefit for this south-western section of the beach (see Image 6.26) which has been rapidly eroding in recent years with large scale reductions in beach volumes. This erosion has been evident for the 11 years between 2003 and 2014 (see Image 6.27) and more so for the latest full annual period between February 2013 and 2014 period (see Image 6.16).



(Source: John Akerman, 1 April 2014)

Image 6.26 End of Church Norton Spit and properties behind on a high tide

In this area, the beach crest has substantially narrowed by around 30 m and reduced in elevation including reaching emergency levels that have triggered the coastal defence interventions on the western side. The proposed managed breach of the spit will provide rapid coastal protection benefit here because, once undertaken, there will no longer be strong erosive flows through the tidal channel and this will ease the erosive pressure.

ARUN DISTRICT COUNCIL P/93/25/PL



(Source: SRCMP 2014b)

Image 6.27 Beach volume changes 2013 to 2014 along Pagham Beach (centre and east, 4dSU23)

Following implementation of the proposed managed breach the model predicts local peak flow speeds on a mean spring of 0.30 m/s, whilst neap flows will not exceed 0.15 m/s. These flow speeds will be insufficient to erode gravel sized material; requiring approximately 0.8 m/s and greater (for coarser fractions). As such, the considerable erosion pressure currently placed on the Pagham frontage by the spit and inlet channel will rapidly ease.

This change will rapidly benefit the south-western end of this area (south-west of Groyne 4). Here, the 15 properties fronting the beach have already been protected through the recent placement of revetment work[23]. In the future, however, the proposed managed breach is expected to ease the pressure on these defences (as the spit joins to the beach and extends it) and reduce the need for this existing revetment to be maintained (for an estimated period of 8 years) and this will have an ongoing cost benefit.

The bay between Groynes 4 and 3 already has some revetment and bags but this area may still be vulnerable to erosion (under existing conditions) given the nature of the defences (Dornbusch, 2014). These defences protect 10 properties whose benefit has not yet been formally claimed under Flood Defence Grant in Aid (FDGIA, see Figure 6.6). These properties will receive benefit for the estimated 8 year period (from reduced tidal erosion pressure and

23 Funding for these works was claimed under FDGIA and were part funded with contributions from the local community on the basis of the protection is afforded.

ARUN DISTRICT COUNCIL P/93/25/PL

increased shingle supply) and there will also be reduced maintenance costs (i.e. there is expected to be no need to maintain the revetments and recycle shingle) over this period.

There is no intention to remove the existing rock armour, or other protective features, from this area as part of this project. Instead it is valuable that they remain in place to ensure they provide continuing protection along this part of the shoreline and to avoid incurring costs associated with such removal work.

In terms of the future protection, this not thought to be needed for 8 years at least (i.e. the duration of the benefit of the proposed managed breach and the length of time it would take for the distil end of the spit to winnow into the wider shoreline). However, on such a dynamic foreshore there is always a risk that the shoreline will become vulnerable and it will be the best, and most cost-effective, solution to keep this protection in place in case there is an unforeseen re-exposure of this location in the short term and to provide a basis for protection over the longer-term.

6.3.5.3 Pagham Beach (erosion between Groyne 3 and the Yacht Club)

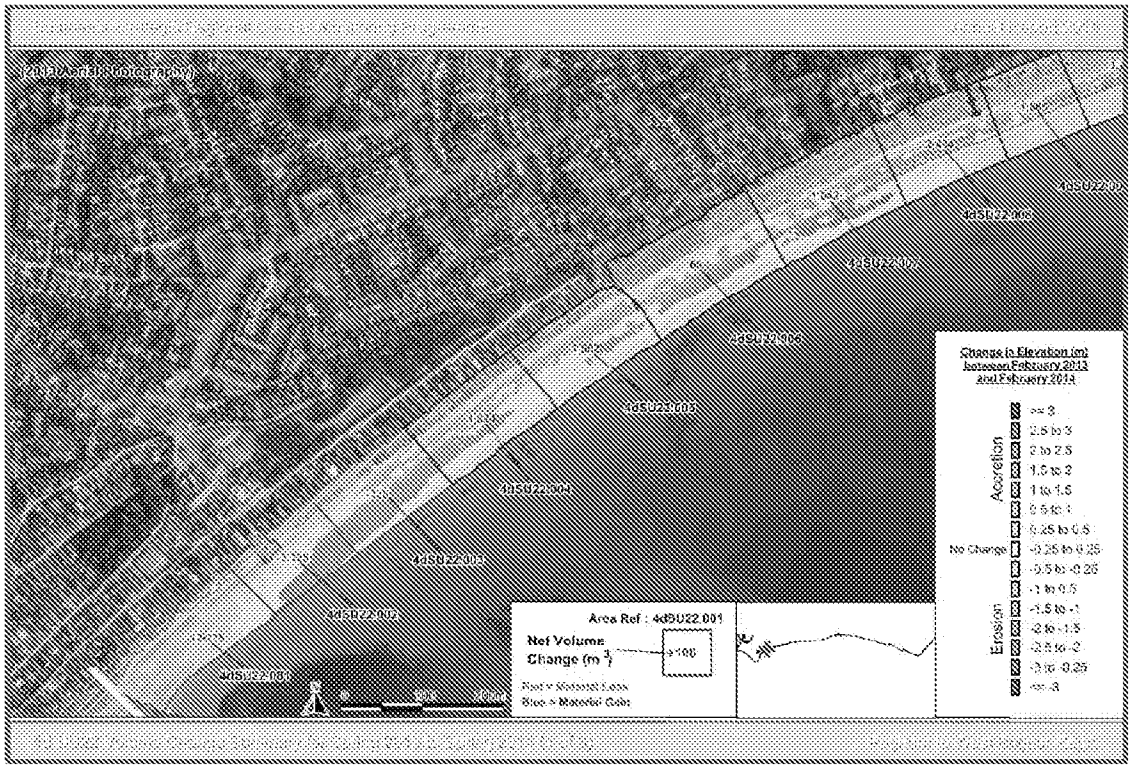
Once implemented, the project will have an immediate coastal protection benefit by removing the risk of erosion from a future encroachment of the spit and tidal channel. It will also, in the short to medium term, reverse the trend of erosion and beach loss by re-introducing long-shore shingle transport to the beach.

The ongoing process of erosion is evident along the section of the beach between Groyne 3 and the Yacht Club where beach volumes have substantially reduced over time. This is evident for the 11 years between 2003 and 2014 (see Images 6.16 and 6.17) and for the latest annual period between February 2013 to 2014 period (see Images 6.26 and 6.28). There has, however, been a small amount of local accretion of the beach (between Groynes 2 and 3) which may in part be due to artificial shingle recycling measures or the trapping of eroded sediment on the up-drift section of the beach.

In general, there has been an approximate retreat of the upper shoreline by between 10 and 30 m over the last decade but also retreat of the lower shore by 5 to 10 m over the 2013 to 2014 period alone. The greatest retreat is occurring just to the north-east of Groyne 1 where the beach is being starved of sediment. Currently the beach crest immediately in front of the properties has remained at a high elevation of around 5.6 to 6 m ODN (possibly with some man-made intervention) but it has narrowed (by around 16 m) in areas to the north-east of Groyne 1 and as the lower beach continues to reduce in elevation this will increasingly compromise the beach crest over time.

This progressive shingle loss may cause erosion damage to properties in the next few years. However, there is a further risk of more rapid damage in the likely event that the spit extends towards the maturing ebb delta area in front of this part of the beach. In that event the encroaching tidal channel could extend into the beach and cause rapid erosion from high flow speeds.

ARUN DISTRICT COUNCIL P/93/15/PL



(Source: SRCMP 2014b)

Image 6.28 Beach Volume changes 2013 to 2014 along Pagham Beach (west, 4dSU22)

Such an event is expected to occur within 1 to 2 years and especially after a winter storm period. However, as discussed previously, the location for such a future effect will be dependent upon the alignment that the tidal channel takes and that, in turn, will be strongly dependent upon whether Groyne 3 stays *in situ*. If this groyne does stay in place the spit may move offshore but if the groyne fails (as Groyne 4 has done) then the spit is likely to move inshore, pass the end of Groyne 2 and contribute to erosion in the vicinity of this groyne. Whilst the precise location and timing of this tidal channel effect are difficult to predict, the proposed spit breach will provide an immediate alleviation of this impending risk. Then, within a few weeks and months, the area will begin to benefit from the import of shingle as the spit feature begins to integrate into the Pagham shoreline.

These processes will benefit the 43 properties that lie along the foreshore from Groyne 3 to the Yacht Club area (see Figure 6.6). These properties are expected to be adversely affected within 2 to 3 years with no intervention. They will be benefited for at least 8 years, thereafter. This 8 year period is based on the time that it is likely to take the separated end of the Church Norton Spit to decline at a rate of 15-20,000 m³/year (as described in Section 6.3.1). However, as described previously, use of the spit decline rate as a measure for how the beach might respond is indicative only. It is not anticipated that there will be simple unidirectional export of the materials from the spit that then move into and along the beach to the north-east and the pattern of shingle movement and the manner in which it reshapes Pagham Beach will be

ARUN DISTRICT COUNCIL P/93/25/PL

influenced by the nature and frequency of storm events that are observed during the years after the project's implementation.

This 8 years period is considered to be as a realistic period for the duration of benefit arising from the work. Indeed, this value is considered to be relatively low (and precautionary) when it is noted that this part of the beach has lost in the region of 65,000 m³ of sediment/shingle over the period from 2003 to 2014 (35,000 m³ as shown in Image 6.17 plus around a further 30,000 m³ imported or recycled in 2009 and 2010) including during the severe storm periods of the 2013/14 winter. The proposed breach of the spit and the unlocking of the retained shingle is likely to resupply at a rate of around 15-20,000 m³/year and would potentially offset the observed losses within 4 years. Ultimately the re-supply could substantially stabilise or reverse the past trend of sediment loss for perhaps more than 10 years.

6.3.5.4 Pagham Beach (erosion between Yacht Club area and end of East Front Road)

The benefits of the proposed project further along the eastern side of Pagham Beach will occur over a longer timeframe than those predicted for the rest of the foreshore (under the present condition). This area of the beach is eroding but at a slower rate than other up-drift sections of the shoreline. This is because any shingle that is exported to the east is re-supplied by sediment imported from the immediate west (supply which will include material that was introduced as part of previous beach nourishment campaigns). Ultimately, and with no intervention, as the supply to the west decreases then the rate of erosion in this area will increase.

It is notable that, in this area, the top of the beach is typically eroding while the lower areas appear to be more stable and preferentially receiving shingle through littoral drift (see Image 6.28). The beach crest in this area has retreated by around 6 or 7 m over the last decade and a continuation (and anticipated acceleration) of this rate will result in damage to properties within 10 to 15 years. Added to this, there is the risk that if the spit and its associated tidal channel continue along its potential meander path that there will be a future encroachment of the spit into this part of the beach in a decade or so. In this event there may be more rapid localised losses to the beach through tidal scouring.

In the years after the implementation of the proposed breach, this area will begin to receive an increased supply of shingle from the redistribution of the spit and ebb delta that will stabilise or reverse the ongoing erosional trend. The net benefits, in terms of avoiding erosion to properties, may well not be observed for a decade however, in keeping with the benefits projected for other areas of the beach the benefit when it arrives can be expected to last for at least around 8 years. There are 34 properties fronting this section of the beach that will be benefited (see Figure 6.6).

As described previously for the section of coast to the west, this 8-year duration of benefit is expected to be a minimum duration and may well be longer. This area has lost in the region of 3,000 m³ of sediment/shingle over the period from 2003 to 2014 but the proposed breach of the spit and the unlocking of the retained shingle is likely to resupply at a rate of around 15-20,000 m³/year for around 8 years. This could substantially stabilise or reverse the past trend of sediment loss for perhaps for up to 20 years.

ARUN DISTRICT COUNCIL P/93/15/PL

6.3.5.5 Pagham Beach (flooding of the Beach and Sandy Road area)

The benefits that the proposal will provide for the section of shoreline between Groyne 3 and the Yacht Club area (as described in the preceding section) will reduce the risk of a possible future flood event behind the beach. This poses a risk to the low elevation areas around Beach Road and Sandy Road (areas that were also subject to flooding in the 1933). In this area, there are 23 properties and a vacuum pumping station (see Figure 6.6).

Flooding of this area could occur as a result of localised wave overtopping along the frontage in the event that the existing beach height and width is no longer sufficient to protect the properties from breaking waves. This is the issue presently seen along the south-eastern section of the frontage where the rock armouring has been placed to address the risk.

As described above, the beach between Groyne 3 and the Yacht Club area is continuing to retreat and reduce in volume (especially in its low shore elevation) although the crest has remained relatively stable. With continued loss of beach material the residential properties are expected to be adversely affected within 2 to 3 years and this could also introduce the risk of wave overtopping under storm conditions. This has the potential to affect 23 properties within the flood zone.

The flood zone in this case is illustrated as the pale blue triangular area around Beach and Sandy Road, as shown in Image 6.29, but also in the equivalent area illustrated in Figure 6.7. Image 6.29 describes the flood risk zones identified by the EA based on the standard of existing defences; currently it identifies a low risk of flooding to this area but this risk is increasing over time as shingle depletion occurs in the fronting beach. Figure 6.7 shows an equivalent triangle zone at risk of flooding for around a 1:10 to 1:200 year period. This plot describes the results of ABPmer analysis which compares the existing land elevation (from 2014 LiDAR data) around the harbour and at Pagham against the extreme water levels that are predicted for a range of return events (3.17 mODN water level for a 1:1 return event to 3.93 mODN at a 1:1000 return event).

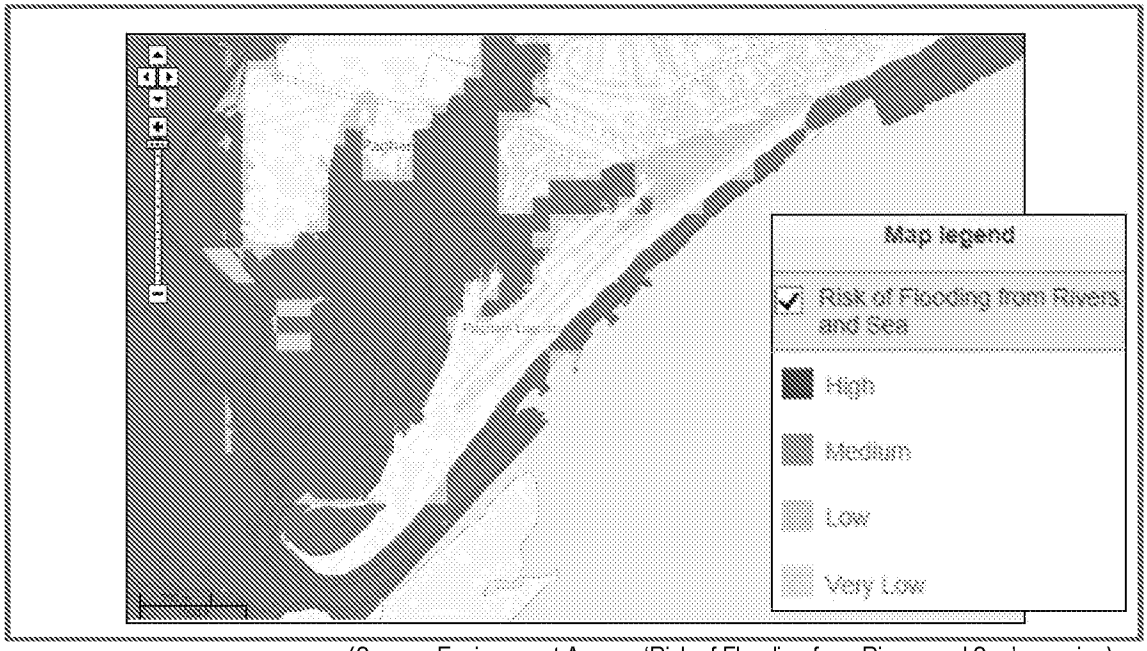
This analysis indicates that there is a low likelihood of any flooding occurring outside of this Beach and Sandy Road area because of the topography of the land. There is also unlikely to be sufficient water in the overtopping events to cause any issues beyond this zone, particularly considering that most of the gardens/roads are constructed from a gravel/sand sub-base which will act somewhat as natural drainage.

The western end of Pagham around Lagoon Road is within a flood zone (as shown in dark blue in Image 6.29) but that is due to the risk of flooding via Pagham Harbour. That risk will be reduced because the Environment Agency is carrying out defence improvements along this frontage (see Section 10.1).

In other areas much of Pagham is highly elevated (above present and future sea levels). As such, flooding through tidal inundation is unlikely (i.e. above a 1 in 1,000 year event) at present

ARUN DISTRICT COUNCIL P/93/25/PL

and into the near future. This is also illustrated by both the EA flood map[24] (see Image 6.29) and the extreme water levels map (see Figure 6.7).



(Source: Environment Agency 'Risk of Flooding from Rivers and Sea' mapping)

Image 6.29 Areas of flood risk along the Pagham frontage (Environment Agency)

6.3.5.6 Pagham Harbour

To understand whether the proposal could adversely affect the existing levels of coastal protection in Pagham Harbour, a numerical modelling exercise was undertaken as described within preceding sections and presented within the Breach Design review report (see Appendix A). As described in Section 6.3.4 this work concluded that there would be no increase in the high water levels within the harbour and also there is separately not expected to be any increase in wave penetration into the harbour.

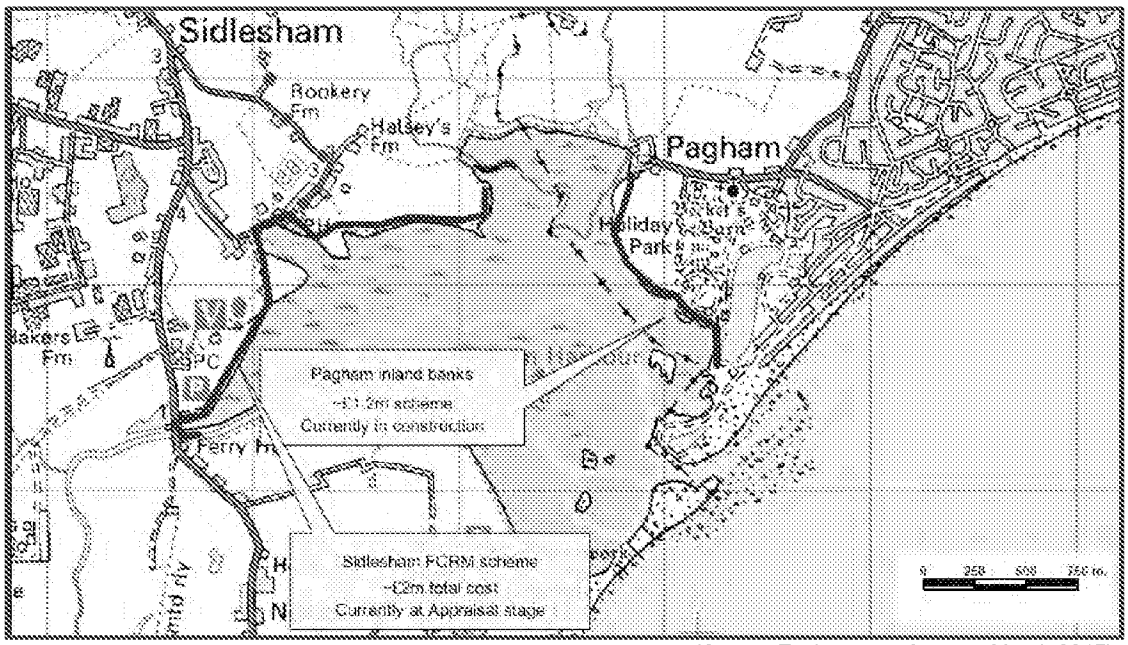
The modelling work indicated that there would be a small but temporary reduction in the high water elevation by up to approximately 0.05 to 0.06 m (5 to 6 cm) over a mean spring tide (see Image 6.25) but by less than 0.02 m (2 cm) over neap tides (Section 6.3.2.4). This effect would only occur in the period where the breach self-adjusts. Once the breach has self-adjusted (especially following an initial a sequence of larger spring tides), it will deepen and allow greater volumes of water through thus restoring the baseline tidal patterns. Critically, this work indicates that there will be no adverse effect during this initial and temporary adjustment period and that the potentially reduced high water levels will technically have a beneficial effect.

As there will be no adverse effects within the harbour, the harbour's internal defences will also not be adversely affected. It is also noted that the Environment Agency already has measures in place to further enhance protection to vulnerable areas around the harbour. The defences

24 http://watermaps.environment-agency.gov.uk

ARUN DISTRICT COUNCIL P/93/25/PL

protecting the western side of Pagham is flooding from the eastern side of the harbour. Works on this section are expected to be completed by October 2015 (Nick Gray, Environment Agency, Pers. Comm.). There are further proposals in the future for defence improvement works on the north west side of the harbour between the Ferry Pumping Station and Sidlesham although these works are at the appraisal stage and have not been commissioned yet.



(Source Environment Agency, March 2015)

Image 6.30 Environment Agency defence improvement areas in Pagham Harbour

6.3.5.7 Conclusions and cost implications

In summary there will be substantial benefits to Pagham Beach and a low lying area behind from the proposed intervention measure. There is also not expected to be any adverse effects on the existing defences within Pagham Harbour. Along the beach the benefits are largely from reduced erosion risk (Outcome Measure 3 (OM3); Defra, 2011) but also from a potentially reduced flood risk (Outcome Measure 2 (OM2); Defra, 2011).

In total there are up to around 110 properties that could be benefited over different timescales and which would otherwise be at risk imminently and certainly within the next 20 years (the timeline which dictates whether FDGiA funding applies (Defra, 2011). In summary the pressures on these Pagham Beach properties and the benefits accruing from the proposal are as follows:

- South-West of Groyne 3 (OM3 Erosion Risk Category): Immediately easing erosion pressure from tidal channel on this section of the breach and removing need for ongoing maintenance of existing revetment work. Estimated 10 properties benefiting that are unclaimed under FDGiA (plus further 15 that have been claimed) for 8 years from completion of the proposed scheme;

ARUN DISTRICT COUNCIL P/93/15/PL

- Between Groyne 3 and Yacht Club area (OM3 Erosion Risk Category): Immediately reducing future risk of erosion from spit and tidal channel migration and then within weeks/months beginning to re-supply the beach with shingle to stabilise beach or reverse the past trends of sediment loss. Estimated 43 properties benefiting (all unclaimed under FDGiA) for at least 8 years from 1-2 years after project implementation;

- Between Yacht Club area the end of East Front Road (OM3 Erosion Risk Category): Within months and years the scheme will begin to re-supply the beach with shingle to stabilise beach or reverse the past trends of sediment loss. Estimated 34 properties benefiting (all unclaimed under FDGiA) for at least 8 years from 5-10 years after project implementation;

- Beach and Sandy Road Area (OM2 Flooding Risk Category): Reduced risk of wave overtopping in the future. Estimated 23 properties benefiting (all unclaimed under FDGiA) for at least 8 years from 2-3 years after project implementation;

Further analysis of the effects on these properties (and the cost: benefit of the work) will be needed as part of any submission of funding to the Environment Agency and this will need to consider the net value (Outcome Measure (OM1)) of these properties and other assets along the beach and the timings over which benefits will accrue. However, the cost benefit case of the proposed projects over any other alternatives.

The cost of implementing the work to protect up to 110 properties for a period of around 8 years (possibly longer) will be in the region of £1 million from the works themselves (estimated £700,000) along with further consenting work (estimated £100,000) and compensation measures (estimated £200,000). By contrast the costs of protecting the 15-25 properties on the western side of the beach also has already cost in the region of £1.5 million over the last 6 winters with the sum being incurred increasing over time with the growth of the Church Norton Spit[25].

25 Over the last three winter periods these measures have cost around £900,000, including £500,000 for the 2012/13 revetment and £360,000 for later remedial/improvement measures. In the years preceding, there were fees incurred for shingle beach nourishment in 2010 (£600,000) and beach shingle recycling in 2009 (£43,000).

ARUN DISTRICT COUNCIL P/93/15/PL

7. Water and Sediment Quality

This section reviews the effects of the proposed works on water and sediment quality receptors. Baseline information and an overview of legislation and planning policy are provided in Section 7.1, followed by the impact assessment in Section 7.2.

7.1 Baseline Review

7.1.1 Data Sources

A range of data sources have been used to characterise the water and sediment quality baseline in the vicinity of the proposed works, including the following:

- Environment Agency monitoring data;
- Environment Agency What's In Your Backyard website;
- Environment Agency Bathing Water Quality website;
- Pagham Beach Foreshore Revetment Proposal (Royal Haskoning, 2013); and
- South East River Basin Management Plan (Environment Agency, 2009).

It should be noted that supplementary water and sediment quality surveys have not been conducted as part of this project as they were not considered necessary (given available information and the nature of the project). Instead this assessment is underpinned by a desk-based review of available data.

7.1.2 Legislation and Policy

Many standards for water and sediment quality are regulated at European Union (EU) level through a range of environmental directives, including the following:

- Water Framework Directive (WFD) (2000/60/EC);
- Priority Substances Directive (2008/105/EC and 2013/39/EU);
- Revised Bathing Water Directive (rBWD) (2006/7/EC);
- Urban Waste Water Treatment Directive (UWWTD) (91/271/EEC);
- Nitrates Directive (91/676/EEC);
- Shellfish Waters Directive (2006/113/EC); and
- Euratom Treaty (Council Directive 96/29/Euratom).

These EU Directives have been transposed into UK legislation through various Acts and Regulations and are described in more detail below. In addition, the UK Marine Policy Statement (HM Government, 2011) provides a national framework for the preparation of Marine Plans and decision making which affects the marine environment.

Defra has overall responsibility for water policy in England and the Environment Agency is the principal regulator of water quality under the Environment Act 1995, Water Resources Act 1991, Environmental Protection Act 1990, Pollution Prevention and Control Act 1999 (Statutory Instrument 1973/2000) and the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 (the Water Framework Regulations). In the marine environment, the

ARUN DISTRICT COUNCIL P/93/25/PL

MMO and statutory port and harbour authorities can also have important roles in managing some aspects of water quality.

7.1.2.1 Water Framework Directive

The Water Framework Directive (WFD), implemented in England and Wales through the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003, establishes a framework for the management and protection of Europe's water resources. The WFD applies to all surface waters out to 1 nautical mile (nm) seaward of the baseline for territorial waters and to ground waters. For management purposes, surface and ground waters are divided into a number of discrete units termed 'water bodies'. The aim of the WFD is to achieve 'good ecological and good chemical status' in all inland and coastal water bodies by 2015, unless alternative objectives are set or there are grounds for derogation. In some cases, this target date may be delayed until 2021 or 2027.

Ecological status is an expression of the quality of the structure and functioning of surface water ecosystems as indicated by the condition of a number of 'quality elements'. These include hydro-morphological, biological and chemical indicators (including dissolved oxygen and certain nutrient concentrations). The WFD recognises that in some water bodies, it may be impossible to get to a near natural condition because they have been substantially modified or developed for reasons such as flood protection or to allow navigation. These are termed 'heavily modified water bodies' (HMWBs) or 'artificial water bodies' (AWBs) and their aim is to achieve 'good ecological potential' as opposed to good ecological status (i.e. as close to natural condition as practical).

Programmes of measures to achieve good status or potential have been developed for each river basin district (RBD) and are set out in a number of regionally based River Basin Management Plans (RBMPs). In 2009, the Environment Agency published the first cycle (2009 to 2015) of RBMPs for England and Wales, reporting the status and objectives of each individual water body. Pagham is situated within the South East RBMP (Environment agency, 2009).

The Environment Agency is currently updating RBMPs in preparation of the second cycle (2015 to 2021). Draft versions were made available for consultation in late 2014, presenting interim results from 2013 and, therefore, provide an indication of water body status that will be reported in the updated RBMPs in (December) 2015. As the draft RBMPs have not been formally adopted and remain under consultation, it is considered prudent to continue to refer to the existing RBMPs in this assessment and exercise caution in the use of interim classifications.

There are two designated water bodies in the direct vicinity of the proposed works, namely Sussex and Pagham Harbour water bodies (Environment Agency, 2009). A WFD Compliance Assessment is provided in Appendix H.

7.1.2.2 Priority Substances Directive

The Priority Substances Directive (2008/105/EC) entered into force in early 2009 and forms an integral part of the WFD, establishing environmental quality standards (EQS) for 33 priority substances in surface waters (rivers, lakes, transitional and coastal waters). Within this list of

ARUN DISTRICT COUNCIL P/93/15/PL

priority substances, 13 are categorised as 'priority hazardous substances' and thus being of particular concern.

In August 2010, the River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2010 came into force, providing the Environment Agency with directions on applying the EQS for harmful pollutants in water bodies. According to Annex V of the WFD and Article 1 of the Priority Substances Directive, good chemical status is reached for a water body when it complies with the EQS for all the priority (hazardous) substances listed in Annex I of the Priority Substances Directive.

As required by the WFD and Priority Substances Directive, a proposal to revise the list of priority (hazardous) substances was submitted in 2012. Subsequently, a new Priority Substances Directive (2013/39/EU) was published in 2013, identifying 12 additional priority substances, setting EQS for those newly identified substances, revising the EQS for some existing substances in line with scientific progress and setting biota EQS for some existing and newly identified priority substances.

It is intended that the new Priority Substances Directive will be transposed into UK legislation in September 2015, ahead of the publication of the second cycle RBMPs, along with revised directions for the Environment Agency. Therefore, at the time of writing, the original Priority Substances Directive (2008/105/EC) remains in force without the forthcoming amendments associated with the new Priority Substances Directive (2013/39/EU); however, it is considered appropriate to report against the revised EQS where relevant data is available.

7.1.2.3 Revised Bathing Water Directive

The revised Bathing Water Directive (rBWD) (2006/7/EC) was adopted in 2006, updating the microbiological and 135rusta-chemical standards set by the original Bathing Waters Directive (BWD) (76/160/EEC) and the process used to measure/monitor water quality at identified bathing waters. The rBWD focuses on fewer microbiological indicators, whilst setting higher standards, compared to those of the BWD.

Bathing waters under the rBWD are classified as excellent, good, sufficient or poor according to the levels of certain types of bacteria (intestinal enterococci and Escherichia coli) in samples obtained during the bathing season (May to September). Table 7.1 presents threshold values for coastal bathing waters as defined by the rBWD (inland bathing waters are classified against slightly different criteria).

Table 7.1 Criteria for defining coastal bathing water classifications under the revised Bathing Water Directive (2006/7/EC)

Bathing Water Classification	Threshold (Colony Forming Units Per 100ml)		Confidence Level
	Intestinal enterococci	Escherichia coli	
Excellent	≤250	≤100	95th percentile
Good	≤500	≤100	95th percentile
Sufficient	≤500	≤185	90th percentile
Poor	Values are worse than 'sufficient'		n/a

ARUN DISTRICT COUNCIL P/93/15/PL

The BWD was repealed at the end of 2014 and monitoring of bathing water quality will be reported against rBWD indicators from 2015. The new classification system considers all samples obtained during the previous four years and, therefore, data has been collected for rBWD indicators since 2012. However, this means rBWD classifications between 2012 and 2014 are 'projected' due to changes to the monitoring regime and the first official classification under this regime will be published towards the end of 2015, when there is a full four-year dataset. The UK Government's target under the rBWD is to achieve 'sufficient' for all bathing waters by 2015, as described under the Bathing Water Regulations 2013 which transposes the rBWD into UK law.

7.1.2.4 Urban Waste Water Treatment Directive

The Urban Waste Water Treatment Directive (UWWTD) seeks to protect the environment from the adverse effects of sewage discharges. It sets treatment levels on the basis of sizes of sewage discharges and the sensitivity of waters receiving the discharges. In general, the UWWTD requires that collected waste water is treated to at least secondary treatment standards for significant discharges.

Secondary treatment is a biological treatment process where bacteria are used to break down the biodegradable matter (already much reduced by primary treatment) in waste water. Under the UWWTD, the UK is required to review environmental waters at four-yearly intervals to determine whether they are sensitive to the effects of sewage discharges.

7.1.2.5 Nitrates Directive

The Nitrates Directive, implemented in the UK under the Nitrate Pollution Prevention Regulations 2015, aims to reduce water pollution from agricultural sources and to prevent such pollution occurring in the future (nitrogen is one of the nutrients that can influence plant growth). Surface waters have to be identified if too much nitrogen has caused a change in plant growth which affects existing plants and animals and the use of the water body.

7.1.2.6 Shellfish Waters Directive

The Shellfish Waters Directive was adopted on 30 October 1979 in order to protect designated shellfish waters, thereby maintaining the high water quality necessary for producing edible shellfish (bivalve and gastropod molluscs, including oysters, mussels, cockles and clams). It sets physical, chemical and microbiological water quality requirements that designated shellfish waters must either comply with ('mandatory' standards) or endeavour to meet ('guideline' standards), including:

- Dissolved oxygen – Measured as percentage saturation, should exceed 70% (as a mean), and individual measurements may not be less than 60% unless there are no harmful consequences on the development of shellfish colonies; and
- Suspended solids – A discharge affecting shellfish waters must not cause the suspended solid content of the water to exceed by more than 30% the content of waters not so affected.

ARUN DISTRICT COUNCIL P/93/25/PL

The Shellfish Waters Directive was subsumed (repealed) by the WFD at the end of 2013, which provides equivalent levels of protection for shellfish waters.

7.1.2.7 Euratom Treaty

The Euratom Treaty establishes basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. Results from monitoring surveys are reported in annual Radioactivity in Food and the Environment (RIFE) report series.

7.1.2.8 UK Marine Policy Statement

The UK Marine Policy Statement (HM Government, 2011) recognises that coastal and offshore developments and other activities can have adverse effects on transitional, coastal and marine waters. During the construction, operation and decommissioning phases of developments, there can be increased demand for water, discharges to water and adverse ecological effects resulting from physical modifications to the water environment. There may also be an increased risk of spills and leaks of pollutants into the water environment and the likelihood of transmission of invasive non-native species, for example through construction equipment, and their impacts on ecological water quality need to be considered.

The Marine Policy Statement enables an appropriate and consistent approach to marine planning across UK waters, and ensures the sustainable use of marine resources and strategic management of marine activities from renewable energy to nature conservation, fishing, recreation and tourism. In developing Marine Plans, the marine plan authority should ensure it has regard to any relevant RBMP or supplementary plan and the programme of measures devised for the river basin district which is summarised in each plan.

Furthermore, the Marine Policy Statement states that the marine plan authority should satisfy itself where relevant that any development will not cause a deterioration in status of any water to which the WFD applies, subject to the provision of Article 4.7 of that Directive, or prevent compliance with any WFD obligation and is consistent with the requirements of daughter directives of the WFD including those on priority substances and groundwater. Decision makers should also take into account impacts on the quality of designated bathing waters and shellfish waters from any proposed development (HM Government, 2011).

7.1.3 Water Quality

The baseline water quality conditions that could potentially be subject to direct and indirect impacts by the proposed works are reviewed in the following sections:

- Temperature and salinity;
- Nutrients;
- Suspended solids;
- Dissolved oxygen;
- Contaminants;
- Radioactivity; and
- Microbiology.

ARUN DISTRICT COUNCIL P/93/25/PL

7.1.3.1 Temperature and salinity

Monthly mean water temperatures from samples collected between 2009 and 2015 at Pagham Harbour are shown in Image 7.1 (Environment Agency monitoring data). The highest monthly mean water temperatures were observed in July (18.8°C ± 0.4 SE[26]) and the lowest in February (6.2°C ± 0.3 SE). The highest and lowest water temperatures recorded during this period were 22.0°C (July) and 4.2°C (February), respectively.

The annual mean water temperature at Pagham Harbour, based on monthly mean values, was 12.5°C. Water temperature was also recorded during weekly Environment Agency monitoring of bathing waters during the bathing season (May to September) between 2009 and 2011. Maximum mean monthly water temperatures were higher at Pagham bathing water (19.7°C ± 0.4 SE in July) compared to Pagham Harbour, with a water temperature high of 22.2°C recorded in June 2010.

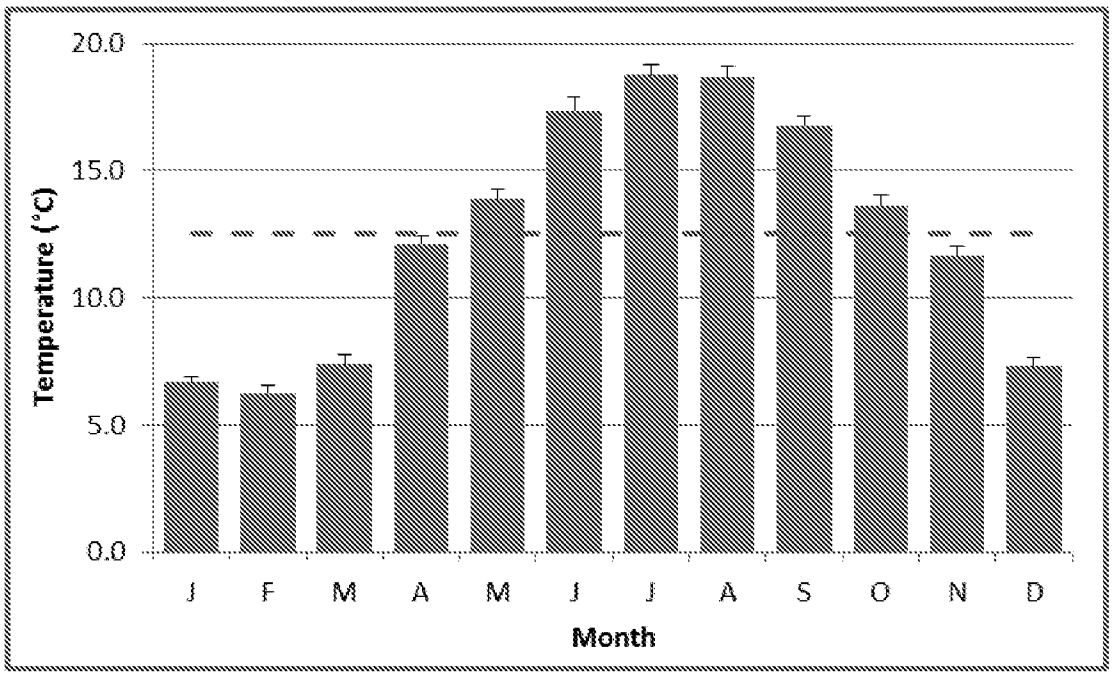


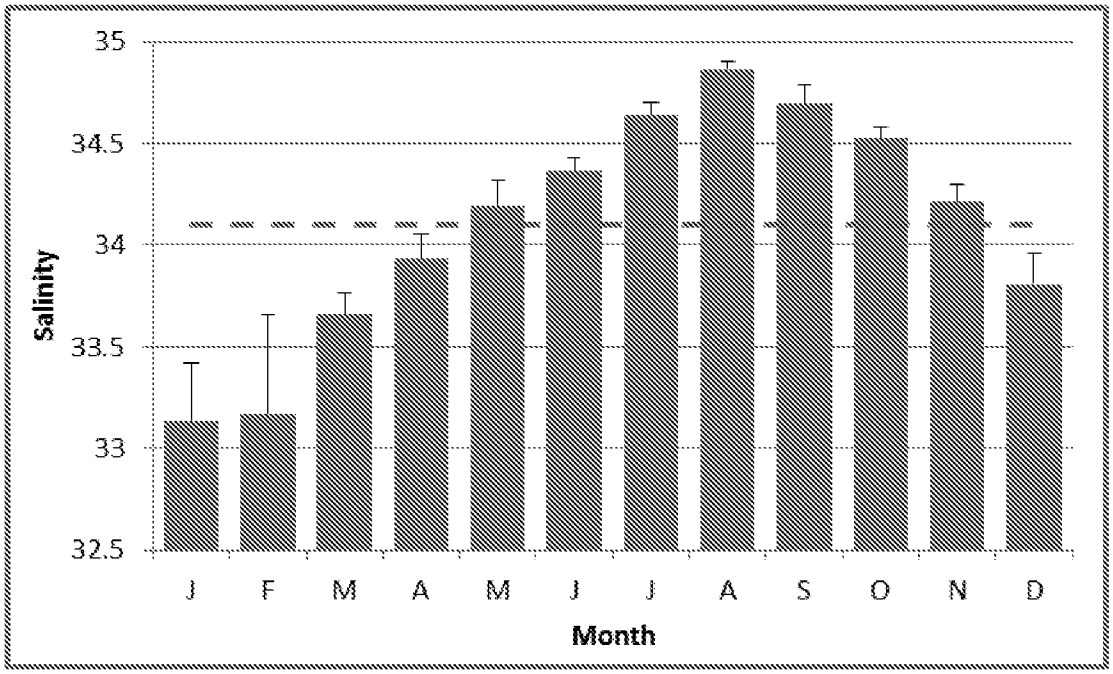
Image 7.1 Monthly mean (A) temperature (°C) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided

As with temperature, monthly mean salinity measurements were collected by the Environment Agency between 2009 and 2015 at Pagham Harbour (Image 7.2). The highest monthly mean salinities were observed in August (34.9 ± 0.04 SE) and the lowest in January (33.1 ± 0.3 SE). The highest and lowest salinities recorded during this period were 35.2 (September) and 25.3 (February; potential anomaly as next lowest value was 31.6), respectively.

26 Standard error defined as the standard deviation of the sampling distribution of a statistic, in this case the mean.

ARUN DISTRICT COUNCIL P/93/15/PL

The annual mean salinity within Pagham Harbour, based on monthly mean values, was 34.1. Environment Agency monitoring of bathing waters during the bathing season (May to September) between 2009 and 2014 showed that maximum mean monthly salinities were lower at Pagham bathing water (34.5 ± 0.2 SE in August and September) compared to Pagham Harbour. However, the highest salinity value (36.5 recorded in August 2011) from the Pagham bathing water was higher than the comparable measurement from Pagham Harbour.



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Image 7.2 Monthly mean salinity for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided

7.1.3.2 Nutrients

The addition of nutrients to estuarine and coastal water bodies occur naturally as a result of geological weathering and inputs from ocean upwelling. However, in recent decades, population growth and related nutrient sources such as agriculture, wastewater treatment plants, urban runoff and consumption of fossil fuels (atmospheric deposition) have increased nutrient inputs to many times their natural levels.

This increase in nutrient sources has occurred to the point that eutrophication is now regarded as one of the greatest threats to coastal ecosystem health (Committee on Environmental and Natural Resources, 2000; National Research Council (NRC), 2000; cited in Bricker et al., 2008). Eutrophication can lead to algal blooms in severe conditions which in turn can result in a decrease in dissolved oxygen (see Section 7.1.3.4), affecting higher trophic levels, including fish. Nutrients are a particular problem for Pagham Harbour and it has been designated as a "Sensitive Area (Eutrophic)" under the UWWTD (Defra, 2012).

ARUN DISTRICT COUNCIL P/93/25/PL

Nitrate, nitrite, ammonia (i.e. ammoniacal nitrogen, see Section 7.1.3.5 for unionised ammonia), dissolved inorganic nitrogen (DIN) and phosphate concentration in Pagham Harbour have been measured by the Environment Agency between 2009 and 2015 (see Image 7.3 to 7.5 for monthly variations in nitrate, nitrite and phosphate concentration). Each nutrient presents a similar annual pattern of availability, with elevated concentrations in late autumn/winter (November, December and January) and reduced levels in the summer (June, July and August). The highest and lowest monthly mean concentrations and annual mean (based on monthly mean) concentration for these nutrients are presented in Table 7.2.

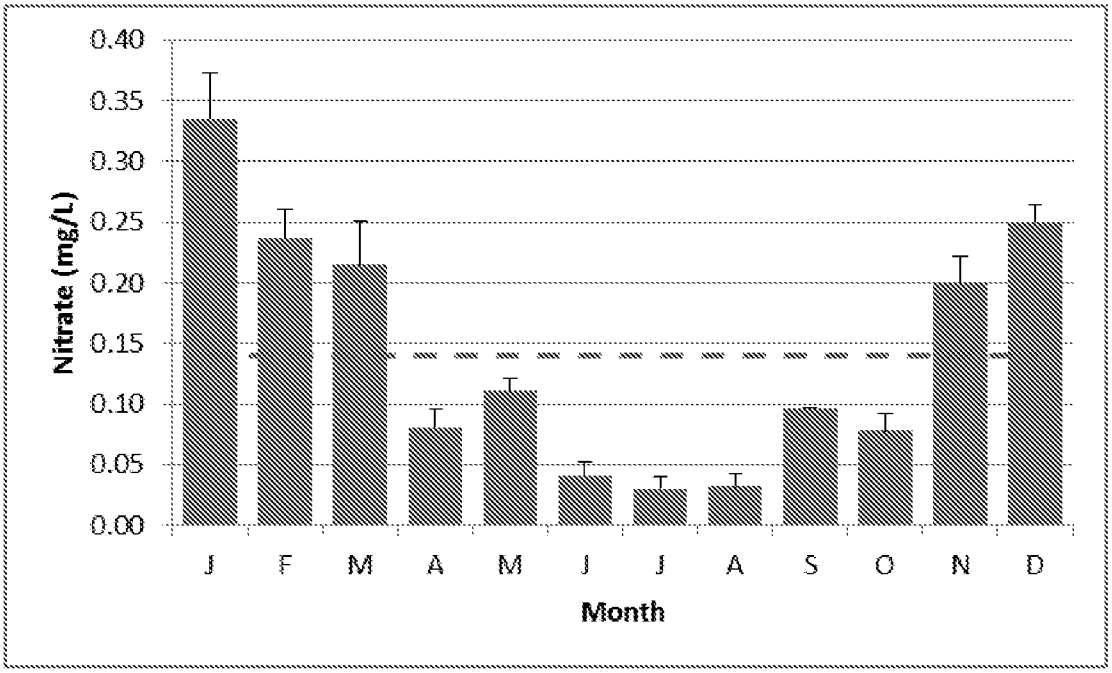


Image 7.3 Monthly mean nitrate levels (mg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided

ARUN DISTRICT COUNCIL P/93/15/PL

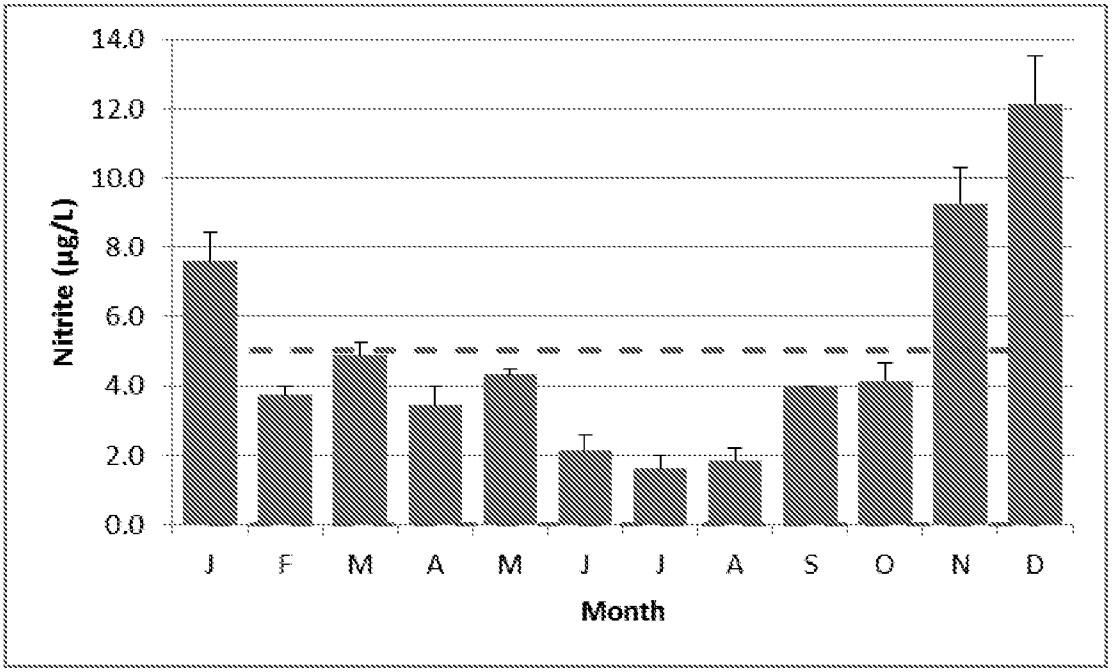
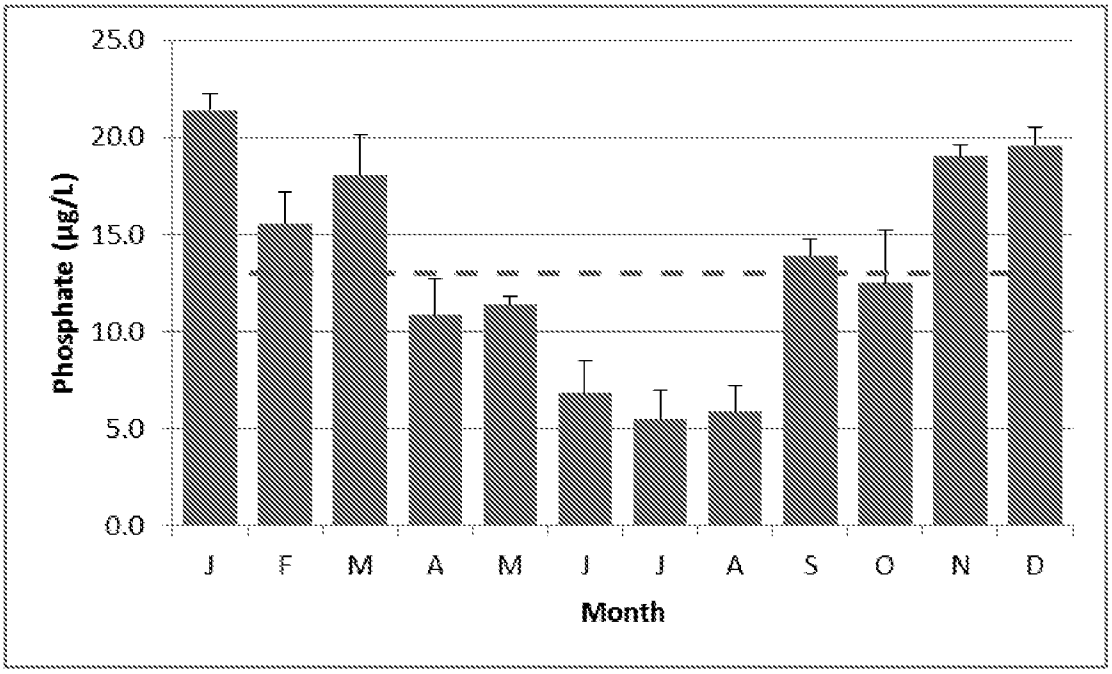


Image 7.4 Monthly mean nitrite levels (µg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided



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Image 7.5 Monthly mean phosphate levels (µg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided

ARUN DISTRICT COUNCIL P/93/25/PL

The Pagham Harbour transitional water body and Sussex coastal water body are both currently designated under the Nitrates Directive (Environment Agency, 2009). In addition, areas to the south-west and north of Pagham Harbour are designated as Nitrate Vulnerable Zones (NVZs), as well as Church Norton Spit[27].

Table 7.2 Monthly mean and annual mean nutrient concentrations for water samples collected from Pagham Harbour between 2009 and 2015

Nutrient	Mean Concentration (Monthly)		Mean Concentration (Annual)
	Highest	Lowest	
Nitrate	0.34 mg/L ± 0.04 SE (January)	0.03 mg/L ± 9.8 SE (July)	0.14 mg/L
Nitrite	12.2 µg/L ± 1.4 SE (December)	1.6 µg/L ± 0.4 SE (July)	4.9 µg/L
Ammonia	43.0 µg/L ± 4.6 SE (November)	10.3 µg/L ± 1.5 SE (July)	20.5 µg/L
DIN	0.37 mg/L ± 0.04 SE (January)	0.04 mg/L ± 0.01 SE (July)	0.16 mg/L
Phosphate	21.4 µg/L ± 0.9 SE (January)	5.5 µg/L ± 1.5 SE (July)	13.4 µg/L
DIN – Dissolved Inorganic Nitrogen; SE – Standard Error.			

(Contains Environment Agency information © Environment Agency and database right)

7.1.3.3 Suspended solids

Environment Agency water quality data for the years 2008 to 2013 show that the annual range of suspended solids for Pagham Lagoon and Pagham Harbour was bound by a lower limit of <3 mg/l and an upper limit of 39 mg/l. No suspended sediment data is available for the Pagham Beach area (Royal Haskoning, 2013). Suspended solids in waters approximately 3 km off the coast of Pagham (see Figure 7.1) collected by the Environment Agency in 2010 and 2011 ranged between <3 mg/l and 8.9 mg/l (Environment Agency monitoring data).

Turbidity measurements, typically reported using the Formazin Turbidity Unit (FTU), provide an indication of the levels of suspended sediment in the water column by measuring light scattered due to the presence of individual particles. Between 2010 and 2015, the Environment Agency collected turbidity measurements in Pagham Harbour, with values ranging between 1.5 FTU (June reading) and 136.4 FTU (January reading). Monthly mean turbidity was highest in January (66.7 FTU ± 11.4 SE) and lowest in July (8.0 FTU ± 1.2 SE), indicating elevated suspended material in the water column during winter months compared to the summer. The annual mean turbidity within Pagham Harbour, based on monthly mean values, was 27.5 FTU.

7.1.3.4 Dissolved oxygen

Dissolved oxygen concentration (Image 7.6) has been measured in Pagham Harbour by the Environment Agency between 2009 and 2015, and ranged between 3.84 mg/L (June reading) and 11.8 mg/L (March reading). These peak measurements are reflected in the monthly mean dissolved oxygen concentrations; they were lowest in July and August (both 7.4 mg/L ± 0.11 SE) and highest in March (10.5 mg/L ± 0.19 SE).

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27 Environment Agency What's In Your Backyard website: (http://apps.environment-agency.gov.uk/wiyby/141443.aspx)

ARUN DISTRICT COUNCIL P/93/15/PL

The annual mean dissolved oxygen concentration within Pagham Harbour, based on monthly mean values, was 8.7 mg/L. The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2010 identify dissolved oxygen standards for transitional and coastal waters, citing concentrations greater than 5.7 mg/L (annual 5-percentile; normalised to salinity of 35) as representative of high status.

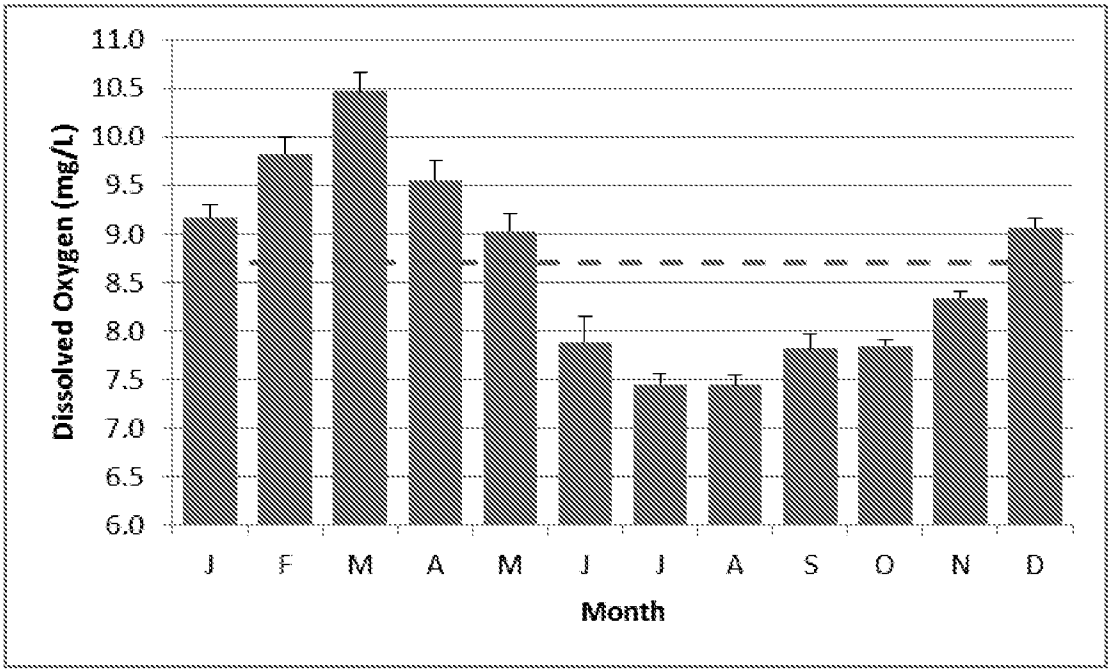
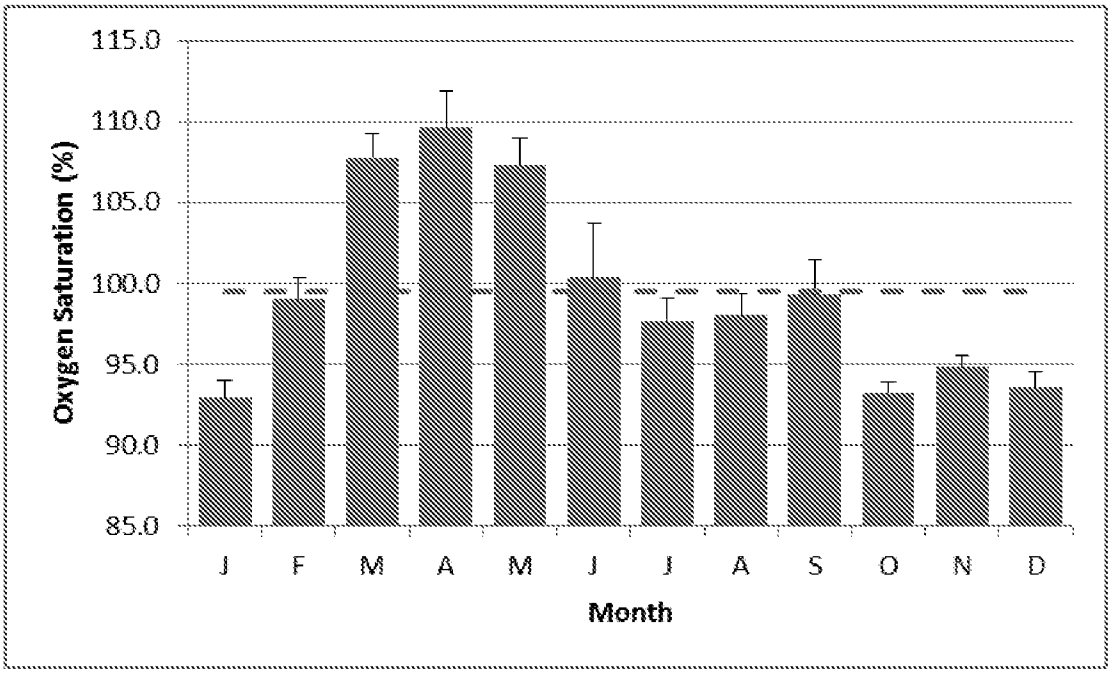


Image 7.6 Monthly mean dissolved oxygen concentration (mg/L) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided

In terms of oxygen saturation (see Image 7.7), lowest and highest measurements were recorded in January (78.9%) and April (126.1%), respectively. Monthly mean oxygen saturation was highest in April (109.6% ± 2.2 SE) and lowest in January (92.9% ± 1.1 SE). The annual mean oxygen saturation within Pagham Harbour, based on monthly mean values, was 99.5%.

Dissolved oxygen saturation is dependent on concurrent physical parameters, including water temperature, salinity, nutrients and sediment oxygen demand. There are currently no recognised standards for dissolved oxygen saturation in transitional and coastal waters, although greater than 70–80% saturation (related to cyprinid and salmonid waters, respectively) in riverine water bodies is classified as high status (The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2010).

ARUN DISTRICT COUNCIL P/93/25/PL



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Image 7.7 Monthly mean dissolved oxygen saturation (%) for water samples collected from Pagham Harbour. Annual mean (red dash) and standard error bars provided

No dissolved oxygen or oxygen saturation data is available for the Pagham Beach area, but values would be anticipated to be relatively high due to the open nature of the coast and the lack of organic material and industrialisation (Royal Haskoning, 2013).

7.1.3.5 Contaminants

There are two designated water bodies in the direct vicinity of the proposed works, namely Pagham Harbour transitional water body and Sussex coastal water body (Environment Agency, 2009). Chemical status of the Sussex coastal water body was good in 2009 and interim classifications from 2014 indicate the chemical status remains good. However, despite reporting good chemical status ('does not require assessment') in 2009, the 2014 interim classification suggests Pagham Harbour transitional water body is now failing to achieve good chemical status due to levels of the priority substance fluoranthene (also see Appendix H).

Fluoranthene is a polycyclic aromatic hydrocarbon (PAH) which occurs widely in the environment (it is the most commonly detected PAH in drinking water). It is produced through the thermochemical decomposition of organic raw materials such as coal and petroleum at high temperatures; thus, their presence is typically associated with the combustion of fossil fuels.

Concentrations of metals in the marine environment are typically below EQS values around the UK, attributed to significant improvements in the treatment of substances prior to their release. The area surrounding Pagham is not currently (nor has it been historically) heavily industrialised and, therefore, water quality could be expected to be good.

ARUN DISTRICT COUNCIL P/93/15/PL

Water quality monitoring data, collected by the Environment Agency between 2012 and 2015 is presented in Table 7.3 alongside the relevant EQS for that parameter. Contaminant concentrations were typically well below the annual average EQS. One sample for chromium (November 2012) and one sample for zinc (December 2012) exceeded the annual average EQS; however, the chromium concentration was less than the maximum allowable concentration EQS and, given the mean concentration for both metals was below the annual average EQS, these elevated values are not considered a major concern.

Contaminant concentrations are similar to those reported in the Pagham Beach Foreshore Revetment Proposal, based on Environment Agency data from between 2008 and 2013 (Royal Haskoning, 2013), indicating no significant variation in water quality during this period.

Table 7.3 Contaminant concentrations in water samples collected from Pagham Harbour between 2012 and 2015 compared to Priority Substances Directive (2008/105/EC and 2013/39/EU) environmental quality standards (EQS)

Parameter	EQS		Concentration		
	AA	MAC	Low	High	Mean ± SE (n)
Ammonia (Unionised) (NH_3)	21 µg/L	-	0.18 µg/L	0.92 µg/L	0.49 µg/L ± 0.04 (35)
Arsenic (As)	25 µg/L	-	<1 µg/L	1.71 µg/L	1.18 µg/L ± 0.03 (35)
Cadmium (Cd)	0.2 µg/L	1.5 µg/L *	<0.04 µg/L	<0.04 µg/L	<0.04 µg/L (51)
Chromium (Cr) (VI)	0.6 µg/L	32 µg/L	<0.5 µg/L	0.66 µg/L	0.66 µg/L (35)
Copper (Cu)	5 µg/L	-	0.27 µg/L	1.26 µg/L	0.58 µg/L ± 0.03 (35)
Cyanide	1 µg/L	5 µg/L	<0.005 µg/L	<0.5 µg/L	<0.5 µg/L (35)
Iron (Fe)	1 mg/L	-	<100 µg/L	<100 µg/L	<100 µg/L (35)
Lead (Pb)	7.2 µg/L	-	<0.04 µg/L	0.35 µg/L	0.08 µg/L ± 0.03 (51)
Mercury (Hg)	0.05 µg/L	0.07 µg/L	<0.01 µg/L	0.03 µg/L	0.02 µg/L ± 0.002 (52)
Nickel (Ni)	20 µg/L	-	0.34 µg/L	1.00 µg/L	0.51 µg/L ± 0.01 (51)
Zinc (Zn)	6.8 µg/L plus ambient background concentration	-	0.40 µg/L	8.36 µg/L	1.97 µg/L ± 0.28 (35)

EQS Environmental quality standard;
AA Annual average (long term);
MAC Maximum allowable concentration (short term);
SE Standard error;
n Number of samples;
* EQS based on water hardness at Pagham (≥200 mg $CaCO_3$/L, see http://dwi.defra.gov.uk/consumers/advice-leaflets/hardness_map.pdf).
Note: Mean concentrations may be an overestimate as they do not include < values.

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7.1.3.6 Radioactivity

Radioactivity in the marine environment arises from both natural and man-made sources and excessive levels can be harmful to humans and animals. Charting Progress 2 (UK Marine Monitoring and Assessment Strategy (UKMMAS), 2010) describes the current status of radioactivity and past trends in UK waters, primarily focusing on the Irish Sea due to the significant influence of discharges from the Sellafield nuclear plant. Discharges of radioactive

ARUN DISTRICT COUNCIL P/93/15/PL

material are strictly controlled and concentrations observed in the UK are reported annually (Radioactivity in Food and the Environment (RIFE) report series). Both sources of information indicate that levels of radioactivity in the English Channel are very low (compared to the maximum dose limit to members of the public and other UK regions).

The nearest nuclear plants are located >100 km from Pagham, namely Dungeness nuclear power station to the east and Winfrith nuclear research facility to the west. Given that current levels of radiation in the vicinity of Pagham do not present an issue to water quality receptors, radioactivity is therefore not considered further in this assessment.

7.1.3.7 Microbiology

There are three designated bathing waters within 5 km of the proposed works, namely Selsey, Pagham and Bognor Regis (Aldwick) (see Figure 7.1). Table 7.4 presents the projected classifications of these bathing waters between 2012 and 2014 as defined under the rBWD[28].

All three bathing waters are projected to have achieved at least the minimum (i.e. sufficient) requirements of the rBWD over this period. Bathing water quality at Pagham, the nearest bathing water to the proposed works, and Bognor Regis (Aldwick) have routinely been projected as excellent and good, respectively. Bathing water quality at Selsey was projected as good in 2012 and 2013, but only achieved sufficient in 2014.

For reference, classifications under the BWD are also presented in Table 7.4, whereby 'mandatory' assumes minimum compliance and 'guideline' relates to a relatively higher standard (equivalent to good under the rBWD).

Table 7.4 Water quality (projected) classifications for coastal bathing waters within 5km of the proposed works as defined under the Bathing Water Directive (76/160/EEC) and revised Bathing Water Directive (2006/7/EC)

Bathing Water	(Projected) Classification		
	2012	2013	2014
Bathing Water Directive (76/160/EEC)			
Selsey	Mandatory	Guideline	Mandatory
Pagham	Guideline	Guideline	Guideline
Bognor Regis (Aldwick)	Mandatory	Mandatory	Mandatory
Revised Bathing Water Directive (2006/7/EC)			
Selsey	Good	Good	Sufficient
Pagham	Excellent	Excellent	Excellent
Bognor Regis (Aldwick)	Good	Good	Good

Sources: Environment Agency Bathing Water Quality website; Defra (2013; 2014)

[28] The rBWD classification system considers all samples obtained during the previous four years; therefore, classifications reported between 2012 and 2014 are 'projected' due to changes to the monitoring regime. The first official classification under this regime will be published towards the end of 2015, when there is a full four-year dataset (see Section 7.1.2.3).

ARUN DISTRICT COUNCIL P/93/15/PL

At the time of writing, data is available from seven monitoring dates during the 2015 bathing season (8 May – 24 June) and water quality at each of the three bathing waters considered above is reported to be excellent (Environment Agency Bathing Water Quality website).

The nearest shellfish waters are in Chichester Harbour (Chichester Channel, Thornham Channel and Emsworth Channel) at a distance of >15 km to the west[29]. Therefore, shellfish waters have not been considered further due to the distance between the nearest site and the proposed works at Pagham.

7.1.4 Sediment Quality

Unlike water quality, there are no formal quantitative EQS values for sediments. Therefore, in the absence of any quantified UK standards, common practice for characterising baseline sediment quality conditions is to compare against the following two separate criteria sets:

- Centre for Environment, Fisheries and Aquaculture Science (Cefas) Guideline Action Levels for the disposal of dredged material; and
- Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines for the protection of aquatic life.

Cefas Guideline Action Levels are used as part of a 'weight of evidence' approach to assessing material suitability for disposal at sea. Cefas guidance indicates that, in general, contaminant levels below Action Level 1 (AL1) are of no concern and are unlikely to influence the licensing decision. However, material with contaminant levels above Action Level 2 (AL2) is generally considered unsuitable for disposal at sea. Dredged material with contaminant levels between AL1 and AL2 requires further consideration and testing before a decision can be made[30]. The action levels should not be viewed as pass/fail thresholds and it should be acknowledged that these guidelines are not statutory requirements.

The Canadian Interim Sediment Quality Guidelines (ISQGs) were developed by CCME to evaluate the potential for adverse biological effects in aquatic systems. Similar to the Cefas Action Levels, the Canadian ISQGs comprise two assessment levels. The lower level is referred to as the threshold effects level (TEL) and represents a concentration below which adverse biological effects are expected to occur only rarely (e.g. some sensitive species). The higher level, referred to as the probable effect level (PEL), defines a concentration above which adverse effects may be expected in a wider range of organisms. The three ranges of chemical concentrations (i.e. <TEL, between TEL and PEL, and >PEL) indicate those concentrations that are rarely, occasionally and frequently associated with adverse biological effects, respectively.

Sediment quality monitoring data, collected by the Environment Agency in April 2011 from Pagham Harbour (five samples), is presented in Table 7.5 alongside Cefas and CCME guideline values for that parameter. Mean contaminant concentrations were below AL1 and

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29 Cefas Shellfish Waters map (https://www.cefas.co.uk/media/41417/chichester.jpg)

30 Cefas Action Levels (http://www.cefas.defra.gov.uk/media/562541/cefas%20action%20levels.pdf)

ARUN DISTRICT COUNCIL P/93/15/PL

TEL levels for the majority of sediment samples obtained, with exceptions for arsenic, chromium and copper:

- Arsenic concentration was greater than TEL, but less than AL1, in all five samples (maximum concentration 13.9 mg/kg);
- Chromium concentration was greater than AL1 and TEL in all five samples, with one sample greater than PEL (169 mg/kg); and
- Copper concentration was greater than AL1 and TEL in all five samples (maximum concentration 46.7 mg/kg).

The above exceedances are typically in the range between lower (AL1 and TEL) and upper (AL2 and PEL) assessment levels, representing contaminant concentrations for which further consideration may be required. However, it should be noted that these samples were obtained from within Pagham Harbour (see Figure 7.1) as opposed to the Church Norton Spit or Pagham Beach where the works are planned. The proportion of fine material (<20 µm) was relatively high in samples collected by the Environment Agency from within Pagham Harbour (31.8% ± 3.19, n = 15).

Table 7.5 Mean contaminant concentration in sediment samples collected from Pagham Harbour in April 2011 compared to sediment quality criteria

Parameter	Cefas Guideline Action Levels (mg/kg)		CCME Sediment Quality Guidelines (mg/kg)		Mean Concentration ± SE (n)
	AL1	AL2	TEL	PEL	
Anthracene (PAH)	-	-	0.0469	0.245	5.87 µg/kg ± 1.13 (5)
Arsenic (As)	20	100	7.24	41.6	9.58 mg/kg ± 1.46 (5)
Benzo(a)anthracene (PAH)	-	-	0.0748	0.693	23.3 µg/kg ± 6.50 (5)
Benzo(a)pyrene (PAH)	-	-	0.0888	0.763	28.8 µg/kg ± 9.22 (5)
Benzo(g,h,i)perylene (PAH)	-	-	-	-	<10.0 µg/kg (5)
Cadmium (Cd)	0.4	5	0.7	4.2	0.09 mg/kg ± 0.01 (5)
Chromium (Cr)	40	400	52.3	160	120 mg/kg ± 16.8 (5)
Chrysene (PAH)	-	-	0.108	0.846	24.2 µg/kg ± 6.92 (5)
Copper (Cu)	40	400	18.7	108	44.1 mg/kg ± 1.16 (5)
Fluoranthene (PAH)	-	-	0.133	1.494	36.7 µg/kg ± 9.46 (5)
Lead	50	500	30.2	112	18.1 mg/kg ± 0.34 (5)
Mercury	0.3	3	0.13	0.7	28.4 µg/kg ± 2.94 (5)
Napthalene (PAH)	-	-	0.0346	0.391	<0.03 mg/kg (5)
Nickel	20	200	-	-	17.2 mg/kg ± 0.53 (5)
PCB – 028	-	-	-	-	<0.1 µg/kg (5)
PCB – 052	-	-	-	-	0.52 µg/kg (5)
PCB – 101	-	-	-	-	0.64 µg/kg (5)
PCB – 118	-	-	-	-	0.72 µg/kg (5)
PCB – 138	-	-	-	-	0.68 µg/kg (5)
PCB – 153	-	-	-	-	0.52 µg/kg (5)
PCB – 180	-	-	-	-	<0.1 µg/kg (5)
PCBs (sum of ICES 7)	0.01	-	-	-	3.08 µg/kg ± 0.04 (5)

ARUN DISTRICT COUNCIL P/93/25/PL

Parameter	Cefas Guideline Action Levels (mg/kg)		CCME Sediment Quality Guidelines (mg/kg)		Mean Concentration ± SE (n)
	AL1	AL2	TEL	PEL	
Phenanthrene (PAH)	-	-	0.0867	0.544	13.3 µg/kg ± 0.23 (5)
Pyrene (PAH)	-	-	0.153	1.398	34.2 µg/kg ± 8.95 (5)
Tributyltin (TBT)	0.1	1	-	-	<3 µg/kg (5)
Zinc	130	800	124	271	66.9 mg/kg ± 1.11 (5)

AL – Action Level; CCME – Canadian Council of Ministers of the Environment; TEL – Threshold effects level; PEL – Probable effect level; SE – Standard error; n – Number of samples; PAH – Polycyclic aromatic hydrocarbon; PCB – Polychlorinated biphenyl; ICES 7 – PCB congeners which cover the range of toxicological properties of the group. Note: mean concentrations may be an overestimate as they do not include < values.

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Other than the limited number of samples collected by the Environment Agency in April 2011 as discussed above, information on sediment quality within the study area is sparse, with a search of publically available sources failing to acquire any additional data. In the absence of further sediment quality data, the sediment characteristics at the site of the proposed works and potential sources of pollutants have been considered to determine the potential for impacts on sediment quality associated with the proposed works.

Pagham Harbour contains a range of sediment types from muds to shingle, with sand and gravel the predominant sediment type. Fine grained sediments high in organic matter more readily adsorb contaminants than coarser particles; however, Pagham Harbour is not industrialised and pollutant inputs are not believed to be sufficient to result in elevated contaminant concentrations in fine sediments present within the Harbour.

Church Norton Spit and Pagham Beach are characterised by steep upper beaches and shallower mid-beaches mostly composed of a flint shingle, which grades to coarse sand and granules on the extensive low gradient foreshore (Wallace, 1990; Barcock and Collins, 1991; Posford Duvivier, 2001; cited in Royal Haskoning, 2013). Due to the coarse nature of these sediments, the potential for contaminant accumulation is low. In addition, Pagham Beach is open to the sea and sediments are likely to be well flushed. Therefore, based on contaminant concentrations (see Table 7.5) and sediment type, sediment quality is generally considered to be good in the vicinity of the proposed works.

7.2 Impact Assessment

7.2.1 Impact Pathway 6: Effects on Suspended Sediment and Water Quality During Construction

7.2.1.1 General scientific context

The potential for changes in water quality to occur arise primarily where sediment is released into the water column as a result of physical disturbance to the seabed. This is particularly the case for fine sediments (<63 µm) which can become suspended more easily. Increased suspended sediment concentrations can cause a wide range of environmental impacts,

ARUN DISTRICT COUNCIL P/93/15/PL

including clogging of gills (e.g. essential feeding apparatus for filter-feeders), smothering of sedentary organisms and attenuation of light (Newell et al., 1998).

Elevated levels of suspended sediment (increased turbidity) can cause a reduction in light penetration through the water column, restricting the light availability for photosynthesis in important primary producers such as phytoplankton and macrophytes. Such primary producers are important sources of food and oxygen and a reduction in their productivity can reduce water quality. High levels of suspended sediment may also increase chemical oxygen demand (COD) and encourage the oxidation of organic matter by bacteria, depressing dissolved oxygen content (Biological Oxygen Demand or BOD).

Larger disturbed particles are generally quickly deposited on the seabed, while finer sediments remain suspended for longer durations and, coupled with a highly dispersive environment, can be transported over greater distances. For example, settlement of medium/coarse sand sediment is most likely to occur within 20–200 m of a cable for an offshore wind farm (Department for Business Enterprise and Regulatory Reform (BERR), 2008). However, it should be recognised that these ranges of sediment deposition are related to offshore cable burial into the seabed, while the proposed works involve the excavation and redistribution of predominantly coarse material in a different location (see Section 3.2).

The potential to impact the marine environment as a result of any sediment-bound contaminants arises primarily when the sediment that is released into the water column disperses and deposits elsewhere. Construction works will not input any additional contaminants into the system through the introduction of contaminated sediment, but could potentially redistribute any contaminants already present in the sediments.

The resuspension of sediment can lead to the release and mobilisation of sediment-bound contaminants into the water column. These include both toxic contaminants, such as heavy metals, pesticides and hydrocarbons, and non-toxic contaminants, such as nutrients. The occurrence of contaminated sediment is most likely to occur where the sediments are finer (with more surface area for absorption of contaminants) and where toxic material has previously settled onto the seabed. The chemical contaminants associated with sediments can be removed or disturbed during construction and may be dispersed, redistributed and deposited elsewhere in the marine environment where they may become available for uptake by marine organisms.

7.2.1.2 Project Impact Assessment

Given that Pagham Harbour has been designated as a "Sensitive Area (Eutrophic)" under the UWWTD (Defra, 2012) and Church Norton Spit is designated a NVZ, nutrient contamination is a key concern of the proposed works. Available water quality data highlights the annual variation in nutrient concentration within Pagham Harbour, decreasing in summer months due to biological uptake/production and increasing during the winter (see Section 7.1.3.2).

The proposed construction works are unlikely to significantly increase the nutrient concentration in the water column due to the low organic content anticipated to be present in the sediment comprising Church Norton Spit. There is the potential for sediment to be

ARUN DISTRICT COUNCIL P/93/25/PL

resuspended during the works as a result of excavating the breach and infilling the existing tidal channel.

However, any resuspension of sediment caused by the works would be small in scale and highly localised. This is because the excavated sediment is predominantly coarse in nature with a mixture of sands, shingle and gravels and therefore any sediment deposited at the infill or breach location would quickly fall back out of suspension and thus rapidly return to the pre-work condition.

Furthermore, the presence of the temporary access causeway that is proposed at the infill location during construction and the fact that coarser material will be placed on the southern side of the infill footprint will also reduce the potential for material excavated and moved during the work to be transported by tidal action both into the harbour or out to sea (see Section 3.2). In any case, any changes in suspended sediment levels would be immediate to short term given the temporary and intermittent nature of the excavation and infilling works. The channel infill will take place over a period of up to two weeks and the excavation of the highest elevation central section of the spit will take place over a one week sequence of dropping spring to neap tides thus further minimising the potential for resuspension.

The increase in COD and BOD associated with elevated suspended sediment concentrations in the water column can have the potential to reduce dissolved oxygen concentrations (LaSalle, 1990). This effect is associated with organic rich material, such as peat or alluvium. However, the material at the site of the proposed work is considered to be predominantly coarse sediment which is low in organic content and, therefore, the potential effects on dissolved oxygen are likely to be minimal.

In the absence of formal sediment EQSs, contaminant concentrations from sediment samples have been compared to Cefas Guideline Action Levels and Canadian ISQGs, which are used to evaluate the suitability of (dredged) material for disposal in the marine environment. Mean contaminant concentrations were below AL1 and TEL levels for the majority of sediment samples collected within Pagham Harbour, apart from arsenic, chromium and copper. All sediment samples were below AL2, with only one sample greater than PEL (chromium). Sediment contaminant concentrations from within the harbour would be expected to be higher compared to the site of the proposed works because of the sediments are likely to consist of greater mud (fine) material (>30%). Overall, the coarse grain sizes (and anticipated low silt content) of sediment at Church Norton Spit and Pagham Beach has been qualitatively assessed as low in contaminants and, therefore, any resuspended sediment is not expected to be heavily contaminated.

The probability of sediment resuspension is considered to be high given that the excavation and placement of material will result in the disturbance and potential resuspension of material. The magnitude of change is considered to be negligible due to the potential changes being confined to the immediate spatial extent over a short/temporary timescale. The exposure to change is therefore considered to be negligible. Despite the high sensitivity of the harbour to changes in nutrient levels and high importance due to its UWWTD and WFD designated status, the overall effects of excavating the breach and infilling the existing tidal channel on suspended sediment levels and water quality conditions is assessed as insignificant.

ARUN DISTRICT COUNCIL P/93/25/PL

7.2.2 Impact Pathway 7: Effects on Water Quality of Spillages (e.g. Fuel) During Construction

7.2.2.1 General scientific context

Any construction accident has the potential to lead to a spillage of cargo or fuel oil from the plant(s) involved. These types of accident are the ones most likely to lead to large scale oil spills; however, they are also relatively rare events.

7.2.2.2 Project impact assessment

There will always be an element of risk from accidents and spillages/leaks in a construction operation (e.g. oil, fuel and lubricants from machinery) which could result in the contamination of the adjacent sediments and water. Should pollution occur from runoff, stored material or accidental spillages, the adverse effect on water resources and their associated ecology could be significant, the scale of which will depend on the nature and magnitude of the pollution incident.

The implications of a pollution incident are highly dependent on both the nature of the substance released and the species that would be affected. However, this risk will be minimised by ensuring that the construction methods, scheme designs and the contractual arrangements are pursued in an appropriate way (see Section 3.2).

In order to reduce the risk of accidental spillages and/or leaks from construction plant, the following guidance will be adopted:

- Environment Agency Pollution Prevention Guidelines (PPG)[31]:
  - Understanding Your Environmental Responsibilities – Good Environmental Practices (PPG1);
  - Works and maintenance in or near water (PPG5);
  - Working at construction and demolition sites (PPG6); and
  - Safe Storage and disposal of used oils (PPG8);
- The Oil Care Code; and
- CIRIA's Environmental Good Practice on Site (CIRIA, 2010).

In adherence with this guidance, a number of best practice measures will be followed. All wastes generated on site will be removed in a timely manner and any materials and containers giving rise to possible spills or contamination of the surrounding environment will be taken from site to be processed at a licensed facility. In the event of a pollution incident then measures to report, manage and minimise any impacts will be pursued.

Plant will also be maintained regularly, will use biodegradable hydraulic oils and will carry spill kits in the event of an accident. Refuelling will be in designated sites away from the water to

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31 Environment Agency Pollution Prevention Guidelines (https://www.gov.uk/government/collections/pollution-prevention-guidance-ppg)

ARUN DISTRICT COUNCIL P/93/25/PL

limit the potential for spillages. Fuel will be stored in the site compound overnight, limiting the potential for fuel theft and vandalism which could cause pollution.

Should any pollution incidents occur, they will be reported immediately to the Environment Agency on the emergency hotline (0800 807060). The workforce will be trained in preventing and dealing with pollution incidents.

Given the resultant very low risk (due to the embedded mitigation measures included in the proposed project methodology), it is expected that the probability of occurrence will be low and the magnitude of change will be small/negligible. This will result in a negligible exposure to change on surface or groundwater receptors. Therefore, despite the high sensitivity of the harbour and high importance due to its UWWTD and WFD designated status, the potential impact of spillages on water quality is assessed as insignificant on the basis that there will be mitigation through adherence to good workings practices and guidance.

7.2.3 Impact Pathway 8: Effects on Status of Water Bodies During Operational Phase

7.2.3.1 General scientific context

The WFD establishes a framework for the management and protection of Europe's water resources (see Section 7.1.2.1). The fundamental aim of the WFD is to achieve good ecological and chemical status/potential in all inland and coastal water bodies by 2015, unless alternative objectives are set or there are grounds for derogation.

Developments in or interacting with the marine environment must assess the potential impacts on WFD water bodies, specifically against a series of ecological and chemical parameters (e.g. dissolved oxygen, nutrients and chemical pollutants). The objectives set under the WFD for all water bodies ensure that developments/schemes must:

- Not cause deterioration in status/potential;
- Not prevent the achievement of good status/potential;
- Not infringe or be in breach of other legislation; and
- Where possible, attempt to enhance the environment.

There are two designated water bodies in the direct vicinity of the proposed works, namely Sussex and Pagham Harbour water bodies (Environment Agency, 2009).

The Sussex coastal water body (ID: GB640704540003) is designated as a HMWB for coastal protection and fin-fisheries. The water body currently has an overall moderate potential, based on moderate ecological potential and good chemical status (Environment Agency, 2009). Moderate ecological potential is due to the mitigation measures assessment identifying numerous measures which are 'not in place' (disproportionately expensive). The current classification is reflected in the latest interim results (2014) whereby the Sussex water body is considered to have overall moderate potential, with moderate ecological potential and good chemical status.

ARUN DISTRICT COUNCIL P/93/15/PL

The Pagham Harbour water body (ID: GB570704700000) was described as coastal in the first cycle South East RBMP (Environment Agency, 2009); however, the second cycle South East draft RBMP (Environment Agency, 2014) and recent interim classifications have amended the designation to a transitional (i.e. estuarine) water body. Similarly, the water body was classified as an AWB in the 2009 classification, while the recent draft RBMP and interim results refer to the water body as a HMWB (reasons for designation unknown). For the purposes of this assessment, and to reflect the anticipated changes, the Pagham Harbour water body will be considered a transitional HMWB.

The overall status of the Pagham Harbour water body is currently moderate, based on moderate ecological potential and good chemical status ('does not require assessment'), and is therefore failing to meet its WFD objectives (Environment Agency, 2009). Moderate ecological potential is due to the biological element macroalgae and supporting element dissolved inorganic nitrogen (DIN) both being assessed as moderate (uncertain). This is reflected in the latest interim results from 2014, whereby overall status is considered moderate.

While these latest results also report ecological potential as moderate, however, the chemical status is assessed as failing to achieve good. In terms of ecological potential, macroalgae is still assessed as moderate, while DIN has been upgraded to good (2013) and high (2014) status in the latest interim results. The biological element angiosperms is also assessed as moderate in the interim results (2014), while the priority substance fluoranthene is failing to achieve good with regards to chemical status.

7.2.3.2 Project impact assessment

A WFD compliance assessment has been conducted to determine whether the proposed works at Pagham could cause a change to the status of WFD water bodies or change the ability of a water body to meet its future objectives (see Appendix H). While the project is expected to lead to changes in suspended sediments and water quality conditions on the marine environment during the construction phase (breach and infill), these are immediate to short term, small scale and localised (see Section 7.2.1).

Negligible changes to the existing condition of the Sussex and Pagham Harbour water bodies are anticipated for the operational phase. In addition, the project could potentially provide a relative improvement in WFD status/potential this is because the works are expected to marginally improve the tidal flushing of Pagham Harbour, thus potentially improving water quality by reducing the risk of excessive nutrient build-up which can lead to eutrophic events. Also, compared to the existing condition or a future unmanaged breach of Church Norton Spit it provides greater certainty of benefit and enhanced stability and marginally lower likelihood of inlet closure. Therefore, it is concluded that the proposed project will support the status and future objectives of nearby water bodies.

Following the impact assessment methodology, the probability of occurrence is considered to be high (because a physical change will occur) but the magnitude of change is considered to be negligible (given the scale and nature of the changes arising). The exposure to change is therefore considered to be negligible. Therefore, despite the potential high sensitivity of certain WFD parameters to change (e.g. dissolved inorganic nitrogen for Pagham Harbour), as well as

ARUN DISTRICT COUNCIL P/93/15/PL

the high importance of the harbour, the operational effects of excavating the breach and infilling the existing tidal channel on WFD water bodies is assessed as insignificant and is considered to be marginally beneficial given the marginally improved flushing levels of the harbour and improved potential stability of the breach.

7.3 Conclusions

Table 7.6 summarises the impact assessment judgements, presents final conclusions on overall impacts across all water and sediment quality impact pathways, and also provides an indication of the confidence in the respective assessments and evidence base. The impact assessment methodology (Section 5.2) provides an explanation of the iterative assessment process, including tables explaining how exposure, vulnerability and finally significance are assessed.

Table 7.6 Water Quality impact assessment summary and conclusions

Assessment	Summary
Exposure to change	Exposure of water and sediment quality parameters to impacts from the proposed project are considered to be negligible based on a low to high probability of occurrence and small to negligible magnitude of change.
Estimation of vulnerability	Although the sensitivity of features is high, water and sediment quality receptors will not be vulnerable to a negligible exposure to change.
Estimation of significance	The significance of the changes brought about by the proposed project on water and sediment quality is assessed as insignificant.
Conclusion	Due to the localised spatial extent of changes occurring over a short/temporary timescale and the embedded pollution control measures that will be in place during construction, impacts are assessed as insignificant. The longer-term effects are also considered to be insignificant but marginally beneficial given the marginally improved flushing levels of the harbour and improved potential stability of the breach.
Confidence assessment	There is a wide range of water quality monitoring data available in the vicinity of the proposed project. A reduced number samples have been recorded on sediment quality. In order to characterise sediment quality, therefore, the sediment characteristics at the site of the proposed project and potential sources of pollutants have also been considered. Overall, confidence in the baseline datasets and characterisation of water and sediment quality is considered to be high. There is also a high level of confidence in the conclusion relating to the physical process changes arising (as described in Section 6) which underpin judgements about the longer-term benefits/effects of the project.

ARUN DISTRICT COUNCIL P/93/25/PL

8. Nature Conservation and Ecology

This section reviews the effects of the proposed works on nature conservation and ecology receptors. Baseline information is provided in Section 8.1 followed by an impact assessment in Section 8.2.

8.1 Baseline Review

8.1.1 Data Sources

A range of data sources have been used to characterise the nature conservation and ecology baseline in the vicinity of the proposed works, including the following:

- Designated nature conservation site citations;
- Natural England's Regulation 35(3) advice package for Pagham Harbour European marine site (English Nature, 2001);
- Natural England SSSI condition website;
- Pagham Harbour Local Nature Reserve Management Plan (RSPB, 2013);
- Site Improvement Plan (SIP) for the Pagham Harbour SPA (Natural England, 2014)
- Environment Agency seagrass survey data, 2014;
- Seagrass survey data, 2005 (Balanced Seas, 2011);
- Habitat Action Plan for Sussex: Estuaries including sub-habitats of mudflat, seagrass beds and saltmarsh (Sussex Biodiversity Partnership, 2004);
- ABPmer site visits and photographs;
- Pagham Beach Coastal Defence Project Environmental Report (Royal Haskoning, 2013);
- JNCC Coasts and seas of the United Kingdom. Region 8 Sussex: Rye Bay to Chichester Harbour. (Barne *et al.*, 1998);
- Medmerry Managed Realignment Environmental Statement. (ABPmer, 2010);
- Survey for *Caecum armoricum* in Pagham Harbour, 2013 (Wilkinson and Baldock, 2013);
- Waterbirds in the UK 2013/14. The Wetland Bird Survey (Hold *et al.*, 2015);
- British Trust for Ornithology (BTO) Wetland Bird Survey (WeBS) data;
- RSPB bird monitoring data;
- Geological Conservation Review (GCR) report describing the coastal geomorphology of Pagham Harbour (May, 2003a); and
- Sussex Local Geological Sites with public access (Sussex Geodiversity Partnership, 2015).

Due to extent of available information, supplementary and bespoke ecological surveys have not been undertaken as part of this project and the assessment is underpinned by available data.

8.1.2 Nature Conservation Designations

Pagham Harbour has long been recognised as being an area of high nature conservation importance. The boundaries of all the designated sites within the study area are shown in

ARUN DISTRICT COUNCIL P/93/15/PL

Figure 8.1. The proposed project directly overlaps with a number of designated sites of local, national and intentional nature conservation interest:

- Pagham Harbour Special Protection Area (SPA);
- Pagham Harbour Ramsar Site;
- Pagham Harbour European Marine Site (EMS) (incorporates the SPA);
- Pagham Harbour Site of Special Scientific Interest (SSSI);
- Pagham Harbour Marine Conservation Zone (MCZ);
- Pagham Harbour Local Nature Reserve (LNR); and
- Pagham Harbour Regionally Important Geological and Geomorphological Site (RIGS).

It is also notable that an RSPB reserve ('Pagham Harbour and Medmerry') covers the majority of these designations; the extent of the reserve is shown in Figure 8.1.

The following nature conservation sites occur outside of Pagham Harbour but within the study area (defined as within 5km of the proposed project):

- Medmerry Managed Realignment[32] (4.0km from nearest boundary to proposed project);
- Bognor Reef SSSI (1.4km from nearest boundary to proposed project);
- Selsey East Beach SSSI (3.8km from nearest boundary to proposed project); and
- Bracklesham Bay SSSI (4.7km from nearest boundary to proposed project);
- Bognor Foreshore RIGS (2.0km from nearest boundary to proposed project);
- Selsey East Beach RIGS (3.8km from nearest boundary to proposed project); and
- Bracklesham Bay RIGS (4.7km from nearest boundary to proposed project).

There is no hydrodynamic or ecological connectivity between the proposed project and any of the above designated sites that occur outside of Pagham Harbour, and thus these sites have been scoped out of the EIA.

A further description of these designations is provided in Appendix F. The boundaries of the designations that have been scoped into the EIA in relation to the proposed project, as well as the latest Mean Low Water (MLW) line, are shown in Figure 8.2. Table 8.1 presents the qualifying features of these designated sites and provides a brief rationale for scoping them in or out of the EIA. The baseline information for the features that have been scoped into the assessment, and other flora or fauna of interest, is provided in Sections 8.1.3 to 8.1.8.

32 Paragraph 118 of the National Planning Policy Framework requires that potential SPAs, possible SACs, listed or proposed Ramsar sites, and any site identified as being necessary to compensate for adverse impacts on classified, potential or possible SPAs, SACs and Ramsar sites be treated in the same way as classified sites. Medmerry Managed Realignment is a site that was created to compensate for the loss of internationally designated habitat in the Solent by coastal squeeze. It is now managed as a wildlife reserve by RSPB.

ARUN DISTRICT COUNCIL P/93/25/PL

Table 8.1 Qualifying features of conservation designations of Pagham Harbour

Designation	Criteria	Qualifying/Notified Features	Scoping View
Pagham Harbour SPA	Article 4.1	Little Tern *Sterna albifrons* (breeding)	Scoped into the assessment on the basis that it is a marine feature that has ecological connectivity with the proposed project.
		Common Tern *Sterna hirundo* (breeding)	
		Ruff *Philomachus pugnax* (overwintering)*	
	Article 4.2	Dark-bellied Brent Goose *Branta bernicla bernicla* (overwintering)	
	Supporting habitats of qualifying features	Mudflat and sandflat communities	Scoped into the assessment on the basis that it is a marine feature that has hydrodynamic connectivity with the proposed project.
		Shallow water over intertidal areas (with permanent water channels)	
		Saltmarsh	
		Shingle for roosting	Scoped into the assessment on the basis that it is a marine feature that has physical and hydrodynamic connectivity with the proposed project.
Pagham Harbour Ramsar	Criterion 6	Dark-bellied Brent Goose *Branta bernicla bernicla* (overwintering)	Scoped into the assessment on the basis that it is a marine feature that has ecological connectivity with the proposed project.
		Black-tailed Godwit *Limosa limosa islandica* (overwintering)	
Pagham Harbour SSSI		Vegetated shingle beach	Scoped into the assessment on the basis that it is a marine feature that has physical and hydrodynamic connectivity with the proposed project.
		Coastal lagoon	Scoped into the assessment on the basis that it is a marine feature that has hydrodynamic connectivity with the proposed project.
		Saltmarsh	
		Broadleaved, mixed and yew woodlands	Scoped out of the assessment on the basis that this is a terrestrial feature that will not be affected by any of the activities or changes brought about by the proposed project.
		Littoral sediment, supralittoral sediment	Scoped into the assessment on the basis that it is a marine feature that has hydrodynamic connectivity with the proposed project.
		Breeding and overwintering birds	Scoped into the assessment on the basis that it is a marine feature that has ecological connectivity with the proposed project.
		Lowland grassland	Scoped out of the assessment on the basis that this is a terrestrial feature that will not be affected by any of the activities or changes brought about by the proposed project.
		Sand dunes, saltmarsh, shingle and low islands	Scoped into the assessment on the basis that it is a marine feature that has hydrodynamic connectivity with the proposed project.
		Geomorphology	Scoped into the assessment on the basis that it is a coastal feature that has physical and

ARUN DISTRICT COUNCIL P/93/25/PL

Designation	Criteria	Qualifying/Notified Features	Scoping View
			hydrodynamic connectivity with the proposed project.
		Nationally important communities of plants and invertebrates	Scoped into the assessment on the basis that these include marine features that could have hydrodynamic connectivity with the proposed project.
Pagham Harbour MCZ		Seagrass beds	Scoped into the assessment on the basis that it is a marine feature that has hydrodynamic connectivity with the proposed project.
		DeFolin's lagoon snail (Caecum armoricum)	Scoped into the assessment on the basis that it is a marine feature that potentially has physical and hydrodynamic connectivity with the proposed project.
		Lagoon sand shrimp (Gammarus insensibilis)	This species is only found in (Sidlesham) Ferry Pool lagoon which is a lagoon adjacent to the Pagham Harbour water body. Water levels in the lagoon are controlled by the RSPB via an inlet sluice from the harbour and a dropboard outlet sluice from the Pool (RSPB, 2013). This feature has therefore been scoped out of the assessment on the basis that there is no hydrodynamic connectivity and therefore it will not be affected by the proposed project.
Pagham Harbour RIGS	Stratigraphy	Underlying Tertiary deposits of London Clay	Scoped into the assessment on the basis that it is a geological feature that has potential physical connectivity with the proposed project.
	Sedimentology	Visible sediments in and around the Harbour, namely shingle beds and mud.	Scoped into the assessment on the basis that these sediments have physical and hydrodynamic connectivity with the proposed project.
	Palaeontology	London Clay beneath beach contains Tertiary flora fossils	Scoped into the assessment on the basis that there is potential physical connectivity with the proposed project.
	Geomorphology	Classic shingle spit landform and for the links between the coastal nearshore and offshore forms and sediments	Scoped into the assessment on the basis that it is a coastal feature that has physical and hydrodynamic connectivity with the proposed project.
	Historical	Site provides evidence of baymouth bar theory	Scoped out of the assessment on the basis that the proposed project will not affect past geomorphological development of the site.
	Biological	Wintering wildfowl and waders, breeding birds and also nationally important communities of plants and invertebrates	Scoped into the assessment on the basis that there is ecological connectivity with the proposed project.
	Educational value	Outstanding palaeobotanical site, key coastal geomorphology site and biological importance	Scoped into the assessment on the basis that there is potential physical, hydrodynamic and/or ecological connectivity with the proposed project.

* Wintering Ruff are an SPA qualifying feature, however, numbers of Ruff at Pagham Harbour are currently small and have been below SPA qualifying levels since the 1980s. Numbers of this species over-wintering within Southern Region and in Great Britain have also been decreasing in the long term and medium term respectively (Cook et al., 2013).

ARUN DISTRICT COUNCIL P/93/25/PL

8.1.3 Marine and Coastal Habitats

Essentially all intertidal and subtidal habitats in Pagham Harbour, as well as those immediately fronting it, are designated, as seen in Figure 8.2. The main intertidal habitats found are mudflats, saltmarshes and vegetated shingle. Small areas of seagrass are also found, as are several saline lagoons. These habitats are now described in more detail. Figure 8.3 provides a habitat map of these marine and coastal habitats found at Pagham Harbour. More detail is provided below on each habitat.

8.1.3.1 Saline lagoons

Saline lagoons are listed on Annex I of the Habitats Directive and are also listed as a habitat of principal importance (for the conservation of biodiversity in England) under Section 41 of the NERC Act.

According to the RSPB, there are some 13.6ha of saline lagoons in, and around, Pagham Harbour. These occur at Ferry Long Pool, Ferry Small Pool, Ferry Pool, Sidlesham Mill, the North Wall, the Severals, Pagham Lagoon and Little Lagoon (Pagham Spit). All are at least brackish, and salinities vary seasonally between 10 and 30 parts per thousand (ppt). Most of these lagoons are not tidal (i.e. the water levels in most are controlled by sluices, pipes and culverts). The RSPB manages water levels in several of those lagoons. Some have no water control *per se*, including Pagham Lagoon and Little Lagoon; which are influenced by tidal changes – Pagham Lagoon only slightly, and Little Lagoon more so. Waters in Little Lagoon rise several hours after high tide in the adjacent Harbour (RSPB, 2013).

The biggest lagoons are Pagham Lagoon, at approximately 9ha, and Ferry Pool, at some 1.6ha. The lagoon on Pagham Spit, Little Lagoon, measures just under 1ha. Pagham Lagoon and Little Lagoon are closest to the proposed works.

Pagham and Little Lagoons form Unit 1 of the Pagham Harbour SSSI. Pagham Lagoon is located within an in-filled palaeochannel of a former tidal inlet to the Harbour and is situated behind Pagham Beach, beyond the road and residential properties. Little Lagoon is on the end of Pagham Spit, adjacent to the training wall for the harbour entrance channel. When its condition was last assessed during the 2010 SSSI condition assessment, Unit 1 was considered to be in an unfavourable condition, but recovering. This was due to it having been affected by a pollution incident with an unknown source.

Surveys carried out by the University of Brighton indicated a rather impoverished flora and fauna in the Little Lagoon. Overall populations of lagoon taxa were still described as relatively good, but an absence of several taxa previously recorded that was reported, which indicated organic enrichment. A previously recorded diverse gastropod community was no longer evident however (Natural England SSSI condition website, accessed May 2015). Further monitoring was to be carried out, and surveys were planned from 2014 onwards (Natural England, 2014).

Invertebrates found in these lagoons are discussed in Section 8.1.4.

ARUN DISTRICT COUNCIL P/93/15/PL

8.1.3.2 Saltmarshes

Saltmarshes are listed on Annex I of the Habitats Directive and are also listed as a habitat of principal importance under Section 41 of the NERC Act. The saltmarshes of Pagham Harbour constitute supporting habitats for the bird interest features of the Pagham Harbour SPA (Brent Geese and wintering Ruff will occasionally feed on saltmarshes (English Nature, 2001))

Prior to the 1910 storm-induced breach of the (artificially) closed shingle barrier (see Section 6.2.6), the harbour had been shielded from the spread of *Spartina* that took place in the late 19th century (Cundy *et al.*, 2002). Once the 1910 breach occurred, *Spartina* colonised by 1919 and there were extensive marshes (129.6 ha) by 1948. By 1986 this had reduced to 96.7 ha indicating a loss of 0.87 ha/year occurring variably within the harbour. This loss is relatively small compared with the erosive losses occurring on more exposed south coast marshes and also in contrast to these external coastal marshes there was no evidence of internal die-back on the Pagham marshes (Cundy, *et al.*, 2002).

According to the RSPB, approximately 155 ha of saltmarshes currently occur within the harbour (RSPB, 2013). These marshes are accreting, so this area is expected to increase over time. Rates of accretion have ranged between 4 to 8mm per annum since the harbour re-opened in 1910, averaging at 5mm per annum (Cundy *et al.*, 2002). The RSPB states that "almost no active habitat management has been done" on the saltmarshes of the harbour (RSPB, 2013).

The SSSI citation (English Nature, 1980) describes the lower saltmarsh zones of Pagham Harbour as being dominated by the hybrid common cord-grass *Spartina anglica* with patches of the glassworts *Salicornia spp.* Above this zone sea-purslane *Artiplex portulacoides* covers large areas with other species such as sea aster *Aster tripolium* in the periphery. The upper margin of the saltmarsh has developed a narrow strip of grassland dominated by sea couch *Elymus pycnanthus*. A 2009 saltmarsh vegetation survey confirmed that the makeup of the Pagham Harbour saltmarshes had not changed significantly (RSPB, 2013)

According to the 2010 SSSI condition assessment, those SSSI units containing saltmarsh (Units 12, 20 and 21) were in favourable condition, though *Spartina* still dominated over large areas (Natural England SSSI condition website, accessed May 2015). Around much of the harbour, the saltmarshes are constrained by embankments, although some natural transition zones exist, most notably in the east of the Harbour, and around Church Norton (see Image 8.1).

8.1.3.3 Mudflats

Mudflats are listed on Annex I of the Habitats Directive and are also listed as a habitat of principal importance under Section 41 of the NERC Act. The mudflats of Pagham Harbour constitute supporting habitats for the bird interest features of the Pagham Harbour SPA.

According to the RSPB, some 140ha of mudflats are found within the harbour, which are not actively managed by the RSPB (RSPB, 2013). According to the 2010 SSSI condition assessment, those SSSI units containing mudflat (Units 12, 20 and 21) were in favourable condition (Natural England SSSI condition website, accessed May 2015).

ARUN DISTRICT COUNCIL P/93/15/PL



(Taken by ABPmer, May 2015)

Image 8.1 Pagham Harbour intertidal and transitions as viewed from the Church Norton side

Some of the mudflat area in Pagham Harbour is covered by seagrass beds (see next sub-section). Green algae covers the mudflats to varying degrees, depending on time of year and nutrient input; Ulva lactuca and Enteromorpha spp. Dominate in Pagham Harbour (English Nature, 2001).

Invertebrates found within these mudflats are listed in Section 8.1.4.

8.1.3.4 Seagrass beds

Seagrass beds are listed as a habitat of principal importance under Section 41 of the NERC Act, and also form one of the interest features which the Pagham Harbour MCZ was designated for. The seagrass beds are understood to form part of the 'mudflats and sandflats' supporting habitats for the bird interest features of the Pagham Harbour SPA (Brent Geese feed on seagrass, amongst others).

The MCZ selection assessment document (Balanced Seas, 2011) reports that the seagrass areas of Pagham Harbour measure 3ha and that there is a possibility that they may be remnants of plantings in the mid-1950s when the local wildfowlers tried to reintroduce seagrass into Pagham Harbour.

Spatial survey data obtained from the Environment Agency (and mapped in Figures 8.3 and 8.4) shows that, when last surveyed (in 2014), the seagrass beds measured approximately 3.4 ha, slightly more than in 2005 (the survey reported on in the MCZ documentation). It appears to now only occur in one area, rather than the two reported in the MCZ documentation. Furthermore, fluctuation in the extent is apparent, as the 2011 survey data (the other year provided by the Environment Agency) shows a bigger area measuring 8.6 ha (see Figures 8.3 and 8.4). This area is located in the south west part of the Harbour, in the intertidal zone – the surface level of the beds ranges between 0.8 and 1.3 mODN, which corresponds to mid to higher mudflat elevations. Two species of seagrass are evidently present, Zostera noltii and Z. angustifolia (Sussex Biodiversity Partnership, 2004).

ARUN DISTRICT COUNCIL P/93/15/PL

8.1.3.5 Spits and beaches

Church Norton Spit and Pagham Beach are characterised by steep upper beaches and shallower mid-beaches mostly composed of a flint shingle, which grades to coarse sand and granules on the extensive low gradient foreshore (Wallace, 1990; Barcock and Collins, 1991; Posford Duvivier, 2001). As the steep upper intertidal section of the shingle/gravel beaches are characterised by large interstitial spaces precluding the retention of water during low tide, there is little suitable habitat within the beach for organisms, particularly as the coarse sediments tend to be highly mobile (Royal Haskoning, 2013). Vegetated shingle is discussed in the next sub-section.

The mid to lower intertidal sections of Pagham Beach (and in some locations on Church Norton Spit and the ebb tidal delta) consist of a range of sediments from muds to shingle, predominantly sand and gravel, colonised by a diverse array of macroalgal species. The mid intertidal is covered in a wide band of green algae (e.g. *Ulva lactuca* and *U. intestinalis*), interspersed with tufts of brown fucoid species (e.g. *Fucus spiralis* and bladder wrack *F. vesiculosus*). There are areas of the lower intertidal where the sediments are stable enough to be colonised by brown and red algal species, with shallow pools of water where there are undulations in the sediment. Brown algae such as bladder wrack and knotted wrack *Ascophyllum nodosum*, and red algae such as Irish moss *Chondrus crispus* and false Irish moss *Mastocarpus stellatus* are very common, providing shelter for marine fauna such as shore crabs, periwinkles, shrimps and gobies (Royal Haskoning, 2013).

8.1.3.6 Vegetated shingle

Coastal vegetated shingle is a habitat listed on Annex I of the Habitats Directive and is also considered a habitat of principal importance under Section 41 of the NERC Act. It does not constitute a supporting habitat for SPA features *per se*, as roosting and nesting terns prefer bare to very sparsely vegetated shingle areas (vegetation cover of <10% is required) (English Nature, 2001). However, 'shingle for roosting' is considered a supporting habitat. Pagham Harbour and Church Norton Spit include some 13ha of vegetated shingle, and 26.5ha in total (RSPB, 2013, reporting on a 2009 survey).

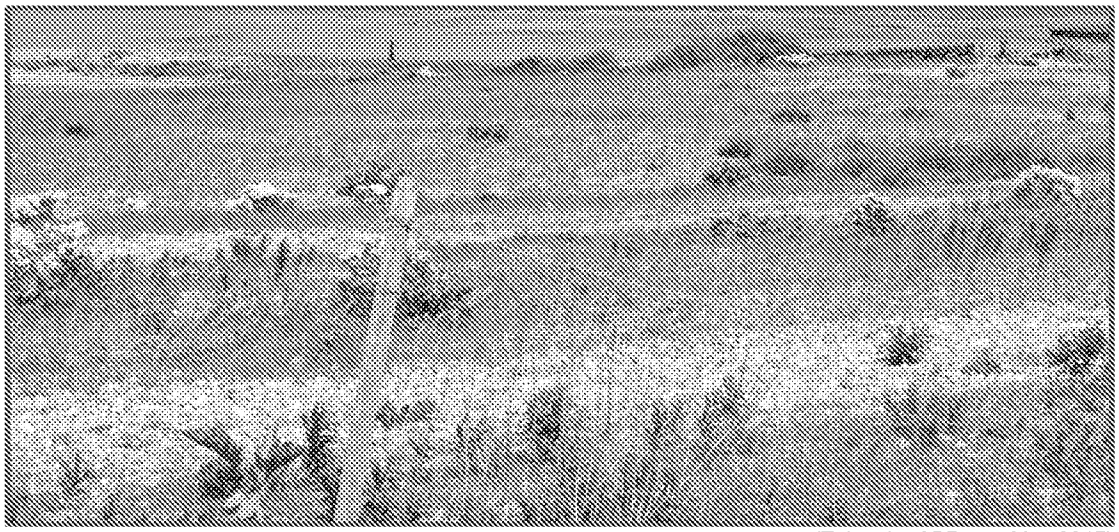
The SSSI units containing shingle vegetation at Pagham are assessed as being either in 'favourable' condition (Units 14, 15, 16 and 24) or in 'unfavourable no change' condition (Unit 23). The latter unit is considered in unfavourable condition due to a lack of appropriate weed control, as it has been heavily invaded by *Centrathus ruber* Red Valerian. Also, residents keeping boats on the unit is considered as contributing to some degradation. This unit is being affected by the erosion due to the harbour channel migration although this was not mentioned in the 2010 SSSI condition assessment.

The vegetated shingle at Pagham Harbour is classed as belonging to the *Rumex crispus – Glaucium flavum* community. The vegetation includes several positive indicator species, dominated by *Crambe* 163*rustace* Sea Kale with frequent *Elytrigia atherica* and occasional *Glaucium flavum* Yellow-horned Poppy, *Echium vulgare* Viper's-bugloss, *Sedum acre* Biting Stonecrop, *Tripleurospermum maritimum* Sea Mayweed, *Cerastium diffusum* Sea Mouse-ear and *Solanum dulcamara* Bittersweet. In addition, scattered *Silene uniflora* Sea Campion occurs on Pagham Spit. Furthermore, there are patches of lichen cover (*Cladonia spp.*) and

ARUN DISTRICT COUNCIL P/93/25/PL

black lichen in particularly undisturbed areas (Natural England SSSI condition website, accessed May 2015).

The RSPB reports that, on Church Norton Spit, the lichen Xanthoria candelaria and Macentina stigonemoides can also be found. Furthermore, the nationally important Childing Pink Petrorhagia nanteuilii annual can be found on the spits and Tern Island (RSPB, 2013) which is shown on Figure 1.1. The long established southwestern part of Church Norton Spit is more vegetated than the location of the breach and spit extension. Image 8.2 illustrates the vegetation that is present in the south-western part of the spit comprising a range of plant species. Image 8.3 shows the sparse vegetation (aproned 1% coverage) at the location of the breach predominantly sea kale in bloom.



(Taken by ABPmer, May 2015)

Image 8.2 Vegetated shingle on southwester part of Church Norton Spit



(Taken by ABPmer, May 2015)

Image 8.3 Vegetated shingle at the location of the proposed breach

ARUN DISTRICT COUNCIL P/93/15/PL

In recent years the shingle of Pagham Harbour does not appear to be managed apart from through the use of fencing for breeding bird protection. Through the 1990s and up to 2004 the Environment Agency carried out annual shingle recycling management for flood risk. This involved taking approximately 15,000 m³/year sediment on average from the harbour mouth nearshore banks and ebb delta to rebuild and reshape the beach fronting the Church Norton spit following winter storms (Bray et al., 2004). This work was not required after 2004 when it was clear that the Church Norton spit was accreting naturally and was self-maintaining (Section 6.2.6).

Inside the harbour, Tern Island, which was raised by 0.7 m in 1991 to bring more of the island above the high water mark and to counteract erosion and it is partially cleared of vegetation every year to provide nesting habitat for shorebirds (RSPB, 2013). In 2015, the vegetated half of Tern Island was furthermore 'scalloped' (i.e. small round sections were cleared of vegetation) as an experiment to attract more breeding terns (Tim Callaway, Hampshire & Isle of Wight Area Manager, RSPB, pers. Comm., May 2015).

Please note that the 'shingle for nesting' habitat areas are outlined in the ornithology section (Section 8.1.5).

8.1.3.7 Coastal subtidal environment

From Selsey Bill to Bognor Regis, the nearshore subtidal seabed predominantly consists of mixed sediments and sand. Typical species on mixed sediments and sand would include sandmason worms Lanice conchilega, anemones Urticina feline and Cerianthus lloydii. Mobile species would include the predatory gastropod molluscs Buccinum undatum and Hinia 165rustacean, occasionally starfish (e.g. Asterias rubens) and brittle stars (e.g. Ophiothrix fragilis), and commercially important species such as the common lobster Homarus gammarus, the edible crab Cancer pagarus and the spider crab Maja squinado. Several sublittoral species reach their easternmost extent of their distribution within Sussex waters. These include the rocky reef species such as jewel anemone Corynactis viridis, the Devonshire cup coral Caryophyllia smithii and the bryozoan Pentapora foliacea. Several non-native species have also become established, such as slipper limpet Crepidula 165rustacea (large quantities of empty shells exist in the strandline on Pagham Beach) and the stalked ascidian Styela clava (Barne et al., 1998).

For the Medmerry Managed Realignment EIA, a marine ecological survey of the fronting subtidal was undertaken and the results from that are now summarised to provide a broad characterisation of the local conditions because no dedicated information on the subtidal immediately fronting Pagham is available. In general the subtidal environment fronting Pagham should be similar to that fronting Medmerry (acknowledging though that Bracklesham Bay, where Medmerry lies, is likely slightly muddier as it lies at the entrance to the Solent). The Medmerry survey found an epifaunal flora which was dominated by a number of different species of red seaweeds and green seaweed but hardly any individuals of kelp were recorded throughout the study area. The dominant visible fauna were piddocks, polychaetes, the slipper limpet and ascidians. Other relatively large features were tube-dwelling polychaete reefs present on some of the rocky areas (ABPmer, 2010).

ARUN DISTRICT COUNCIL P/93/15/PL

8.1.4 Benthic Invertebrates

The lagoons around Pagham Harbour are notable as they have yielded some rare species, most notably two species which are designated MCZ features, namely the DeFolin's lagoon snail (*Caecum armoricum*) and the Lagoon Sand Shrimp (*Gammarus insensibilis*). These, and other lagoonal specialists, are discussed in the following subsection, before other invertebrates found around Pagham Harbour and the shingle habitats are discussed.

8.1.4.1 Lagoon specialists

Pagham Lagoon possesses characteristic invertebrate fauna that show little regional variation, for example, the lagoonal snails *Hydrobia ventrosa* and *Littorina tenebrosa* and the lagoonal isopod *Idotea chelipes*. The nationally endangered starlet sea anemone *Nematostella vectensis* has also been found in Pagham Lagoon (last recorded in 1990 according to RSPB, 2013). This species is protected under Section 5 of the Wildlife and Countryside Act 1981 and is a nationally important species within the Pagham Harbour Ramsar site.

The species present in Little Lagoon, at the end of Pagham Spit, are apparently similar to those recorded within the Pagham Lagoon, with the exception of *N. vectensis* (Barne *et al.*, 1998). Furthermore, it is here that a 2013 survey found many specimens of the DeFolin's lagoon snail. A detailed baseline review of this species is now presented in the next sub-section.

8.1.4.2 DeFolin's lagoon snail

The DeFolin's lagoon snail is a very small gastropod, which measures only around 2mm long, and looks nothing like the more familiar sea snails with its curved test-tube like shell (White, 2007); see Image 8.4. It is considered nationally rare, and is protected under Schedule 5 of the (1981) Wildlife and Countryside Act in 1992 (Sections 9.1, 9.2, 9.4 (a to c) and 9.5a). This snail is one of the three features protected by the Pagham Harbour MCZ (see Section 8.1.2).



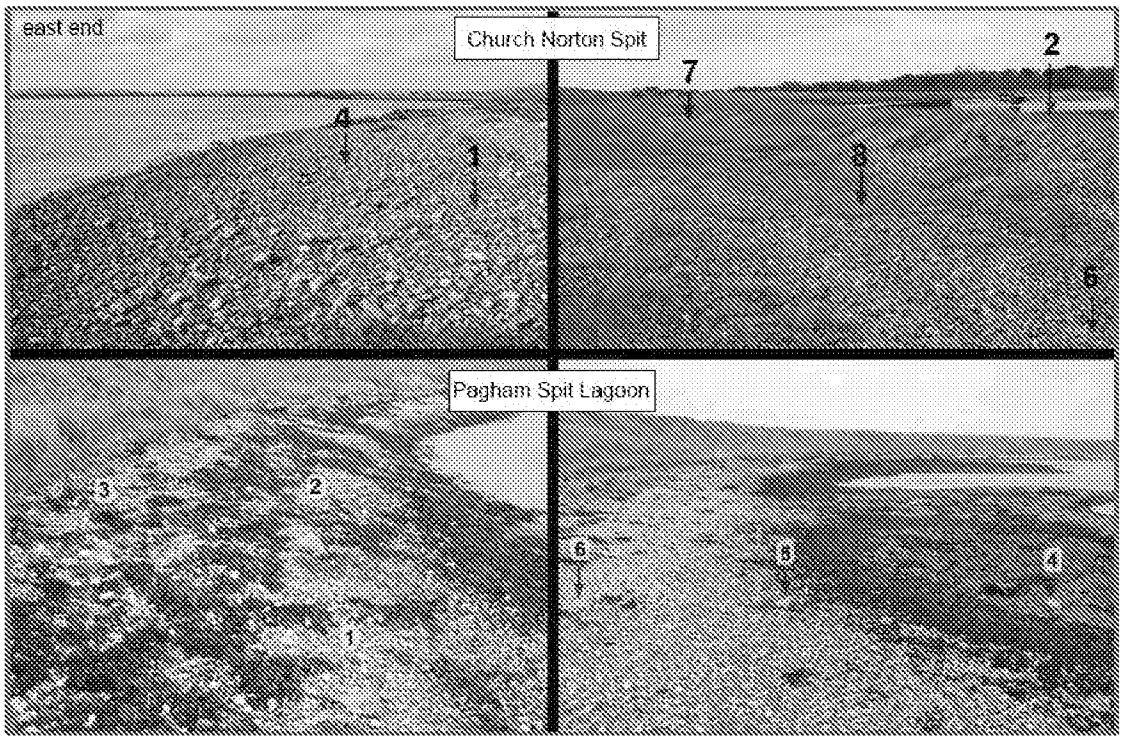
(Source: Baldock and Bass, 2012)

Image 8.4 DeFolin's lagoon snail (copyright Lin Baldock)

ARUN DISTRICT COUNCIL P/93/25/PL

In 2007, both live and dead C. armoricum specimens were found during a survey undertaken on Church Norton Spit[33]. The location of these specimens were on the landward side of the spit, just below the High Water Spring line, in habitat described as 'small pebbles with patches of organic detritus just below the surface layer'. Two samples were taken; these contained approximately 20 shells per sample, which were described as 'fresh dead', as well as 'at least one or two live individuals per sample' (Pain et al., 2009, p. 780). Figures 8.4 and 8.5 show the locations of this find, as well as the sample locations, and results, of the 2013 survey which is described in the following paragraphs. The surveyors found that the gastropod mollusc (snail) Truncatella subcylindrica was abundant in these samples, as was the bivalve Lasaea rubra.

In March 2013, a dedicated DeFolin's lagoon snail survey was undertaken at Church Norton Spit and Little Lagoon on behalf of Natural England. Locations were selected based on insights gained during survey work at the Fleet (Dorset), which had shown that the DeFolin's lagoon snail appears to prefer pebbles that are loose and uncompacted, and where the gastropod Truncatella are often found (see also Appendix J for more detail). Intertidal sediments samples were collected at around the high tide level at 11 locations on the inland side of Church Norton Spit where the gastropod Truncatella was found, and where the shingle was relatively free of interstitial sand and fine sediment. At Pagham Spit Lagoon (also known as 'Little Lagoon'), seven samples were taken from the southwest end. Most of the sample locations are shown in Image 8.5 below (Wilkinson and Baldock, 2013); all of them are mapped in Figure 8.5.



(Source: Wilkinson and Baldock, 2013; Plates 1 to 4)

Image 8.5 Sample locations for the 2013 DeFolin's lagoon snail survey

33 The original purpose of this survey was to gain further insights into the habitat preferences of the gastropod mollusc Truncatella subcylindrica, which was known to occur on the Spit.

ARUN DISTRICT COUNCIL P/93/25/PL

The results are detailed in Table 8.2 and mapped in Figure 8.5. At Church Norton Spit, no live C. armoricum were found within the samples taken during the 2013 survey. Only four dead shells and several shell fragments were recorded; including at the site where the 2007 finds took place (Site 7). It was thought that the presence of entire dead shells, as well as shell fragments, does however suggest that there is an extant population in close vicinity of the sampling sites. At Little Lagoon, 16 live DeFolin's lagoon snails were found at three of the seven sample locations at mid-shore level, with recently dead shells from five locations. Locations 1 and 2 yielded a particularly high number of finds. The finds demonstrated that this species occupies a very restricted intertidal zone on the lagoon shore (Wilkinson and Baldock, 2013).

Table 8.2 The occurrence of DeFolin's lagoon snail during the 2013 survey

Type	Church Norton Spit											Little Lagoon						
	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	4b	5	6
Dead shells	1+	+		1+	+		1+			1+		1						
Fresh dead adult												15	7		3	3	1	
Live adult												8	5				1	
Live juvenile												1			1			
Fresh dead juvenile												16	198					
+ Shell fragment																		

No samples were taken in the area where the breach is proposed to take place.

8.1.4.3 Other invertebrates

According to the Pagham Harbour SSSI citation, 'notable invertebrates include the sand dart Agrotis ripae, Matthew's wainscot moth Mythimna favicolor and the long-winged conehead grasshopper Conocephalus discolour' (English Nature, 1980). Toadflax brocade moth occurs on the shingle spits and eastern part of Pagham Harbour. Flame wainscot moth is another notable species that has been recorded in the nature reserve but outside the tidal reaches of the harbour. The mudflats of Pagham Harbour are rich in invertebrates, particularly polychaetes such as the lugworm Arenicola marina and the ragworm Nereis diversicolor.

During the 2013 DeFolin's lagoon snail survey (Wilkinson and Baldock, 2013; see Section 8.1.4.2), the surveyors also noted other invertebrate fauna found, commenting that 'all samples from Church Norton Spit lacked the diversity of fauna found at the Pagham Spit Lagoon site' (Wilkinson and Baldock, 2013; p.3). The following invertebrates were also recorded in the samples taken from Church Norton Spit during the survey; noting number of survey stations observed and also abundance per sample (rare, occasional, frequent, common, abundant):

- Bivalve mollusc Mytilus edulis (found at 1 (of 11) locations, rarely found);
- Gastropod molluscs: T. subcylindrica (9, mostly occasional, frequent at location 8); Auriculinella bidentata (3, rare to occasional & shell); Myosotella myositis (3, occasional & shell);
- Amoeboid protists Foraminifera (2, rare);
- Worms: nematoda (1, occasional); enchytraeidae (5, mostly occasional);

ARUN DISTRICT COUNCIL P/93/15/PL

- Chelicerata mites (2, rare); and
- Flies: chironomidae (2, occasional & rare), diptera larvae (2, rare).

Please note that invertebrates which are likely to be found in the subtidal marine environment fronting Pagham Beach and Church Norton Spit were summarised in Section 8.1.3.7.

8.1.5 Ornithology

Pagham Harbour provides habitat for important populations of breeding tern species, overwintering Ruff and Dark-bellied Brent Goose, as well as regularly supporting in excess of 18,000 migratory waterbirds (Holt et al., 2015; English Nature, 2001).

Baseline information on waterbirds was collected through a desk based review of published literature and includes the following key data sources:

- Pagham Harbour Wide Wetland Bird Survey (WeBS) Core Counts (Describing Roosting Birds) Over 5 years from 2009/10-2013/14: The latest annual WeBS report[34] provides the most up-to-date details of the high water 'Core Count' data for Pagham Harbour covering the five winter periods up to 2013/14 (Holt et al., 2015). It provides a single, comprehensive source of information on the current status and distribution of waterbirds in the UK;
- Pagham Harbour Wide WeBS Low Tide Counts (Describing Feeding and Loafing Birds): WeBS Low Tide counts for Pagham Harbour were undertaken between 1995/96 and 1999/00 and also in 2013/14. Data for the most recent five years (2013/14 and 1996/97 to 1999/00) is summarised in the report;
- Population Trends for Species in the South of England: Information on long term trends in the population status of waterbirds in the south of England is available for the period up to 2009/2010 from the latest Wetland Bird Survey 'Alerts Report' (Cook et al., 2013). This is an information source describing waterbird numbers on protected areas and has an 'alert system' where species that have undergone major declines in numbers are identified;
- WeBS Core Counts at Pagham Spit and Church Norton Spit (Describing Roosting Birds) Over 5 Years from 2009/10-2013/14: The latest WeBS Core Count data were obtained from the British Trust for Ornithology (BTO) for the WeBS count sector which overlaps with the foreshore along Pagham Spit and Church Norton Spit ('Pagham Sea-20418');
- WeBS Low Tide Counts at Pagham Spit and Church Norton Spit (Describing Feeding and Loafing Birds) 2013/14: The latest WeBS Low Tide count data was obtained from the British Trust for Ornithology (BTO) for the count sectors which overlap with the foreshore along Pagham Spit and Church Norton Spit (BP001 and BP023); and

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[34] The annual WeBS report presents the results of WeBS and includes data from other national and local waterbird monitoring schemes. It provides a single, comprehensive source of information on the current status and distribution of waterbirds in the UK.

ARUN DISTRICT COUNCIL P/93/15/PL

- Breeding Waterbird Numbers: Monitoring data provided by the RSPB on the breeding status of terns, gulls and waders in Pagham Harbour.

The baseline ornithological review has been split into the following discrete sections:

- Statutory Designations in Pagham Harbour: Summary information from the Pagham Harbour SPA and Ramsar citations (Section 8.1.5.1).
- Feeding and Roosting Waterbirds within Pagham Harbour: The status of waterbirds (such as waders, waterfowl and seabirds[35]) using Pagham Harbour for feeding and roosting. This section describes harbour-wide waterbird populations (Section 8.1.5.2).
- Feeding and Roosting Waterbirds birds along Pagham Spit and Church Norton Spit: Data describing localised bird numbers specifically along Pagham Spit and Church Norton Spit (Section 8.1.5.3).
- Terns and Other Breeding Waterbirds in Pagham Harbour Including Church Norton Spit: The status of terns and other breeding waterbirds using Church Norton Spit and other key sites in Pagham Harbour (Section 8.1.5.4).

8.1.5.1 Statutory designations in Pagham Harbour

Pagham Harbour qualifies as a Special Protection Area (SPA) and Ramsar site for supporting passage and wintering bird populations of European and international importance (English Nature, 2001). These designations are presented in Section 8.1.2 and described in detail in Appendix F. The location and extent of these designated sites within the harbour is shown in Figure 8.2. Summary information on the abundances of bird qualifying species within the SPA and Ramsar citations (i.e. at the time of designation) are presented in Tables 8.3 and 8.4 respectively.

Table 8.3 Qualifying bird species in the Pagham Harbour SPA

Internationally Important Populations of Regularly Occurring Annex 1 Species	
Species	Breeding Population
Little Tern	7 pairs (0.3% of British population, 5 year mean1992-1996)
Common Tern	0 pairs (0% of British population, as at 1996)
	Wintering Population
Ruff	10 individuals (1.4% of the British population, 1995-1999)
Internationally Important Populations of Regularly Occurring Migratory Species	
Species	Wintering Population (5 year Peak Mean 1991/92-1995/96)
Dark-bellied Brent Goose	1,794 individual birds (0.6% of Western Siberian/Western European population)
*** The 2001 SPA Review of the Pagham Harbour SPA considered Pintail should be listed as a regularly occurring migratory species (628 individuals representing 1% of the wintering Northwestern Europe population).	

35 In the UK seabirds are considered to be species within the families Procellariidae–petrels and shearwaters, Hydrobatidae–storm-petrels, Phalacrocoracidae–cormorants/shags, Stercoraridae–skuas, Laridae–gulls, Sternidae-terns and Alcidae–auks).

ARUN DISTRICT COUNCIL P/93/25/PL

Table 8.4 Qualifying bird species in the Pagham Harbour Ramsar

Ramsar Criterion 6 – Species/Populations Occurring at Levels of International Importance	
Species	Species with Peak Counts in Winter (5 Year Peak Mean 1998/9- 2002/3)
Dark-bellied Brent Goose	2,512 individual birds (1.1% of the population)
Ramsar Criterion 6 – Species/Populations Identified Subsequent to Designation for Possible Future Consideration	
Species	Species with Peak Counts in winter (5 Year Peak Mean 1998/9- 2002/3)
Black-tailed Godwit	377 individual birds (1% of the population)

The possible/draft marine Solent and Dorset Coast SPA is proposed to cover the foraging activity for Little, Sandwich and Common Tern species designated at the adjacent qualifying breeding tern SPA colonies along the Solent and Dorset coast. The proposal is currently being finalised with formal consultation planned for 2015.

8.1.5.2 Waterbirds within Pagham Harbour

Roosting Abundance and Distribution at High Water

The Wetland Bird Survey (WeBS) is the monitoring scheme for non-breeding waterbirds in the UK which is organised by the BTO. WeBS Core Counts are the coordinated monthly counts of waterbirds (wildfowl and waders) on inland and coastal wetlands. The surveys are principally undertaken from September to March, with fewer observations made during summer months. They are undertaken generally on high tides, by volunteer counters who submit their data to the BTO for analysis. Therefore they describe roosting bird numbers in the estuary at high water.

In order to describe the existing ornithological interest of the study area, the most recent Core Count data have been obtained from the BTO. When describing the importance of a site for waterbirds, it is standard practice to use the most recent five years of data that are available. A summary of the peak numbers in Pagham Harbour over the period 2009/10 to 2013/14 is presented in Table 8.5. The extent of the Pagham Harbour WeBS Core Count sector is shown on Figure 8.6. Long term trends for key species in Pagham Harbour based on WeBS alert data is summarised in Figures 8.7a and 8.7b (Cook et al., 2013). The location of the main roosting sites for wading birds in Pagham Harbour based on data provided by the RSPB is shown in Figure 8.8.

The most commonly occurring wildfowl (ducks and geese) species recorded in Pagham Harbour in the Core Count surveys was the Dark-bellied Brent Goose and Wigeon with 5-year peak means of 2,529 and 2,770 birds respectively. Both of these species have remained relatively stable or increased in the long term (i.e. the last 25 years) but have declined in the medium term (i.e. last ten years) in the south of England (Figure 8.7a). Dark-bellied Brent Goose generally roost in areas of shallow standing water in Pagham Harbour at high tide (English Nature, 2001). Other commonly occurring wildfowl species recorded as part of the surveys included Teal, Pintail and Canada Goose.

ARUN DISTRICT COUNCIL P/93/15/PL

Overwintering Lapwing and Dunlin were the most abundant wading bird species recorded in the surveys. These species had 5-year peak means of 2,445 and 1,821 birds respectively. Both of these species have showed a decline in both the medium term and short term in south of England (Figure 8.7b). The reduction in Dunlin numbers in the south of England echoes wider trends at a national scale. This decrease has been associated with an increase in The Netherlands, implying that a larger proportion of birds from northern breeding populations were wintering on the Dutch Wadden Sea probably as a result of climatic amelioration (Thaxter et al., 2010). Black-tailed Godwit, Grey Plover, Golden Plover, Knot and Curlew were other waders also recorded in relatively high abundances (5-year peak means of >500 birds).

Saltmarsh and the damp unimproved grassland surrounding the harbour are used by roosting wading birds at high water. Lapwing and Golden Plover primarily roost in the north eastern parts of Pagham Harbour on a rising tide. On a low high tide Dunlin, Grey Plover and Knot primarily roost on upper shore habitat in the eastern parts of Pagham Harbour. On very high tides Dunlin, Grey Plover and Knot roost on the ends of Church Norton Spit. Oystercatcher primarily roost on Tern Island and Redshank on elevated intertidal habitat in the southwest of the harbour (Figure 8.8).

ARUN DISTRICT COUNCIL P/93/25/PL

Table 8.5 Latest high water WeBS core count data for Pagham Harbour (2009/10 to 2013/14)

Taxonomic Group	Species	2009/10	2010/11	2011/12	2012/13	2013/14	5-year Peak Mean
Duck, geese and swan (Anatidae)	Mute Swan	32	26	65	27	73	45
	Greylag Goose	1	3	32	1	3	8
	Canada Goose	54	95	112	257	124	128
	Brent Goose (Dark-bellied)	3,015	2,453	2,500	2,351	2,325	2529
	Shelduck	317	362	270	215	290	291
	Wigeon	2,738	1,752	4,057	2,605	2,697	2770
	Gadwall	7	36	16	12	8	16
	Teal	1,240	966	681	1,823	1,014	1145
	Mallard	305	329	317	360	214	305
	Pintail	337	552	187	335	244	331
	Shoveler	25	49	15	36	91	43
	Pochard		16	11	1	4	6
	Tufted Duck	37	44	44	70	51	49
	Scaup	2	6				2
	Eider	2	4			7	3
	Long-tailed Duck					3	1
	Common Scoter		31	21	16	10	16
	Velvet Scoter				2		>1
	Goldeneye	8	10	12	10	11	10
	Red-breasted Merganser	19	17	25	22	39	24
Divers (Gavidae)	Red-throated Diver		1		1	4	1
	Black-throated Diver		1				>1
	Great Northern Diver	1		1			1
Grebes (Podicepidida) and Cormorants (Phalacrocoracidae)	Little Grebe	21	31	35	37	32	31
	Great Crested Grebe	31	25	26	25	30	27
	Cormorant	254	291	239	171	167	224
Herons and Egrets (Ardeidae)	Little Egret	95	70	49	91	76	76
	Grey Heron	10	7	14	9	15	11

ARUN DISTRICT COUNCIL P/93/15/PL

Taxonomic Group	Species	2009/10	2010/11	2011/12	2012/13	2013/14	5-year Peak Mean
Rails (Rallidae)	Moorhen	65	56	41	53	26	48
	Coot	121	206	156	78	155	143
Waders (Rallidae, Haematopodidae, Recurvirostridae, Burhinidae, Charadriidae and Scolopacidae)	Oystercatcher	192	382	311	266	244	279
	Avocet	18	18	19	20	21	19
	Ringed Plover	187	80	93	213	196	154
	Golden Plover	310	470	650	836	600	573
	Grey Plover	1,329	1,215	528	919	1,066	1011
	Lapwing	1,195	1,438	2,067	4,107	3,420	2445
	Knot	798	500	700	1,450	834	856
	Sanderling	12	4	2	3	41	12
	Dunlin	2,299	1,706	1,619	1,483	1,999	1821
	Ruff	1	3	1	1	1	1
	Snipe	20	34	22	55	36	33
	Black-tailed Godwit	833	806	137	562	1,000	668
	Bar-tailed Godwit	6	12	24	19	25	17
	Whimbrel	38	5	13	19	8	17
	Curlew	451	799	453	402	480	517
	Redshank	271	386	349	226	252	297
	Turnstone	230	220	325	444	510	346
Gulls (Laridae) and Terns (Sternidae)	Black-headed Gull	471	770	583	663	878	673
	Mediterranean Gull	114	336	123	133	375	216
	Common Gull	68	109	77	61	78	79
	Lesser Black-backed Gull	2	15	4	7	4	6
	Herring Gull	236	422	207	232	873	394
	Great Black-backed Gull	195	424	252	176	240	257
	Little Tern	35	13	20	29	24	24
	Sandwich Tern	38	142	53	32	36	60
	Common Tern	23	30	16	32	31	26

ARUN DISTRICT COUNCIL P/93/25/PL

Feeding Abundance and Distribution at Low Water

WeBS Low Tide Counts aim to periodically record bird distributions on the major estuaries in the UK. The exposed substratum at low water (i.e. intertidal area) is divided into sectors, enabling the distribution of feeding and loafing birds to be determined in finer detail. The most recent data that were available for Pagham Harbour were obtained from the BTO. Table 8.6 presents the peak counts over the period 1996/97 to 1999/00 and 2013/14. The extent of the Pagham Harbour Low Tide sectors is shown in Figure 8.9. The distribution of birds based on the 2013/14 survey is shown in Figures 8.10a to 8.10c.

The most commonly occurring wildfowl species recorded in Pagham Harbour in the Low Tide counts was the Dark-bellied Brent Goose, Wigeon and Teal. This is consistent with the wildfowl species recorded in highest numbers in the WeBS Core Counts described above which primarily correspond to roosting birds. Dark-bellied Brent Goose had a 5-year peak mean of 1,629 birds with the 5-year peak mean of Wigeon and Teal approximately 1,285 and 767 birds respectively. Wigeon and Dark-bellied Brent Goose were generally distributed along northern and eastern areas of Pagham Harbour in the 2013/14 survey with Teal showing a more scattered distribution (Figure 8.10a).

Dunlin was the most abundant wading bird species recorded in the Low Tide Counts with a 5-year peak mean of 3,183 birds. Flocks of Dunlin were widely distributed throughout Pagham Harbour in the 2013/14 survey (Figure 8.10b).

Other abundant waders recorded in the Low Tide Counts included Lapwing and Grey Plover with 5-year peak means of 1,456 and 816 birds respectively. Lapwing were widely distributed in high densities throughout much of Pagham Harbour with Grey Plover primarily restricted to northern areas of Pagham Harbour and along Church Norton Spit (Figures 8.10b and 8.10c).

Other frequently recorded wading bird species such as Black-tailed Godwit, Curlew and Redshank were widely distributed throughout the harbour in the surveys (Figures 8.10b and 8.10c).

ARUN DISTRICT COUNCIL P/93/25/PL

Table 8.6 Latest WeBS low tide data for Pagham Harbour (1996/97 to 1999/00 and 2013/14)

Taxonomic Group	Species	1996/97	1997/98	1998/99	1999/00	2013/14	5 Year Peak Mean	Low Water Distribution Based on the Results of the 2013/14 Survey
Duck, geese and swan (Anatidae)	Brent Goose (Dark-bellied)	2,982	1,312	538	990	2,325	1,629	Dark-bellied Brent geese are found in tidal estuaries mainly feeding on eelgrass (Zostera marina) and sea lettuce (Ulva). At low water they were primarily distributed on the mudflats in the north and eastern parts of Pagham Harbour. The species was also recorded on nearby fields. Since the 1970s, Dark-bellied Brent Geese have diversified their feeding habits to include farmland with cereals and pasture, and amenity grasslands in the region (Hampshire and Isle of Wight Wildlife Trust, 2010).
	Shelduck	239	365	177	86	206	215	Primarily recorded on the eastern and northern parts of Pagham Harbour.
	Wigeon	1,100	2,745	450	929	1203	1,285	Widely distributed with the highest densities in the north and eastern parts of Pagham Harbour.
	Teal	949	1,660	525	475	224	767	Scattered distribution throughout Pagham Harbour.
	Mallard	121	853	172	188	137	294	Primarily recorded in Pagham Lagoon.
	Pintail	759	1,134	391	445	244	595	Recorded along the northern and eastern parts of Pagham Harbour.
	Canada Goose	24		1	4	77	27	No information available.
	Mute Swan	16	7	10	18	20	14	
Waders (Rallidae, Haematopodidae, Recurvirostridae, Burhinidae, Charadriidae and Scolopacidae)	Oystercatcher	251	273	141	55	114	167	Mainly recorded in the southern end of Pagham Harbour and along Church Norton Spit.
	Ringed Plover	153	71	46	57	102	86	Mud and sand habitat around islets at the southern end of Pagham Harbour.
	Golden Plover	850	568	171	361	550	500	Widely distributed with the highest densities on the western part of the harbour.
	Grey Plover	978	1436	381	221	1,066	816	Mudflat along the northern part of Pagham Harbour, particularly near the main ferry channel. Also recorded along Church Norton Spit.

ARUN DISTRICT COUNCIL P/93/15/PL

Taxonomic Group	Species	1996/97	1997/98	1998/99	1999/00	2013/14	5-Year Peak Mean	Low Water Distribution Based on the Results of the 2013/14 Survey
	Lapwing	1,788	941	527	794	3,230	1,456	Widely distributed in high densities throughout much of Pagham Harbour.
	Knot	258	286	147	281	509	296	Primarily recorded along the western side of harbour and along Church Norton Spit.
	Dunlin	3,525	5,910	2,383	2,096	1,999	3,183	Widely distributed throughout Pagham Harbour.
	Black-tailed Godwit	59	72	124	300	619	235	Scattered distribution throughout the harbour.
	Bar-tailed Godwit	21	282	6	3	25	67	Recorded in low densities.
	Curlew	359	247	465	387	480	388	Scattered distribution throughout the harbour.
	Redshank	450	328	150	163	172	253	Scattered distribution throughout the harbour.
	Turnstone	411	161	91	32	212	181	Recorded in small flocks, primarily on Church Norton Spit.
Grebes (Podicepidida) and Cormorants (Phalacrocoracidae)	Little Grebe	4	6	8	14	19	10	No information available.
	Great Crested Grebe	13	6	14	24	3	12	
	Cormorant	60	97	40	6	36	48	
Herons and Egrets (Ardeidae)	Little Egret	7	10	4	10	18	10	
	Grey Heron	14	4	7	6	4	7	
Gulls (Laridae)	Black-headed Gull	3	Not counted	Not counted	Not counted	319	161	
	Mediterranean Gull	Not counted				375	375	
	Common Gull					78	78	
	Lesser Black-backed Gull					4	4	
	Herring Gull					873	873	
	Great Black-backed Gull					240	240	

ARUN DISTRICT COUNCIL P/93/15/PL

Diving Birds and Seabirds

Pagham Harbour also supports wintering and passage seaduck (Merginae), diving duck (Aythyinae) and grebes (Podicepididae). Most seaduck and diving duck species undertake surface diving to capture molluscs such as mussels and clams as well as crustacea. Some seaduck species are piscivores such as mergansers. Divers and grebes are piscivores, preying on a variety of small fish such as clupeids, sandeel and small gadoids by undertaking pursuit diving (BirdLife International, 2012).

Seaducks and diving ducks are typically recorded in low numbers in Pagham Harbour with Tufted Duck, Common Scoter, Goldeneye and Red-breasted Merganser recorded most commonly (peak WeBS counts of approximately 10 to 50 birds annually). The Great Crested Grebe and Little Grebe are also recorded in Pagham Harbour (peak WeBS counts of approximately 20 to 40 birds annually). Very few divers (Gaviidae) have been recorded in the WeBS surveys.

Commonly recorded seabird species in Pagham Harbour include gulls, terns and Cormorant. Black-headed Gull, Mediterranean Gull and Herring Gull were the most abundant gull species recorded in WeBS Core Counts. These species are recorded year round in Pagham Harbour with the largest numbers recorded in winter and passage periods. Gulls are generalist feeders, utilising both terrestrial and marine habitats. Small numbers of gulls also breed in Pagham Harbour. Gulls and terns breeding in Pagham Harbour are discussed in more detail in Section 8.1.5.4.

8.1.5.3 Waterbirds along Pagham Spit and Church Norton Spit

Roosting Abundance and Distribution at High Water

The WeBS Core Count sub-sector Pagham Sea (20418) covers the upper foreshore along Pagham Spit and Church Norton Spit. The extent of this sub-sector is shown in Figure 8.6.

The most recent five years of data for the overwintering period that is currently available (2009/10 to 2013/14) was obtained from the BTO (Table 8.7). As described previously, Core Counts are generally on high tides and are therefore primarily describe roosting bird numbers.

To help describe the value of the site in a national and regional context, the overall peak mean counts in Tables 8.7 are also compared against the previously recorded harbour-wide abundance WeBS Core Counts (see Table 8.5) for the most recently available five years (2009/10 to 2013/14)) and against the national 'importance thresholds' (Holt et al., 2015)[36].

In general, Pagham Spit and Church Norton Spit are used by moderate numbers of waterbirds at high water during winter and passage periods, particularly waders and gulls.

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36 A wetland in Britain is considered nationally important if it holds 1% or more of the estimated British population of one species or subspecies of waterbird and the threshold numbers are based on this 1% value.

ARUN DISTRICT COUNCIL P/93/15/PL

Dunlin was the most abundant wading bird recorded in the recent WeBS Core Count surveys. The 5-year peak mean of Dunlin was 636 birds in this sub-sector which represented 35% of the total abundance recorded across the entire Pagham Harbour area (when compared to 5-year harbour-wide peak mean counts from the 2009/10 to 2013/14 WeBS Core Count period).

Five year peak mean counts of approximately 100 to 200 Grey Plover, Knot and Turnstone were also recorded. The peak mean count of Grey Plover represents 13% of the 5-year harbour-wide counts. The values of Knot and Turnstone represent 25% and 55% respectively of the total abundance recorded in Pagham Harbour.

Moderate to low numbers of other wading birds including Ringed Plover (5-year peak mean of 94 birds, representing 61% of harbour-wide counts) and Oystercatcher (5-year peak mean of 55 birds, representing 20% of harbour-wide counts) were also recorded during the surveys.

Dark-bellied Brent Goose was the most commonly recorded wildfowl species with a 5-year peak mean of 55 birds (representing 2% of the total abundance recorded in Pagham Harbour). Low numbers of other wildfowl including Teal and Wigeon were also recorded roosting at high water in the sector (5-year peak means of 9 and 10 birds respectively, representing <1% of the 5-year harbour-wide peak mean counts).

Small flocks of seaducks and diving ducks including Red-breasted Merganser, Common Scoter, Long-tailed Duck and Eider were also recorded offshore from the spits.

Large numbers of gulls including Black-headed Gull and Herring Gull (5-year peak mean of approximately 250 birds for both species) were recorded during winter and spring periods. Small numbers of Tern species were also recorded in the WeBS Core Count surveys during spring and summer months along Pagham Spit and Church Norton Spit. Gulls and terns breeding in Pagham Harbour are discussed in more detail in Section 8.1.5.4.

ARUN DISTRICT COUNCIL P/93/25/PL

Table 8.7 Winter WeBS core counts data for the Pagham Sea sector (2009/10 to 2013/14)

Taxonomic Group	Species	2009/10	2010/11	2011/12	2012/13	2013/14	5-year Peak Mean	Winter 5-Year Peak Mean (2009/10 to 13/14) as: % of National Thresholds and WeBS 5-Year Harbour-Wide Peak Mean	
								% National Threshold	% Harbour-Wide WeBS Count
Duck, geese and swan (Anatidae)	Mute Swan			1 (FEB)	4 (OCT)		1	<1%	2%
	Brent Goose (Dark-bellied)	101 (JAN)	13 (OCT)	6 (JAN)	(6) (FEB)	98 (JAN)	55	6%	2%
	Shelduck					8 (SEP)	2	<1%	1%
	Wigeon	2 (MAR)		4 (JAN)	27 (JAN)	10 (NOV)	9	<1%	<1%
	Teal	40 (DEC)	4 (FEB)			4 (JAN)	10	<1%	1%
	Eider	2 (JAN)	4 (APR)			7 (JAN)	3	1%	100%
	Long-tailed Duck					3 (DEC)	1	1%	100%
	Common Scoter		31 (FEB)	21 (FEB)	16 (DEC)	10 (FEB)	16	2%	100%
	Red-breasted Merganser	10 (JAN)	17 (DEC)	22 (FEB)	8 (DEC)	22 (JAN)	16	19%	67%
Grebes (Podicepidida) and Cormorants (Phalacrocoracidae)	Great Crested Grebe	21 (SEP)	13 (JAN)	13 (SEP)	20 (NOV)	20 (SEP)	17	9%	63%
	Cormorant	25 (DEC)	14 (FEB)	31 (FEB)	21 (JAN)	17 (JAN)	22	6%	10%
Waders (Rallidae, Haematopodidae, Recurvirostridae, Burhinidae, Charadriidae and Scolopacidae)	Oystercatcher	44 (JAN)	(72) (NOV)	49 (APR)	80 (MAY)	30 (MAY)	55	2%	20%
	Ringed Plover	73 (AUG)	68 (OCT)	39 (NOV)	179 (MAY)	113 (FEB)	94	28%	61%
	Grey Plover	147 (OCT)	151 (FEB)	14 (APR)	201 (JAN)	140 (FEB)	131	30%	13%
	Knot	600 (JAN)	300 (FEB)		100 (DEC)	80 (FEB)	216	7%	25%
	Dunlin	168 (AUG)	750 (FEB)	60 (SEP)	800 (JAN)	1400 (JAN)	636	18%	35%
	Bar-tailed Godwit			5 (MAY)		2 (FEB)	1	<1%	6%
	Curlew		40 (JAN)		2 (JAN)	40 (FEB)	16	1%	3%
	Redshank	34 (JAN)	27 (FEB)	2 (FEB)	26 (DEC)	27 (JAN)	23	2%	8%
	Turnstone	168 (NOV)	163 (FEB)	182 (FEB)	301 (JAN)	132 (FEB)	189	39%	55%
Gulls (Laridae) and Terns (Sternidae)	Black-headed Gull	142 (NOV)	138 (FEB)	35 (JAN)	276 (NOV)	672 (SEP)	253	1%	38%
	Mediterranean Gull	113 (JAN)	108 (FEB)	61 (FEB)	119 (DEC)	136 (JAN)	107	*214%	50%
	Common Gull	61 (JAN)	73 (FEB)	27 (JAN)	49 (JAN)	44 (FEB)	51	1%	65%
	Lesser Black-backed Gull	2 (OCT)	3 (MAR)		1 (DEC)	2 (JAN)	2	<1%	33%

ARUN DISTRICT COUNCIL P/93/15/PL

Taxonomic Group	Species	2009/10	2010/11	2011/12	2012/13	2013/14	5-year Peak Mean	Winter 5-Year Peak Mean (2009/10 to 13/14) as % of National Thresholds and WeBS 5-Year Harbour-Wide Peak Mean	
								% National Threshold	% Harbour-Wide WeBS Count
	Herring Gull	229 (JAN)	294 (FEB)	157 (JAN)	232 (NOV)	352 (FEB)	253	3%	64%
	Great Black-backed Gull	16 (DEC)	15 (DEC)	12 (MAY)	56 (NOV)	12 (NOV)	22	3%	9%
	Little Tern	17 (JUL)	1 (JUN)	20 (JUL)	7 (JUN)		9	*18%	38%
	Sandwich Tern	8 (APR)	8 (JUL)	27 (JUL)	8 (APR)	4 (JUN)	11	*22%	18%
	Common Tern	2 (JUN)	2 (JUL)	7 (MAY)	1 (JUN)	3 (JUN)	3	*6%	12%

* British or all-Ireland wintering population is less than 50 birds, 50 is normally used as a minimum qualifying level
( ) Bracketed months indicate the month of the peak count.

ARUN DISTRICT COUNCIL P/93/15/PL

Feeding Abundance and Distribution at Low Water

The WeBS Low Tide Count sub-sectors which overlap with Church Norton Spit and Pagham Spit are BP001 and BP023 respectively. The extent of these sectors is shown in Figure 8.9. The results from the most recently undertaken survey in 2013/14 were obtained from the BTO. Table 8.8 presents the peak counts, peak densities, average counts and average densities recorded during 2013/14.

To further describe the value of the site in a national and regional context, the peak counts presented in Table 8.8 are also compared against the harbour-wide abundance levels (for the 2013/14 winter) and against the national 'importance thresholds'.

Small waders (Knot, Dunlin, Turnstone and Grey Plover) were the most abundant waterbirds recorded at low water along Church Norton Spit (Sector BP001). Dunlin were the most numerous wading bird recorded in the 2013/14 survey with a peak count of 908 birds and an average count of 484 birds. The peak count represents 45% of the total abundance recorded across the entire Pagham Harbour area. Large flocks of Grey Plover and Knot (peak counts of approximately 500 birds and average counts of 200-300 birds) were also recorded. The peak count of Grey Plover only represented 4% of harbour-wide counts whereas the peak count of Knot represented 98% of the estuary wide counts.

Church Norton Spit is characterised by steep upper beaches and shallower mid-beaches which consists of flint shingle. The middle to lower intertidal sections comprises a range of sediment from muds to shingle and are colonised by a range of macroalgae such as *Ulva lactuca* and *Fucus spiralis* (Royal Haskoning, 2013). Small wading birds when feeding in shingle areas typically turn over algae and small stones to find prey such as amphipods and gastropods. These species feed on a range of polychaetes and bivalves in patches of muddier sediment. Waders such as Turnstone and Ringed Plover also search for sandhoppers and kelp fly eggs amongst the strand line of beaches (Holden and Cleeves, 2002).

Much lower overall numbers of birds were recorded along Pagham Spit (BP023). Turnstone was the most abundant wader with a peak count of 20 birds and an average count of 5 birds. The peak count of Turnstone represented 9% of harbour-wide counts. Small numbers of other waders including Oystercatcher, Curlew and Dunlin were also recorded.

Wildfowl were also recorded along Pagham Spit in low numbers with Wigeon the most numerous species (peak count of 28 and average count of 14 birds representing 2% of harbour- wide counts). Other wildfowl recorded included Dark-bellied Brent Geese and Teal.

ARUN DISTRICT COUNCIL P/93/25/PL

Table 8.8 Winter WeBS low tide count data for the Pagham Sea sector (2013/14)

Sector	Taxonomic Group	Species	Peak count	Peak Density	Average Count	Average Density	Winter 2013/14 Peak Mean as % of National Thresholds and WeBS Low Tide Harbour-Wide Peak Mean	
							% National threshold	% Harbour-wide WeBS Count
BP001	Grebes (Podicepidida) and Cormorants (Phalacrocoracidae)	Great Crested Grebe	1	0.20	<1	0.05	1%	33%
		Cormorant	14	0.27	4	0.07	6%	39%
		Little Egret	6	0.13	2	0.03	12%	32%
	Herons and Egrets (Ardeidae)	Grey Heron	1	0.02	<1	0.01	2%	25%
	Waders (Rallidae, Haematopodidae, Recurvirostridae, Burhinidae, Charadriidae and Scolopacidae)	Oystercatcher	77	2.08	57	1.53	2%	68%
		Ringed Plover	4	0.11	2	0.04	1%	4%
		Grey Plover	460	12.43	200	5.40	87%	4%
		Knot	500	13.51	292	7.90	18%	98%
		Dunlin	908	24.54	484	13.07	16%	45%
		Bar-tailed Godwit	23	0.62	12	0.31	4%	92%
		Curlew	159	3.38	51	1.08	11%	33%
		Redshank	90	1.91	34	0.71	8%	52%
		Turnstone	211	5.70	124	3.34	42%	100%
BP023	Duck, geese and swan (Anatidae)	Brent Goose (Dark-bellied)	10	0.31	4	0.11	1%	<1%
		Wigeon	28	0.88	14	0.45	1%	2%
		Teal	5	0.16	1	0.04	<1%	2%
	Grebes (Podicepidida) and Cormorants (Phalacrocoracidae)	Little Grebe	2	0.40	1	0.10	3%	11%
		Great Crested Grebe	1	0.20	1	0.10	1%	33%
	Herons and Egrets (Ardeidae)	Grey Heron	1	0.04	<1	0.01	2%	7%
	Waders (Rallidae, Haematopodidae, Recurvirostridae, Burhinidae, Charadriidae and Scolopacidae)	Oystercatcher	5	0.38	3	0.25	<1%	4%
		Curlew	2	0.07	1	0.02	<1%	<1%
		Redshank	10	0.37	4	0.14	1%	6%
		Turnstone	20	1.54	5	0.38	4%	9%

ARUN DISTRICT COUNCIL P/93/15/PL

8.1.5.4 Terns and other breeding waterbirds in Pagham Harbour including Church Norton Spit

Pagham Harbour SPA is designated for breeding populations of two tern species, Common Tern and Little Tern (as discussed in Section 8.1.5.1). In addition, small numbers of Sandwich Tern also breed in Pagham Harbour. The location of nesting areas used by terns in recent years is shown on Figure 8.11.

The numbers of Little Tern breeding pairs and fledged young raised were first recorded in 1945 and have been monitored annually in Pagham Harbour since 1948. The results of the surveys are shown in Figure 8.12. Other tern species have been monitored annually since 1980. The breeding success of all tern species nesting in Pagham Harbour over the last twenty years (1994 to 2014) based on the latest available monitoring data from the RSPB is shown in Table 8.9.

Small numbers of wading birds also breed on Pagham Harbour. Oystercatcher breeding numbers have been monitored since 1948 and Ringed Plover number since 1973. The breeding success of these species over the last twenty years (1994-2014) is summarised in Table 8.10.

This section will initially provide a general review of the ecology and life history of tern species recorded in Pagham Harbour before focusing on the status of each of these species within the harbour. Finally the status of other breeding waterbirds in the area will be discussed.

Tern Ecology

Tern species arrive back after winter migration on UK shores in April and May. Little Tern primarily breed on sand and shingle beaches, spits or inshore islets. The species nests in well-camouflaged shallow scrapes close to the tide edge (JNCC website, accessed April 2015), and require vegetation cover of less than 10% (English Nature, 2001). Sandwich Terns and Common Terns breed in similar habitat to Little Terns as well as along rocky shorelines. Common Terns will also nest inland on man-made rafts in lakes and occasionally on flat roofs (Holden and Cleeves, 2002; BirdLife International, 2015).

Terns primarily feed on small fish such as sandeel (*Ammodytes* spp.) and clupeids (such as sprat) as well as other fish fry. Little Terns have very short foraging ranges compared to other seabirds, with most prey obtained from within 5 km of the colony and 1 km of the shore (Bertolero *et al.*, 2005; Perrow *et al.*, 2006). Common Tern can forage further afield (up to 37 km), and the Sandwich Tern can forage at considerable distance offshore where suitable habitats occur such as offshore sandbanks (BirdLife International, 2012; Thaxter *et al.*, 2012).

Little Tern colonies are found around much of the coastline, but the main concentration is in the south and east of England, from Hampshire to Norfolk (JNCC, 2001). During the Seabird 2000 survey it was found that some 1,900 pairs were breeding in the UK, at fewer than 60 breeding locations. This represented a 23% reduction in numbers when compared to 1986 counts, when just over 2,500 pairs were found. Numbers have continued to slowly decline since 2000, and in 2013, it was reported that extant colonies held 1,386 pairs (JNCC website, accessed April 2015).

ARUN DISTRICT COUNCIL P/93/15/PL

Common Tern numbers increased by 9% through the 1970s and 1980s although a fall in numbers was recorded in the Seabird 2000 surveys. Since then, there has been an upward trend in abundance, albeit with some fluctuation. However, a decline at some colonies has been recorded in recent years (JNCC website, accessed April 2015).

The UK population of Sandwich Tern increased from approximately 10,000 pairs in the 1970s to over 14,000 in the 1980s. The breeding abundance of Sandwich terns in the UK peaked in 1988, declining thereafter until the mid-1990s. Since then numbers have fluctuated with a particularly low abundance recorded in 2008 (JNCC website, accessed April 2015).

Little Terns in Pagham Harbour

At Pagham, Little Terns tend to start breeding from mid-April and stay on the nests until the end of July. They nest primarily on Church Norton Spit, although the exact location varies year on year, as can be seen in Figure 8.11. The location of the colony has generally moved eastward with the continued development of the distal end of the spit. This reflects the Little Terns' preference for nesting on more recently accreted, bare shingle (Tim Callaway, RSPB, pers. comm., July 2015). The favoured tern nesting area on Church Norton Spit are fenced off during the breeding season, but many birds are disturbed by dogs being walked off leads (Natural England, 2014). Small numbers also nest on Tern Island within Pagham Harbour.

The minimum number of breeding pairs and fledged young of Little Terns in Pagham Harbour in 1945 and between 1948 and 2014 is shown in Figure 8.12. It is clear from the results that the number of nesting pairs present in Pagham Harbour has shown a high degree of inter-annual variability. Throughout in the majority of years though (across the full period surveyed) breeding success has been poor often with no young fledging despite often high numbers nesting. However, in recent years greater reproductive success, as a proportion of birds nesting, has been observed.

The largest number of breeding pairs throughout the entire monitoring period was in 1945 (198 pairs) although no young were fledged in this year. Between 1948 and 1965, variable numbers of between 12 and 60 breeding pairs were observed with the exception of 1955 and 1958 when no pairs were recorded. Over this period young were successfully fledged in only three years (two young in 1949/1953 and 12 young in 1957) (Figure 8.12).

Over the period 1965 to 1982, variable numbers of between 20 and 70 breeding pairs of Little Tern were recorded in Pagham Harbour (with the exception of 1975 and 1973 when no nesting pairs were recorded). However, fledged young were only successfully raised in 1971, 1978-79 and 1981-1982 (between 10 and 25 young). Since 1982 numbers of breeding pairs have been much lower (between one and 23 birds) (Figure 8.12).

The number of breeding Little Tern pairs and fledged young recorded over the last twenty years in the area can be seen in Table 8.9. Between 1996 and 2006 no breeding pairs of Little Tern were recorded in Pagham Harbour. Since 2007 breeding numbers have ranged from three to 23 pairs with the number of fledged young ranging from one to 12 birds.

ARUN DISTRICT COUNCIL P/93/15/PL

The 2014 breeding season was the most successful season for Little Tern in Pagham Harbour since 1982 with a total of 12 fledged young recorded from a total of 12 observed breeding pairs. Eleven of these pairs were recorded on the Church Norton Spit and one pair on Tern Island. In 2013 a similar number of breeding pairs to 2014 was recorded (11 pairs), although these pairs failed to successfully fledge any young.

In 2013, 1,386 pairs were recorded in colonies across the UK. Based on numbers recorded in 2013/14 at Pagham Harbour, the currently site holds approximately 0.8% of the national population (0.3% were recorded in the JNCC standard data form for the SPA (last updated in 1999) (JNCC, 2006).

Common Terns in Pagham Harbour

Breeding Common Tern in the area are generally restricted to Tern Island (Figure 8.11). The number of Common Tern breeding pairs in the harbour from 2007 to 2014 has been between one and 32 pairs with the most successful breeding season in 2007 when 17 fledged young were recorded. Between 1994 and 2006 only six pairs of Common Tern were recorded with only one chick successfully fledged over this period (Table 8.9).

The 2014 breeding season for Common Tern was the second most successful since 1981 with a total of seven fledged young recorded from 13 pairs. There are approximately 12,000 breeding pairs of Common Tern in the UK. Based on numbers recorded in 2013/14 at Pagham Harbour, the currently site holds approximately 0.1% of the national population (0% was recorded in the JNCC standard data form for the SPA (last updated in 1999) (JNCC, 2006).

Sandwich Terns in Pagham Harbour

Breeding Sandwich Tern in the area is restricted to Tern Island (Figure 8.11). Low numbers Sandwich Tern pairs have been recorded breeding in Pagham Harbour since 1983 but have had limited success in rearing chicks. Over the last twenty years only five fledged young have been recorded (three in 2014 and two in 2009).

Other Waterbirds Breeding in Pagham Harbour

Low numbers of Oystercatcher and Ringed Plover breed in Pagham Harbour, primarily on Church Norton Spit and Pagham Spit (Figure 8.13). Oystercatcher also occasionally breed on nearby farmland.

The number of breeding Oystercatcher pairs has remained relatively consistent over the last twenty years with between 10 and 19 pairs recorded annually during most years. Numbers of fledged young were highest in 2007 and 2002 (eight and six chicks respectively). Numbers of fledged young in other years have remained low (>5 young).

Ringed Plover numbers have also remained relatively consistent with between 10 and 24 pairs recorded annually in most years over the last 20 years. Numbers of fledged young were highest in 2007 and 2014 (16 and 12 birds respectively) with >10 young recorded in other years (Table 8.10).

ARUN DISTRICT COUNCIL P/93/25/PL

Black-headed Gulls breed on Tern Island. Numbers appear to have increased from the occasional pair recorded annually prior to 2012 to over 44 pairs in 2014. Young were successfully fledged from breeding pairs in 2013 and 2014 (eight and three birds respectively). Single breeding pairs of Herring Gull and Mediterranean Gull were also recorded on 2013 and 2014 (Table 8.10).

One or two pairs of other waterbirds including Lapwing, Shelduck and Mute Swan have also been recorded occasionally breeding in Pagham Harbour.

ARUN DISTRICT COUNCIL P/93/15/PL

Table 8.9 Breeding success of seabird species at Pagham Harbour 1994 to2014

Species	Year	Number of Pairs	Number of Fledged Young	Breeding Success (Productivity /Pair)	Breeding Site
Little Tern	2014	12	12	1	Eleven pairs on Church Norton Spit, one pair on Tern Island.
	2013	11			Seven pairs on Church Norton Spit, three pairs on Tern Island.
	2012	23	1	0.04	Twenty-two pairs on Church Norton Spit, one pair on Tern Island.
	2011	7	6	0.86	All pairs on Church Norton Spit
	2010	6			
	2009	16	6	0.38	
	2008	3			
	2007	8	5	0.63	
	1995	12			Unknown
Common Tern	2014	13	7	0.54	Majority of pairs on Tern Island
	2013	14	1	0.07	
	2012	14			
	2011	8			
	2010	5	1	0.2	
	2009	14			
	2008	1			
	2007	32	17	0.53	
	2004	1	1	1	
	2003	2			
	1995	3			
Sandwich Tern	2014	1	3	3	All pairs on Tern Island
	2013	3			
	2012	20			
	2009	1	2	2	

ARUN DISTRICT COUNCIL P/93/15/PL

Species	Year*	Number of Pairs	Number of Fledged Young	Breeding Success (Productivity /Pair)	Breeding Site
Black-headed Gull	2014	44	3	0.07	Majority of pairs on Tern Island
	2013	18	8	0.4	
	2012	46			
	2011	1			
	2010				
	2009	1			
	2008	1			
Herring Gull	2014	1			Ferry Field
	2013	1	3	3	Tern Island
Mediterranean Gull	2014	1			All pairs on Tern Island
	2013	1			
* Only years with breeding pairs observed have been included. Source: RSPB					

ARUN DISTRICT COUNCIL P/93/15/PL

Table 8.10 Breeding success of wading bird species at Pagham Harbour 1996 to 2014

Species	Year	Number of Pairs	Number of Fledged Young	Breeding Site
Oystercatcher	2014	18	5	Majority of pairs on the Pagham or Church Norton Spits, however Oystercatcher occasionally breed on farmland on the reserve.
	2013	13	4	
	2012	18		
	2011	13	3	
	2010	17	0	
	2009	12	2	
	2008	8	1	
	2007	13	8	
	2006	14	3	
	2005	5	1	
	2004	11	3	
	2003	9		
	2002	12	6	
	2001	10		
	2000	1		
	1999	4		
	1998	14		
	1997	19		
	1996	15		
Ringed Plover	2014	15	5	All ringed plover on either Pagham or Church Norton Spits
	2013	13	4	
	2012	14		
	2011	9	3	
	2010	15	0	
	2009	10	2	
	2008	11	1	
	2007	14	8	
	2006	14	3	
	2005	6	1	
	2004	6	3	

ARUN DISTRICT COUNCIL P/93/15/PL

Species	Year*	Number of Pairs	Number of Fledged Young	Breeding Site
	2003			
	2002	3	6	
	2001	13		
	2000			
	1999			
	1998	14		
	1997	12		
	1996	24		

ARUN DISTRICT COUNCIL P/93/25/PL

8.1.6 Other Protected Species

Under the Wildlife and Countryside Act 1981 (as amended) it is an offence to intentionally damage, destroy or obstruct access to any structure or place which water voles use for shelter or protection or to disturb water voles while they use such places.

Water voles prefer sites with wide strips of vegetation along the banks or in the water. This provides useful cover from predators, as well as an abundant supply of food throughout the year. They are almost entirely herbivorous so this lush vegetation is essential. They also thrive in areas which have relatively soft, but stable, banks for their burrows. The preference is for steep, tall banks so that nest chambers can be situated above high water.

Water voles are not strong swimmers and tend to be very buoyant, especially when young, which makes water courses with strong currents difficult to navigate. They are therefore more likely to be found in slow moving rivers and streams, or water-bodies such as ditches, dykes, ponds and moats. However water voles have been known to colonise the lower freshwater reaches of tidal rivers with quite extreme water level fluctuations. Whilst able to tolerate brackish conditions of coastal borrow dykes are not as common in estuarine habitat or saltmarsh except where there are relatively stable, reed fringed lagoons that offer stable water conditions (Strachan and Moorhouse, 2006). This protected species has been recorded within Pagham Harbour in the upper tidal fringes of the southwestern and western parts of the harbour (Figure 8.14).

8.1.7 Coastal Geomorphology

The national coastal geomorphology importance of the site is recognised in the Pagham Harbour SSSI which identifies this as a key site both as a classic shingle spit landform and for the links that have been demonstrated between the coastal nearshore and offshore forms and sediments. Further details of the geomorphological SSSI interest are contained in Appendix F.

The coastal geomorphology of the SSSI Units comprising Church Norton Spit (Units 14 and 15) are currently in favourable condition. The most recent favourable condition assessment was undertaken in June 2010 for SSSI Unit 15 which identified that the shingle spit had shifted in position, as part of the natural dynamic processes of the shingle system, and that this change had not affected the favourable condition of this unit. Another non-statutory designation also highlights the coastal geomorphological significance of the site, namely the Pagham Harbour RIGS. Furthermore, a Geological Conservation Review (GCR) report describing the coastal geomorphology of the area was published on Pagham Harbour in 2003 (May, 2003a).

Pagham spit is the best-documented example of a number of double spit systems in southern England, which together enhance our understanding of estuary-mouth sediment dynamics (May, 2003a). In contrast to other double spits in England and Wales where sand is the main sediment, Pagham spit is formed predominantly of shingle. The development of shingle ridges has allowed the extension, breaching and repositioning of the detached ridges to be traced with greater certainty than is possible with sandy structures (May, 2003a).

ARUN DISTRICT COUNCIL P/93/25/PL

The double spit system at Pagham Harbour is very dynamic and also distinct from others by having changed from spit to bay-bar to spit again. The historical evidence indicates that the double spit form has resulted from a combination of unidirectional sediment movement and past breaching (May, 2003a). Past breaches include both natural breaches by storms (in 1910 and further in 1955) and the creation of a managed breach closer to the Church Norton side in 1937 (Section 6.2.6). Pagham Harbour thus adds considerably to the understanding of spit development and breaching and has provided significant information to the science of coastal geomorphology.

The shingle spit across the mouth of Pagham Harbour comprises a series of sub-parallel shingle ridges and recurves, which mark different phases of extension and accretion. Shingle reaches the beach via the intertidal zone (May, 2003a). The behaviour of the spit and the ebb tidal delta are intimately linked with water and sediment circulation around the Selsey peninsula. The area also provides an excellent example of the role of weed-rafting of shingle in coastal sediment budgets. As described in Section 6, the supply of shingle to the spit has been and continues to be dominated by transport from the direction of Selsey Bill. This is supplemented by kelp-rafted pebbles (May, 2003a).

In terms of the dynamically active processes, there has been a rapid extension of Church Norton Spit that has not been seen elsewhere at any other shingle spit in England in the last 60 years (and possibly longer) (see Section 6.2.6). The spit feature has exhibited very varying extents over the past 100 years, ranging from very short lengths to its current longest extent (since the 1910 breach). While the migration of the Church Norton Spit is predominantly controlled by the balance in longshore drift and the influence of the tidal inlet channel, the channel itself has been artificially constrained by existing man made features, namely the training wall in the harbour, and the groynes and rock revetments at Pagham Beach (see Section 6.2.6 for more detail). Over time, shingle has become locked in the spit, thus reducing supply to Pagham Beach and exacerbating erosion along this frontage (as described in Section 6.2.7).

8.1.8 Geology

The Pagham Beach frontage is SSSI designated due to exposed London Clay fractions having yielded significant floral fossil finds, although clay has rarely been exposed at Pagham, and finds have been limited. Rather, the beds nearer to Bognor have yielded numerous finds, and these are considered part of 'an outstanding palaeobotanical site of great importance to studies of Tertiary floras' (Sussex Geodiversity Partnership, 2015).

Clay has been exposed at the Pagham Beach frontage in the past, though none has been sighted in recent years. Venables (1962) reports that the exposures which have in the past been observed along the Pagham frontage would belong to the 'Upper Clay' strata of the London Clay exposures, which can be exposed along the frontage between Barn Rocks (just west of Barrack Lane, Aldwick) and Pagham. The Upper Clay strata has yielded significantly fewer micro fossils than the Middle Clay strata, which is located between Barn Rocks and Bognor Rocks (east of Dark Lane, Aldwick). Exposures of the Upper Clay strata were described as 'infrequent, transitory and limited in extent' by Venables (1962), who quotes one occasion during which grey clay was exposed along the Pagham Beach frontage, which was

ARUN DISTRICT COUNCIL P/93/25/PL

found to contain 'crowded plant remains in a carbonaceous state of preservation' (p.255). No further exposures have been seen on the foreshore at Pagham.

In Pagham Harbour, exposures have also been seen in the past. A 'ribbon of black clay' used to be exposed near the training wall, but is now buried under shingle (pers. comm. Ray Radmall (Pagham Parish councillor, May 2015). According to the Sussex Geodiversity Partnership, the exposed London Clay on the foreshore platform inside Pagham Harbour (around SZ 881970) is thought to be 'unfossiliferous (weathered?)' and does not contain anything 'visibly of note' (pers. comm. David Bone, Sussex Geodiversity Partnership, May 2015).

Beyond the study area, at the nearby managed realignment scheme at Medmerry, it is noteworthy that (superficial) geological finds were made during the excavations of the borrow pits and channels within the realignment site. These were Ice Age erratics[37], and ranged from boulders a metre or more in diameter down to cobble-size specimens. Such erratics are found around the coast and occasionally from inland excavations, but the Medmerry scheme revealed a number of these boulders *in situ*. The rocks are believed to originate from Brittany or the Channel Islands, where similar rock types occur, and were ice-rafted across the English Channel during the Ice Age (Sussex Geodiversity Partnership, 2013). The Sussex Geodiversity Partnership notes that a large erratic, which apparently measured 27' 5", was recorded by Godwin-Austen in 1857 at Pagham (location not specified) (pers. comm. David Bone, Sussex Geodiversity Partnership, May 2015).

8.1.9 Potential Future Baseline

8.1.9.1 Closure of the tidal inlet

The potential future conditions at the site were reviewed in Section 6.2.8. This explained that there was no sign of depletion in shingle supply in the short to medium term at the most and that the spit is likely to grow and cause continuing erosive pressure on Pagham Beach to the east. This beach is designated SSSI and much of its most erosion threatened western and central sections also fall within the SPA boundary. The ecological effects of these changes are not considered in detail within this EIA on the basis that such changes can be seen largely as natural (albeit they will inevitably be influenced by historical and recent man-made interventions and activities). These losses of beach material would also (for all the, separately considered, coastal erosion, amenity and human health problems that that would cause) be offset in nature conservation terms by equivalent increases of shingle habitat through the growth of the spit.

The future occurrence that does warrant further consideration here though is the possibility of the tidal inlet closing due to the natural processes. There is considered to be a low likelihood of this happening given historical evidence (Section 6.2.6), but it cannot be completely discounted. There is also a greater potential risk of this happening in the future as the extended spit seeks to pass around the physical obstructions presented by the groynes. Were it too close and especially if the spit were to roll back then reopening it might well be very

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37 An erratic is a piece of rock that differs from the size and type of rock native to the area in which it occurs.

ARUN DISTRICT COUNCIL P/93/15/PL

difficult. This potential closure risk is mitigated by the proposed project which is expected to be more stable once implemented than the existing condition.

Concern for the risk nature conservation features of the harbour from a future closure has been expressed in this regard; for example, the Site Improvement Plan (SIP) for the Pagham Harbour SPA (Natural England, 2014) lists 'physical modification' of the spit as the highest priority issue for the site. It states that, were the entrance to close, changes to the wetland areas behind the spit could "affect the breeding, roosting and feeding habitats of many of the bird species currently using the intertidal areas" (see Appendix F for more detail). The potential effects (based on an RSPB study (Ausden, 2014)) of a closure are therefore reviewed below.

Changes to Habitats and Protected Species

Should the tidal entrance to Pagham Harbour close, then the current area of intertidal habitat inside the harbour would become a large coastal lagoon. Physical conditions in this lagoon are difficult to predict, and would depend on how much, and how frequently, saline water entered the lagoon through overtopping of the shingle ridge or percolation through the shingle, whether there was any tidal effect based on percolation, how long the lagoon remains more or less isolated from the sea, how much freshwater drained into the harbour, and the effect of nutrients entering the lagoon in runoff from adjacent agricultural land and outputs from Sidlesham and Pagham sewage works (Ausden, 2014).

If the coastal lagoon received little or no input of saline water through overtopping of the shingle ridge or percolation, then the lagoon would progressively become less saline. A shallow, low salinity lagoon would be likely to become increasingly dominated by common reed (in the very long term), as has occurred at coastal lagoons on the Suffolk Coast (Spencer and Brooks, 2012) and at Slapton Ley in Devon. Under this scenario, the lagoon might also become increasingly eutrophic due to accumulation of nutrients entering the lagoon in runoff from surrounding farmland and outputs from Sidlesham and Pagham sewage works (Ausden, 2014).

Vegetated shingle (a SSSI feature) at Pagham Harbour has been assessed as being either in 'favourable' condition, or in 'unfavourable no change' condition due to invasive Red Valerian and a range of other garden escapes (Section 8.1.3.5). The closure of the harbour could facilitate the spread of these to Church Norton spit. The most recent assessment of the condition of the SSSI also considered there to be some degradation of shingle vegetation due to some of the neighbouring residents keeping their boats on the shingle. Heavy trampling is generally accepted to be damaging to vegetated coastal shingle. Any increase in numbers of people visiting the coastal shingle to the south of the current harbour entrance might therefore increase trampling in this area, although most of the SSSI on Church Norton spit is already fenced off during the breeding season. Hence, closure of the harbour entrance might be expected to have little or no impact on the condition of vegetated shingle (Ausden, 2014).

Seagrass beds occur in both intertidal areas and saline lagoons, with different species of seagrass occupying different zones. Seagrass beds (an MCZ feature) would therefore be likely to persist, or might increase, at Pagham Harbour following closure of the harbour entrance, although the species-composition of these seagrass beds is likely to change (Ausden, 2014).

ARUN DISTRICT COUNCIL P/93/25/PL

Development of a coastal lagoon through closing of the entrance to Pagham Harbour is unlikely to be damaging to DeFolin's lagoon snail (an MCZ feature). This species is found in greater numbers in Little Lagoon than inside the harbour (Section 8.1.4) and therefore the creation of a large coastal lagoon might actually be beneficial. It may also be beneficial to the Lagoon Sand Shrimp (an MCZ feature) currently restricted to Sidlesham Ferry Pool as it would greatly increase the area of suitable habitat for this species.

Closure of the harbour entrance would not be expected to have any impact on other lagoons in the harbour, including Little Lagoon and Pagham Lagoon (an SSSI feature), or their specialist flora and fauna (Ausden, 2014).

There is no evidence to suggest that adjacent terrestrial habitats, namely grassland or woodland, would be affected by the closure of the harbour entrance.

Potential Effects on Waterbirds

Changes in habitat as a result of a closure of the tidal inlet channel are likely to have marked effects on waterbirds, particularly overwintering birds feeding on the intertidal habitats within the harbour. Large reductions in the populations of certain waders, namely Black-tailed godwit (a Ramsar feature) and Grey Plover (a SSSI feature), are considered likely (Ausden, 2014). Densities of Ringed Plover (a SSSI feature) on the intertidal area at Pagham are relatively low (Section 8.1.5), so it is difficult to predict whether closure of the harbour entrance would significantly reduce these numbers.

Impacts on wildfowl are more difficult to predict, as many wildfowl feed in water as well as on intertidal habitat. Numbers of species such as Pintail (a SSSI feature), who prefer shallow water or mudflats, are likely to decline (Ausden, 2014), particularly if waters were to generally be relatively deep in the new lagoon (Natural England, 2014). Dark-bellied Brent Geese (an SPA, Ramsar and SSSI feature) using Pagham Harbour feed mainly on grassland, especially on the North Fields (Section 8.1.5). If the intertidal area at Pagham Harbour became a coastal lagoon, then these birds could still roost at the lagoon, and continue feeding on their existing favoured grass fields (Ausden, 2014). Therefore, numbers of Dark-bellied Brent Geese might not necessarily be greatly affected by closure of the harbour entrance.

In addition, closure of the harbour entrance would also, almost certainly, result in large reductions in numbers of wintering/passage Curlew, Knot, Oystercatcher, Redshank, Turnstone and probably Dunlin at Pagham Harbour (Ausden, 2014).

With regard to the breeding terns, namely Common Terns and Little Terns which are qualifying SPA interest features, these might benefit from a lagoon becoming established, should good stocks of small fish become established in the lagoon; i.e. should feeding conditions improve (as both these bird species mainly prey on small fish, and feed fairly close to their nests (Thaxter et al., 2013)). A decreased risk of tidal surges would also benefit those terns nesting within the harbour.

ARUN DISTRICT COUNCIL P/93/15/PL

An important additional impact of closing of the harbour entrance is that it would allow people to walk south along the coast from Pagham to Church Norton. Since there is currently greater visitor pressure originating from the Pagham area, than from Church Norton area, closure of the harbour mouth might increase the number of people visiting Church Norton Spit. This can currently only be accessed from south of the harbour entrance or by boat/canoe. Disturbance to birds using the spit, including nesting terns, would increase as a result of this improved coastal access. Furthermore, it is likely that there would also be an increase in recreational disturbance if the spit were in effect to become a beach. A coastal lagoon might also attract more water based recreational users, thus potentially leading to more disturbance to birds feeding, nesting and roosting on and/or adjacent to the lagoon.

Closure of the harbour entrance is not expected to have any significant effect on the condition of the islands in Pagham Harbour on which Common Terns (an SPA feature) currently nest. As with Little Terns, development of a large, coastal lagoon could provide additional feeding areas for Common Terns, subject to the nutrient status and salinity of any such lagoon. Subject to the latter therefore, closure of the harbour entrance would be expected to have a possible small to medium positive impact on breeding Common Terns (Ausden, 2014).

Potential New Conservation Interest

While closure of the harbour entrance would result in the loss of some of Pagham Harbour's current conservation interest, it would also result in development of new wildlife interest at the site. Coastal lagoons are a rare habitat in the UK, and many existing coastal lagoons are threatened by the impacts of climate change (Spencer and Brooks, 2012; Beer and Joyce, 2013). Therefore, development of a large saline coastal lagoon following closure of the harbour entrance at Pagham would significantly increase the area of this rare habitat in England.

A large, saline coastal lagoon has the potential to support large numbers of wintering wildfowl, and smaller numbers of wintering/passage waders (Ausden, 2014). Saline lagoons in the UK can also support a range of breeding waterbirds (notably Avocets), and are an important feeding habitat for breeding Spoonbills in Northwest Europe (Triplet et al., 2008). It is difficult to predict whether any coastal lagoon that developed at Pagham Harbour would have suitable nesting areas for Avocets and other waterbirds, although these could be created (Ausden, 2014).

Saline lagoons also support a characteristic invertebrate fauna and flora, containing a number of rare species (e.g. Barnes, 1989). They also support a diverse fly and beetle fauna on marginal saline areas, which includes a high proportion of rare species (Gibbs, 2005). It is not known how well saline lagoon specialist species are able to disperse and colonise new lagoonal habitat. A number of specialist saline lagoon species are present in the area of Pagham Harbour, and might colonise any new coastal lagoon which developed, although unfortunately, the nearest potential source of saline lagoon specialist species in Pagham Lagoon is thought to have become very impoverished (Joyce, 2011). The nutrient status and salinity levels of any new coastal lagoon may have an important bearing on its ability to support new conservation interests.

ARUN DISTRICT COUNCIL P/93/25/PL

8.1.9.2 Climate change

It is recognised that climate change presents various pressures to habitats in terms of the likely increase in sea level rise. In Pagham Harbour, these changes could potentially lead to a reduction in intertidal habitat due to coastal squeeze in areas where hard sea defences back part of the harbour. This will have implications for associated benthic intertidal communities and reducing the available feeding area for foraging waterbirds. In addition, climate change could lead to potential changes in water temperature and an elevated threat from invasive non-native species. The introduction and establishment of non-native species may also have future impacts on the ecology with species competing for food and space with indigenous organisms.

Birds could also be impacted in the future by a range of human pressures including fisheries (changing prey stock levels and causing by-catch), marine developments and pollution. Future climate change has the potential to have a particularly large impact on the abundance and distribution of different bird species. JNCC and the Centre for Ecology and Hydrology (CEH) undertook a scientific review of the potential future impacts associated with climate change as part of the Marine Climate Change Impact Partnership (MCCIP) Annual Report Card (Mitchell and Daunt, 2010). The main findings from this report are summarised below:

- Range shifts: Most seabird species in the UK are at the southern limit of their range in the North-east Atlantic - this may be because they are adapted to living in a particular climate. If this is the case, as the climate in the UK changes, there may be a shift in range that may or not cause a decrease in breeding numbers, depending on the availability of nesting sites and food elsewhere.
- Changes to physical habitat: Future climate change is also likely to have direct impacts on breeding seabirds. Rising sea levels, particularly in the southern North Sea may wash away coastal nesting habitat of ground-nesting seabirds such as terns. Increases in storminess may lead to nests being washed away during the summer or to large scale mortality during the winter.
- Changes to the food web: Climate change is considered to impact on seabirds primarily by reducing the number, quality or availability of prey fish, in particular sandeels, and this process is expected to intensify in the future. The continued warming of waters around much of the UK has led to changes in species competition and abundance at lower trophic levels, with detrimental effects on sandeels. If sea temperatures continue to rise as predicted, it is likely that seabirds that feed on small shoaling fish will continue to experience poor breeding seasons with increasing frequency. The combination of reduced recruitment and lower adult survival associated with high sea temperatures will lead to further large declines in population size.

Although these issues are recognised, the proposed project seeks to address existing and anticipated coastal erosion problems (as well as post-breach benefits) over a period of around 10-20 years. This is because, for this coastline, making predictions beyond this timeframe is not possible. For this reason the longer-term issues associated with climate change and sea level rise have not been reviewed in detail (they will instead need to be considered on an ongoing basis as part of the continuing process of adaptive management).

ARUN DISTRICT COUNCIL P/93/25/PL

8.2 Impact Assessment

8.2.1 Impact Pathway 9: Effects of Loss/Change of Shingle Habitat During Construction

8.2.1.1 General scientific context

The construction phase will involve the extraction and movement of around 50,000 m³ of shingle from an area of just over 1 ha. This will be moved to create the breach and to then infill the existing channel. The intertidal sides of this area are largely 'barren littoral shingle habitat' (MNCR Biotope Code LS.LCS.S.BarSh) which is characterised by sediment particle size ranging from 4 - 256 mm, sometimes with some coarse sand mixed in (Connor et al., 2004). This biotope is normally only found on exposed open coasts in fully marine conditions. Such shores tend to support very limited macrofauna in their very mobile and freely draining substratum. The few individuals that may be found are those washed into the habitat by the ebbing tide, including the occasional amphipod or small polychaete.

The crest of the spit above the intertidal area is partially vegetated shingle (see Section 8.1.3.6 and Image 8.3). On a global basis, this is a rare and declining habitat although it is found extensively around the UK (Randall, 2004). The development of vegetated shingle communities is dependent on the structure stability, matrix composition (size distribution of clastic material), and the availability of nutrients and freshwater.

Following any period of sustained disturbance, if conditions are favourable, the recovery of vegetated shingle communities follows a typical series of successional colonisations. The pioneer phase of succession can therefore occur within a suitable growing season. The extent to which there is further succession and continual colonisation of the shingle habitat over a period of years depends on the environmental stresses imposed.

Hindrance to this successional colonisation and the recovery of vegetated communities can be in the form of trampling from human activity, grazing by insects and rabbits, or continual environmental pressures including inundation by seawater, substrate shifting, high winds, burial and sea spray (Houston et al., 2009; Smith, 2009). Scott (1963) identified three levels of foreshore stability based on vegetation stability:

- 'No vegetation – disturbance too frequent to support plant growth: as at the foot of sea-cliffs, distal points of spits, high energy beaches etc.
- Summer annuals – beach stable over growing season only: mainly *Galium aparine* and *Atriplex* spp. on drift line
- Short-lived perennials – beach stable for +3 years: considerable strand and foreshore vegetation e.g. *Glaucium flavum, Rumex crispus, Beta maritima*' (Randall, 2004)

The extent to which shingle recovers to a baseline conditions depends upon its stability and particularly the degree of shingle export of future sediment supply. An analysis of the project's effect on the extent of habitat has been presented in Section 6.3.1 which reviews 'Impact Pathway 1: Effects of Changing the Spit Morphology on Coastal Processes Regime Across the Front of Pagham Harbour and Pagham Beach'. That section includes a description of how the site is likely to evolve in the period immediately after the work has been completed which is

ARUN DISTRICT COUNCIL P/93/25/PL

relevant for understanding the impacts from the construction, and also operational, phase of the work.

8.2.1.2 Project impact assessment

This pathway considers the immediate change to shingle habitat arising as a direct result of the construction works. Shingle is important habitat as roosting area for overwintering birds in the Pagham SPA and it can be a nesting habitat for tern species (especially where it is bare of vegetation)[38]. Where shingle habitat is vegetated it is a habitat listed on Annex I of the Habitats Directive and is also considered a habitat of principal importance under Section 41 of the NERC Act. This pathway also addresses the effects of construction on shingle habitat in the context of the geomorphological and geological (also 'palaeobotanical') interests of the site. The longer-term impacts that occur to this habitat as a result of future shoreline evolution are discussed in Section 8.2.7.

The proposed project occurs wholly within the Pagham Harbour SPA and Ramsar site. The excavation of the breach will directly affect shingle habitat over 1.2 ha. This represents around 1.3% of this habitat within the Pagham Harbour SPA and Ramsar site[39]. Of this area, the side slopes will remain exposed as intertidal after completion of the work but the centre of the channel (around 0.6 ha) will be set at MLW and is then expected to deepen in the period after the work is completed and tidal flows begin occurring. This 0.6 ha area is therefore considered to represent a loss from the system that will occur as a result of the construction phase.

This loss from the system will be offset during the construction phase because the excavated material will be relocated and placed across the existing tidal channel over an area of 0.7 ha. This will therefore 'create' a new area of shingle habitat that is equivalent to the area lost (see Figure 2.2). Therefore there will be no let loss of this habitat immediately following construction.

During the works, the excavated shingle will also be stockpiled across an area of alongside the breach location on the crest of the spit. This zone (of around 0.5 ha) will be changed (subject to coverage and subsequent vegetation removal) during the proposed works. The movements of the excavating plant will also cause change/damage during the construction phase as discussed under Impact 12 (Section 8.2.4).

The coarse sediments in the middle to upper intertidal sections of the spit that will be mainly affected tend to be highly mobile and therefore provide limited suitable habitat for macrofauna. The value of the shingle spit in supporting nesting and roosting birds is described in detail in Section 8.1.5. The lower intertidal sections of the spit, ebb tidal delta and inlet channel (which are largely outside the excavation zone) are characterised in parts by a range of common green, brown and red algal species, providing shelter for marine fauna such as shore crabs, periwinkles, shrimps and gobies. The long established south-western part of Church Norton

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38 The impact on nesting Little Terns is considered separately in Sections 8.2.2 and 8.2.8

39 The existing (baseline) area of shingle habitat within the boundaries of Pagham Harbour SPA and Ramsar site has been calculated using the latest available LiDAR data (rather than the areas provided in the SPA and Ramsar site citations).

ARUN DISTRICT COUNCIL P/93/25/PL

Spit, is partly vegetated comprising a range of lichen and plant species, including the nationally important Childing Pink (Section 8.1.3.6, Image 8.2) whilst the footprint of the breach and spit extension is sparsely vegetated (Image 8.3).

The changes to the shingle habitat will definitely occur (high likelihood) but the magnitude is considered to be negligible with no net loss of area and some qualitative but temporary damage to areas with low vegetation cover. Therefore, the exposure of shingle habitat within the SPA/Ramsar from the project is considered to be low in the context of available and evolving shingle habitat. The sensitivity of the shingle habitat to the construction of the breach and infill is considered to be low because of the paucity of infauna and sparseness/tolerance of the existing vegetation (which are pioneer (mainly sea kale) species that are then expected to re-colonise rapidly in around 1 or 2 years). This indicates that although the importance of the SPA/Ramsar supporting shingle habitat is high the impact is insignificant.

The proposed breach and infill also overlap with the boundaries of the Pagham Harbour SSSI which is designated as a key site for coastal geomorphology both as a classic shingle spit landform and for the links that have been demonstrated between the coastal nearshore and offshore forms and sediments (see Section 8.1.7). The shingle spit will be modified during the construction phase. The geomorphological and geological impacts are therefore considered further below.

The exposure to change of SSSI geomorphological spit feature from the excavation of the breach and infilling the existing tidal channel is considered to be low given the small magnitude of change and high probability of occurrence. The sensitivity of the spit feature and its intolerance to the construction of the breach and infill is considered to be low because it is a dynamic feature and breaching constitutes part of the important geomorphological functioning of a double spit system (see Section 6.2) with the change ultimately resulting in a shift towards more of a double spit morphology. Furthermore, it is expected to recover from any impact as the shingle spit from Church Norton is likely to reform in the future (see Section 6.3.1). The importance of the SSSI geomorphological spit feature is considered to be high given both its rarity and national designated status. Overall, therefore, the impact is considered to be minor adverse significant.

With regard to the geological interest of Pagham Harbour SSSI, the London Clay areas appear to be exposed mostly along the eastern extent of Pagham Beach, where it adjoins the 'Bognor Foreshore' RIGS/'Bognor Reef' SSSI (Section 8.1.8). The location where the breach works are proposed to take place has previously been the location of the inlet's low water channel (especially in the latter part of the last century, see Figure 6.3) and therefore no significant London Clay exposures with associated plant fossils would be expected to remain here.

Taking all these considerations into account, the exposure of the change to the geological interest feature value of the Pagham Harbour SSSI is considered to be negligible. This is based on a low probability of occurrence and a small magnitude of change. The sensitivity of these features is considered to be moderate given that if they were to be present they might be damaged by the excavation works, although most likely they would be relocated and preserved at the proposed infill location. SSSIs are a nationally designated site and therefore the

ARUN DISTRICT COUNCIL P/93/25/PL

importance of the geological interest is assessed as moderate. Overall, the impact on the geological interest feature value of Pagham Harbour SSSI is considered to be insignificant.

8.2.2 Impact Pathway 10: Effects of Loss/Change of Little Tern Breeding Habitat During Construction

8.2.2.1 General scientific context

Within this section the effects of the construction phase of the work on breeding Little Terns is addressed. This species is afforded particular consideration here as its breeding populations are an interest feature of the Pagham Harbour SPA. The potential effects on other breeding birds are also noted although the works will be timed to avoid breeding periods in keeping with the requirements of the Wildlife and Countryside Act 1981.

Little Terns breed on barren or sparsely vegetated beaches, islands and spits of sand, shingle and pebbles. They nest just above the high tide-line and create a bare scrape positioned on the ground in areas of limited vegetation cover (del Hoyo et al., 1996). The preference for nesting in relatively open landscape is thought to help maintain visual contact between chicks and returning adults, and provides forewarning of approaching predators or disturbance events (Allcorn, 2003). It has been found that tern species generally show site fidelity to natal breeding sites (Atwood and Massey, 1988; Burger, 1984). However, terns also readily move to newly created habitat (such as freshly accreted shingle) within a breeding site (Allcorn, 2003).

The preference of terns to nest on beaches and other low lying coastal ground close to the littoral (tidal) zone makes the nests very susceptible to damage or destruction through tidal inundation due to storm events and flooding[40]. Also, the ground level location and often exposed nature of nests makes tern species susceptible to predation. In a review of Little Tern predation, foxes were the most commonly reported species causing nest failures at colonies (38%), closely followed by raptors (24%) (Allcorn, 2003). Other species causing predation include corvids (crows and ravens) and gulls. Vegetation overgrowth (rapid vegetation succession encroaching upon nesting habitats) can also influence nesting productivity (number of fledged chicks per occupied nest) (BirdLife International, 2015; JNCC website, accessed April 2015; Medeiros et al., 2012; Radcliffe et al., 2008).

In a review of seabird census data collected between 1967 and 2000, predation was cited as a cause of nest and chick losses in 50% of breeding years and was the most common cause of failure cited. Tidal flooding was reported as causing failures at 23% of colony years, weather (rain and sand blow) at 13%, disturbance at 10% and poor food availability at 5% (Allcorn, 2003).

Little Terns have very short foraging ranges compared to other seabirds, with most prey obtained from within 5 km of the colony and 1 km of the shore (Bertolero et al., 2005; Perrow et al., 2006). Consequently, Little Terns nest close to areas of high food availability so that they

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40 Predictions of increased storminess and sea-level change under climate change scenarios may lead to increased prevalence of such events although that is not considered within this Environmental Statement

ARUN DISTRICT COUNCIL P/93/25/PL

can provide chicks with sufficient food to maintain their growth and survival (Holloway 1993; Bertolero et al., 2005).

8.2.2.2 Project impact assessment

This pathway considers the effects on Little Tern nesting areas arising from the immediate changes to shingle habitat as a direct result of the construction works. The longer-term impacts on Little Tern habitat due to the future evolution of the spit is discussed in Section 8.2.8.

As discussed in the preceding sections, the construction work will not cause a net loss of shingle habitat. There will however be disturbance to an area of around 1.7 ha (1.2 ha excavations from the breach and 0.5 ha in area of the temporary stockpile). While the exact location of breeding Little Tern colonies is variable between years, these working areas are no longer considered to be the preferred breeding sites. These areas were used historically but over the last few years Little Tern nest sites have moved along the spit as it has grown. Little Tern nests have not been positioned in or adjacent to the proposed breach area since 2010 (see Figure 8.11). In 2013 and 2014 breeding Little Terns favoured the unvegetated 'bowl shaped' platforms that have formed in the sheltered (landward) side of the northern (distal) end of Church Norton Spit. The wider access areas on Pagham foreshore and along Church Norton Spit (latter for pedestrian access needed) are also not favoured by Little Terns.

Other species do nest in the construction areas (including Oystercatcher and Ringed Plover) and nearer to the access routes (especially along Church Norton Spit) but the works will be timed to be completed before mid-March or after the end of July and into August) to avoid impacting on these species. Further advice on the specific timing will be sought from NE and the RSPB in the light of observations made closer to the work beginning. In other words, work will not begin if it cannot be assured that it will be completed before the breeding season and will not start if pre-fledged young are still on site.

Given the above considerations, the probability and magnitude of an impact to Little Tern breeding habitat are both considered to be negligible. Little Terns are considered to have a low to moderate sensitivity to the shingle changes as in recent years this has been unused nesting habitat. Consequently vulnerability is assessed as being none. The importance of the feature is scored as high because of the protection afforded to Little Terns but the impact of change in breeding habitat during construction is considered to be insignificant.

8.2.3 Impact Pathway 11: Effects of Loss/Change of Habitat for DeFolin's Lagoon Snail During Construction

8.2.3.1 General scientific context

A detailed review of the DeFolin's lagoon snail's ecology is presented in Appendix J. In summary, fairly little is known about this very small gastropod, which has to date only been found in four locations in Great Britain (including two at Pagham Harbour). It has been noted that populations of this species are probably under-reported, given its apparently narrow habitat niche, as well as its small and near-translucent nature (Pain et al., 2009).

ARUN DISTRICT COUNCIL P/93/25/PL

DeFolin's lagoon snail resides in gaps between small pebbles (i.e. the 'interstitial') on the landward side of shingle ridges, in positions where sea water percolates into a lagoon. It is considered to be a sub-surface deposit feeder which consumes vegetable detritus as well as bacterial and diatom film (White, 2007). Based on insights gained from surveys at the Fleet (Dorset) (Baldock and Bass, 2012), where this species was first discovered in the UK, and at Pagham (Wilkinson and Baldock, 2013; Pain et al., 2009), DeFolin's lagoon snails appear to be found in areas which combine the following aspects:

- Slowly seeping water (it has not been found in areas of high flows);
- Non-compacted, small, pebbles with patches of organic detritus – pebbles which would shift easily underfoot, with very little sand or fines found in-between;
- Close to vegetation (halophyte shrubs at the Fleet), but not immediately underneath (though coverage by dead Zostera leaves is tolerated);
- Around the Mean High Water line; and
- Abundance of gastropod Truncatella subcylindrica and/or Lasaea bivalves.

As outlined in Section 8.1.4, the DeFolin's lagoon snail is protected under Schedule 5 of the (1981) Wildlife and Countryside Act (under Sections 9.1, 9.2, 9.4 (a to c) and 9.5a) having been scheduled in 1992. It is worth noting that in 2013, the Conchological Society of Great Britain and Ireland (ConchSoc) suggested to downgrade the protection afforded to C. armoricum to Section 9(4) only, due to full protection hindering the recording and study of this species (sampling currently requires a licence from Natural England); as this species is not considered at risk from collection. This does not mean however that ConchSoc considers that this species is not at risk of extinction through loss of its habitat (ConchSoc, 2013). Protection would still be afforded in this respect by Section 9(4) of the Act ('places of shelter etc.').

8.2.3.2 Project impact assessment

This pathway considers the immediate change to potential DeFolin's snail populations and their habitat as a direct result of the construction works including the access arrangements. The longer-term impact on the species due to future shoreline evolution is discussed in Section 8.2.9.

Direct Habitat Loss at the Breach

Based on the survey undertaken in 2013, and also the 2007 finds described previously, it cannot be discounted that Church Norton Spit may be home to relatively small populations of the DeFolin's lagoon snail. However, based on the finds during recent surveys, it appears that more sheltered saline water bodies (i.e. lagoons such as the Fleet or the Little Lagoon on Pagham Spit) provide more optimal habitat.

Based on the surveys, and the apparent habitat preferences listed in the previous section, it is thought that live DeFolin's lagoon snails are most likely to be present towards the more sheltered landward sections of the Church Norton Spit (i.e. south-western end of the spit on the western side of the proposed breach). It is considered unlikely that the breach or side-casting works for channel infilling would directly affect DeFolin's lagoon snail habitat, as the landward

ARUN DISTRICT COUNCIL P/93/15/PL

area of the shingle spit affected by these works is subject to high flow rates, due to it being immediately adjacent to the harbour inlet channel (see Section 6.2.3.2 and Image 6.3), and high flows are not favoured by this snail species.

Direct Habitat Damage Along Access Routes

As discussed in the previous section, whilst Church Norton Spit is unlikely to be optimal DeFolin's lagoon snail habitat, the likely presence of relatively small populations along its more sheltered southwestern harbour shores cannot be discounted. During construction, some daily pedestrian access may be required from Church Norton or via East Beach (Section 3.2.1). Alternative emergency access will also be from East Beach. However, no day-to-day plant access is planned to take place from the south-western (Church Norton) side of Pagham Harbour. Both the staff and emergency access routes will remain on top of and on the seaward side of the shingle ridge and therefore will not overlap with the DeFolin's lagoon snail habitat.

Impact Summary

Given the above considerations there is anticipated to be a small magnitude of change to the morphology of the shingle habitat but a low probability of an effect on DeFolin's snail (i.e. no significant overlap with the preferred DeFolin's habitat is anticipated), the exposure to change is assessed as negligible. Despite the high sensitivity of this species to habitat loss and its high importance in terms of its rarity and nationally designated status, the overall impact on the DeFolin's lagoon snail from direct habitat loss and/or change is considered to be insignificant.

8.2.4 Impact Pathway 12: Effects of Loss/Change of Shingle Habitat Outside Development Footprint During Construction

8.2.4.1 General scientific context

The tolerance and recoverability of shingle habitat to physical loss and/or damage from constriction plant is reviewed in Section 8.2.1.1. Heavy vehicles that are driven over shingle spits and beaches have the potential to compact the shingle which in turn could potentially affect their ecology and especially the vegetation cover. Any exposed palaeobotanical interest features are also at risk of being damaged by the movement of plant or vehicles.

8.2.4.2 Project impact assessment

This pathway considers the immediate change on shingle habitats from the plant access arrangements during the construction. The effects on the geomorphological and geological/palaeobotanical interests of the site are also considered. The longer-term impacts that occur to this habitat as a result of future shoreline evolution are discussed in Section 8.2.7.

The access arrangements for the project are described in Section 3.2.1 and are illustrated in Appendix D. As indicated in these sections, there will be access of plant from the Pagham side but also possible staff/pedestrian and emergency access, as required, from the Church Norton side.

ARUN DISTRICT COUNCIL P/93/25/PL

On a day-to-day basis during the construction there is expected to be relatively minimal movement of plant into and out of the breach excavation area. Instead, the plant will remain on the site overnight and there is no need for materials to be imported for the proposed works. However, plant will need to be refuelled and there will be a need for a safe staff access route.

The main access route for refuelling will be from the site compound at Pagham Car Park to the breach site. This will be via the south-western end of Pagham Beach/Spit and across the proposed temporary causeway that will be created (Section 3.2.1, Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes"). However, to initially get the plant onto the spit and to help build this access causeway, a temporary crossing will be created at the shallowest part of the channel near the north-eastern end by using some of the existing shingle ridges on the landward side of the channel (Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes"). Access from the site compound to this proposed mobilisation crossing point will be across Pagham Beach. Once across the channel, the plant will travel directly up and over the spit and then travel along the seaward side on the foreshore to gain access to the breach site. This route should only be used once.

Once the temporary access causeway has been created (at 0mODN), the remaining material that is excavated from the breach location will be stockpiled in an area to the north of the breach and just seaward of the infilling areas (Appendix D, refer to sketches "Pagham Spit Breach – Step 1 to 5"). Plant movements during construction and the stockpiling of material have the potential to damage underlying shingle habitat and any associated macrofauna, algae and/or vegetation. The value of this habitat to, and impacts on, supporting nesting birds is described in detail in Section 8.2.2.

For the most part the plant will stay along established paths and access routes on the Pagham side and will remain along the crest of the spit moving across northern areas of the spit that are less vegetated. They will however need to move across shorter sections of more vegetated areas (approximately 100 m). The temporary access routes and stockpile area will be agreed in advance with Natural England and RSPB to minimise the footprint of impact and any potential damage to vegetated shingle.

The exposure to change of the shingle habitat is considered to be low given the high probability of an occurrence but also the small magnitude of change (which will localised and confined to discrete/agreed access pathways during the approximately 9 to 11 week construction period only). The sensitivity of the shingle habitat to damage by construction plant is considered to be low to moderate given that barren shingle habitats is characterised by disturbance (low sensitivity) but that vegetated areas are more stable and can take a few years to recover depending on the successional maturity of the species present (moderate sensitivity). The importance of the SPA/Ramsar supporting shingle habitat is high. Overall, therefore, the impact of plant operations on shingle habitat is considered to be minor adverse significance.

Plant during construction will also overlap with the geomorphological interest of Pagham Harbour SSSI, namely the shingle spit. Although there is a high probability of an occurrence (i.e. plant will definitely access the area) but change to this feature will be negligible and hence the exposure to change is considered to be negligible given that the change is temporary and relatively local in spatial extent in the context of the natural variability in the geomorphological

ARUN DISTRICT COUNCIL P/93/25/PL

development of the site. The sensitivity of the geomorphological value of the shingle spit to heavy plant is considered to be low to none given that the overall structure and function of the spit will not be altered as a result of plant movement (i.e. it will not change the supply or movement of sediment). The importance of the SSSI geomorphological spit feature is considered to be high given both its rarity and national designation. Overall, therefore, the impact on the geomorphological spit interest feature is considered to be insignificant.

The palaeobotanical interest of the Pagham Harbour SSSI could also potentially be damaged by vehicles tracking along the Pagham Beach foreshore at low tide. London Clay areas containing plant fossils are exposed mostly along the eastern extent of Pagham Beach outside the proposed footprint of the access works (Section 8.1.8). All material comprising the shingle spit has recently been deposited and therefore no significant London Clay exposures would be expected within the spit. The exposure of the change to the geological interest feature value of the Pagham Harbour SSSI is therefore considered to be negligible (based on a negligible magnitude of change and low probability of occurrence). The sensitivity of plant fossils is moderate given that if they were to be present they could potentially be permanently damaged or destroyed by vehicles tracking over them and are not tolerant to this impact. SSSIs are a nationally designated site and therefore the importance of the geological interest is assessed as moderate. Overall, therefore, the impact on geological interest feature value of Pagham Harbour SSSI is considered to be insignificant.

8.2.5 Impact Pathway 13: Effects on Ecology in Pagham Harbour During Construction Phase

8.2.5.1 General scientific context

Intertidal habitats within estuaries and natural harbours are typically subject to changes over a range of spatial and temporal scales. For example, the resuspension and deposition of sediments fluctuate on a daily basis (through tidal action), lunar cycles (due to the differing influences of spring and neap tides) and on a seasonal basis (due to storm activity and conditions of extreme waves). Some of these changes will take place over brief periods of time because they will be driven by storm events causing intermittent pulses of sediment movement. Therefore, the benthic assemblages and species that characterise these habitats are tolerant of, and indeed reflective of, an environment exhibiting typical small-scale oscillations in exposure/emergence and suspended sediments. Benthic invertebrate assemblage characteristics indicate that the levels of disturbance generally increase down the shore and towards the estuary mouth and this leads in turn to reduced invertebrate abundance.

Intertidal mudflat biotopes have a low sensitivity to an increase in suspended sediment or a decrease in emergence regime (MarLIN website). Benthic assemblages and species that characterise these mudflat habitats are considered to be tolerant of an environment exhibiting typical small-scale perturbations in exposure/emergence and suspended sediments.

Seagrass beds are considered to have a low sensitivity to increases in suspended sediment and changes in emergence regime (MarLIN website). Increased sediment availability may result in raised eelgrass beds or smothering of the leaves. Increased suspended sediment concentrations will also reduce the light reaching submerged plants. However, intertidal seagrass can 'escape' this effect since it is able to take advantage of the high light intensities

ARUN DISTRICT COUNCIL P/93/25/PL

available at low tide (Vermaat et al., 1996). A long term change in the emergence regime is likely to increase or reduce the extent of the seagrass population in the intertidal. However, expansion depends on available habitat and competition in infaunal dominated sediments (e.g. Hediste diversicolor or Arenicola marina (Hughes et al., 2000; Philippart, 1994a).

Saltmarshes are dependent on suspended sediment to thrive and respond to sea level rise, however, a marked increase in the rate of siltation may increase sedimentation rates above growth rates resulting in smothering. Turbidity reduces the light attenuation through water. However, saltmarsh vegetation is exposed for the majority of the tidal cycle and able to photosynthesize. Decreased emergence is likely to decrease the extent of the saltmarsh, moving the pioneer community up shore. Small sudden changes in water level should not have any effect on existing saltmarsh vegetation as all saltmarsh plants tend to exhibit fairly wide ranging niches. Each saltmarsh species has a different tolerance to tidal flooding, and therefore a different, although often overlapping, vertical range. Research looking into species' vertical range (or niche) determined that the number of hours uncovered during daylight between September and November consistently predicts species limits (Clarke et al., 1993).

Percolation and isolated lagoons are likely to be most sensitive to changes in water quality because of their very limited water exchange (flushing) with the sea or fresh waters (Johnston and Gilliland, 2000). Silled and sluiced lagoons will be less sensitive, but generally still have very restricted water exchange. Overall, lagoonal inlets may be expected to be the lagoon type least sensitive to changes in freshwater quality or anthropogenic inputs, as seawater enters on each tide. Increased suspended sediments and sedimentation may result in the possible smothering or inhibition of feeding for fragile specialist lagoonal species. Any nutrients locked in the sediments that are suspended will result in increased phytoplankton growth, subsequent death and retention of the resulting organic particulate matter and retention of nutrients arising from breakdown of this organic material. Saline lagoons would generally have a low recovery potential from water quality impacts, and particularly from eutrophication impacts, given their restricted flushing regimes.

A detailed review of the DeFolin's lagoon snail's ecology is provided in Appendix J and summarised in Section 8.2.3.1. Overall, the sensitivity of this specialist species to changes in emergence regime is considered to be high (MarLIN website). Intolerance will depend upon whether the emergence change retains marine percolation and the speed with which the change occurs. Slow, long term change in retaining percolation could probably be accommodated, otherwise intolerance will be high and recoverability low. There is no available evidence on the effects of increases in suspended sediment on this species, however it is considered to be a sub-surface deposit feeder and is therefore unlikely to be particularly sensitive to an increase in sedimentation.

Where water channels dry out completely, water voles are exposed to an increased chance of predation and may either be killed directly, or choose to relocate to more optimal habitat nearby (Essex Wildlife Trust, undated). Rapid depopulation of dry channels is almost always the result. Colonies are also vulnerable to flooding and although adults can escape from rising water, it may be impossible for mothers to remove young to safety if the whole burrow system becomes inundated.

ARUN DISTRICT COUNCIL P/93/25/PL

8.2.5.2 Project impact assessment

This pathway considers the changes that will occur within Pagham Harbour during the construction works. This includes the effects that arise for benthic habitats and bird species as a consequence of changing water levels (from the installation of the temporary access causeway) and due to the potential release of sediment from excavations and translocation work.

Effects on birds are addressed on the basis that the works will not be undertaken during the breeding season but are likely to extend into the overwintering period. Thus it is the effects of foraging on overwintering waterbirds (especially Ruff, Black Tailed Godwit and Dark-bellied Brent Goose as interest features of the SPA) that are considered.

Changes in Water Levels

The temporary causeway will be constructed over a period of a week to a level of 0 mODN to provide low water access during construction (see Section 3.2). This causeway will remain in place for a period of around 8 weeks, until the channel is fully infilled with excavated material from the breach location at the end of the campaign.

The presence of the causeway will essentially retain water in the harbour at just above MSL. This will convert a small area of lower elevation mudflat within the Pagham Harbour SPA and Ramsar to shallow subtidal habitat over the construction period. Based on GIS analysis, this area will be 4.2 ha which represents 4.5% of this supporting habitat within the Pagham Harbour SPA and Ramsar site[41]). The invertebrate species that characterise the intertidal mudflat habitat are predominantly polychaetes, namely A. marina and N. diversicolor (Section 8.1.4). These characterising species are all found in the shallow subtidal and therefore, the habitat is not considered to be sensitive to changes in emergence and tidal exposure (MarLIN website).

The exposure of intertidal mudflat to changes in water levels is considered to be medium at worst given that the magnitude of change is small to medium (and only temporary) and the probability of occurrence is high. However the characterising species will have a low sensitivity and low vulnerability to change from the period of submergence and will also exhibit rapid recovery (within days/weeks/months) once the tidal regime is restored post-excavation. Given the high importance of this habitat as a supporting feature of the Pagham Harbour SPA/Ramsar site, the impact on the affected intertidal mudflat habitat will be of minor adverse significance.

The decrease in overall intertidal habitat area during construction will also result in a reduction in its functioning as foraging habitat for birds in Pagham Harbour, particularly small waders that are restricted to feeding in intertidal areas and are not able to feed on shallow subtidal waters (e.g. Dunlin). The habitat change is considered to be of a small to medium magnitude and the

41 The existing (baseline) area of intertidal mudflat habitat within the boundaries of Pagham Harbour SPA and Ramsar site has been calculated using the latest available LiDAR data (rather the areas provided in the SPA and Ramsar site citations).

ARUN DISTRICT COUNCIL P/93/25/PL

exposure also medium at worst because the probability of occurrence is high. However, the sensitivity of foraging birds to the temporary loss of intertidal mudflat habitat area during construction is considered to be low given that the majority of the harbour will continue to be intertidal and provide suitable feeding habitat while the temporary shallow subtidal habitat will continue to provide foraging habitat to larger bids (including Ruff, Black Tailed Godwit and Dark-bellied Brent Goose which are interest features of the SPA). The importance of birds in Pagham Harbour is assessed as high because of overwintering foraging birds are interest features of Pagham Harbour SPA/Ramsar site. Overall, therefore, the temporary effects on functional supporting habitat for foraging birds within Pagham Harbour from changes to the tidal environment during the shingle excavation and translocation work is considered to be minor adverse significant.

No other habitats or species will overlap with the changes in water levels that will occur within the harbour during the construction works. Seagrass beds, for example, occur in the mid to high mudflat elevations (above 0.8 mODN) and will not be impacted during construction. No other habitats overlap with the changes in low water, including saltmarsh, saline lagoons and vegetated shingle. DeFolin's lagoon snail occurs just below the MHWS level and water voles present in the harbour occur in the upper tidal fringes. These protected species are therefore also outside the area of change and will not be impacted.

Changes in Suspended Sediment Concentrations

There is the potential for sediment to be resuspended during the works as a result of excavating the breach and infilling the existing tidal channel. However, any resuspension of sediment caused by the works would be small in scale and highly localised. This is because the excavated sediment is predominantly coarse in nature with a mixture of sands, shingle and gravels and, therefore, any sediment deposited at the infill or breach location would quickly fall back out of suspension and thus rapidly return to the pre-work condition. Furthermore, the temporary access causeway that is proposed at the infill location during construction and the fact that coarser material will be placed on the southern side of the infill footprint will also reduce the potential for material to be transported by tidal action both into the harbour or out to sea (see Section 3.2).

Any localised changes in suspended sediment levels that do occur will be immediate to short term given the temporary and intermittent nature of the excavation and infilling works. Much of the excavation work will also take place above the tidal level wherever possible. The channel infill will take place over a period of up to two weeks and the excavation of the highest elevation central section of the spit will take place over a one week sequence of dropping spring to neap tides thus further minimising the potential for resuspension.

Overall, the exposure to change is considered to be negligible due to the potential changes in suspended sediments being of a high probability but negligible in scale (being confined to the immediate spatial extent of the works over a short/temporary timescale (see Section 7.2.1)). The only habitat within the harbour to potentially overlap with the small and intermittent sediment plume during construction is intertidal mudflat. Intertidal mudflat is considered to have a low sensitive to the predicted negligible changes in suspended sediments. The importance of intertidal mudflat as a supporting feature of the Pagham Harbour SPA/Ramsar

ARUN DISTRICT COUNCIL P/93/25/PL

site is high. Therefore, the overall impact of changes in suspended sediment concentrations on habitats within the harbour during construction is considered to be insignificant.

No other habitats or species will be affected by the changes in suspended sediment concentrations that will occur within the immediate locality of the construction works.

8.2.6 Impact Pathway 14: Effects from Any Increased Disturbance on Overwintering Birds Due to Construction Work

8.2.6.1 General scientific context

A detailed review of bird disturbance based on the findings of a large number of observations and scientific studies has been included in Appendix K. This review includes information on the current understanding of disturbance responses associated with a range of different activities as well as the potential short and long term consequences of such disturbance. An overview of the key issues associated with this subject is presented below.

Disturbance can cause birds to cease feeding which can decrease the total amount of time available for feeding as well as disrupting other behaviour such as breeding (Coleman et al., 2003; Martín et al., 2014). Where disturbance causes birds to take flight, it can increase energy demands and may increase food consumption by decreasing the available habitat area (Stillman et al., 2007).

Repetitive disturbance events can result in possible long term effects such as loss of weight, condition and a reduction in reproductive success, leading to impacts at the population level (Durell et al., 2005; Gill, 2007; Goss-Custard et al., 2006; Belanger and Bedard, 1990). Birds typically show a dispersive response to disturbance with prolonged disturbance causing displacement (Dwyer 2010; Navedo and Herrera, 2012).

Disturbance often occurs through a combination of visual and noise stimuli simultaneously, although some occurrences may be through a visual or noise stimulus separately (Wright et al., 2013). The effect of such disturbance is related to the frequency of the events and the status of the conditions that are prevalent (Liley and Fearnley, 2011; Coleman et al., 2003; Ruddock and Whitfield, 2007; Stillman et al., 2012).

It generally appears that birds are more easily disturbed by irregular human presence and predators such as dogs and raptors than the regular and defined presence of machinery, boats and other vehicles. The character of these activities is however also relevant (Glover et al., 2015; McLeod et al., 2013; Guay et al., 2014; IECS, 2009). For example, McLeod et al. (2013) conducted 730 experimental approaches to 39 species of waterbird, using five stimulus types (single walker, three walkers, bicycle, car and bus) selected to mimic different human management options available for a controlled access, Ramsar-listed wetland. Across species, where differences existed (56% of 25 cases), motor vehicles always evoked shorter disturbance distances than humans on foot. This was also noted by IECS (1997), in that a person approaching feeding birds on the mudflat caused birds to fly when the person was approximately 300m from the birds, whereas machinery could approach birds within 50m before the birds moved away.

ARUN DISTRICT COUNCIL P/93/25/PL

Large groups of noisy people; the chaotic and high speed approach of dogs off leads; aerial objects such as kites and small aircraft are all considered activities particularly likely to heighten the disturbance response of individuals (Smit and Visser 1993; Beale and Monaghan 2004). Monitoring of birds as part of the Grimsby River Terminal Project found that noise from construction (including piling) caused only 1% of the disturbance events observed, with large disturbances mainly caused by the presence of raptors, aircraft and helicopters (Xodus, 2012).

With respect to piling specifically, it has been concluded that although piling has the potential to create most noise during construction; it often consists of rhythmic "bangs", which birds are likely to become accustomed to after a short period (ABP Research, 2001). In a series of IECS reports to Saltend Cogeneration Company, it was noted that during visits in February and March birds appeared indifferent to piling noise generated from the landward side of the seawall and bird numbers using the mudflats at low tide were similar during periods of piling and no piling. As construction extended towards the seawall some birds were disturbed over a small area, while others remained feeding within 200m of piling activities (IECS, 2009a).

Response levels to different activities based on the review by IECS (2009a) are summarised in Table 8.11.

Table 8.11 Response level to activity

Response Level	Activity
High	Jets (particularly low flying) Subsonic transport aircraft Free running dogs within 100m
High - Moderate	Irregular construction noises above 70dB (A)
Moderate	Shooting, (wildfowling and military) Recreational activity, (walking, running, dogs), within 100m Boat disturbance within 100m Regular construction noises 50-70dB (A)
Low	Recreational activity, (walking, running, dogs), outside 100m Noise below 50dB (A)

8.2.6.2 Project impact assessment

This pathway considers the effects of the construction works on bird populations as a result of the construction activities on site. The anticipated construction work will either occur in November to December 2015 or in 2016 (before or after the Little Tern breeding period which is April to July 2016). Therefore the works will extend into the winter period and these activities have the potential to cause temporary noise and visual disturbance effects on roosting and feeding waterbirds (including Ruff, Black Tailed Godwit and Dark-bellied Brent Goose as interest features of the SPA) during the overwintering period. The works will not be undertaken during the summer nesting season and therefore the effect on breeding birds form disturbance is not considered.

As part of the proposed project, sheet piles will be driven into the tidal inlet channel adjacent to the proposed infill area using a vibratory hammer to create the temporary access 'causeway'.

ARUN DISTRICT COUNCIL P/93/15/PL

In addition, noise and visual disturbance of waterbirds may also occur through construction machinery, equipment, vehicles and construction workers throughout the 9 to 11 week construction period.

During the construction phase, activities will be restricted to a relatively localised area around the construction site (breach and channel infill) and also along defined access routes. With respect to access routes, initial access will from Pagham Beach across to the distal end of Church Norton Spit at the shallowest part of the channel (using some of the existing shingle ridges on the landward side of the channel). This route should only be used once. For the remaining duration of the project, access will be via the temporary access 'causeway' across to the end of the Pagham Spit (see Section 3.2.1 and Appendix D, refer to sketch "Pagham Spit Breach - Site Access Routes").

Within the construction site, the level of disturbance stimuli is dependent on the type of activity being undertaken. In general, human presence on the foreshore (e.g. walking) is considered to cause greater disturbance than vehicles or watercraft and waterbirds are more easily disturbed by irregular movements than the regular and defined presence of machinery, vessels and other vehicles (IECS, 1997; ABPmer, 2013; Guay et al., 2014; Glover et al., 2015; McLeod, et al., 2013;). Other research has also indicated that in general, birds appear to habituate to continual noises (such as piling and engine noise) as long as there is no large amplitude 'startling' component (Hockin et al., 1992; IECS, 2009a; IECS, 2009b).

Based on the results of these studies and a wide range of other research which is summarised in the scientific review above and presented in detail in Appendix K, regular construction activities are expected to generally cause infrequent, mild behavioural responses in a localised area in the vicinity of the works. The distance over which birds are expected to be disturbed from activities involving plant movements rather than human activities is in the region of 50m.

The responses observed are likely to range from increased vigilance, avoidance walking and short flights with birds rapidly resettling and resuming feeding or roosting near their original location. The birds using the foreshore are expected to already be reasonably habituated to anthropogenic activities due to recreational pressure, mainly from dog walkers, and the birds are also expected to become further habituated to the ground works and other construction activities. Nevertheless, occasional larger disturbance events (causing birds to flush and leave the immediate vicinity) could occur.

It is also possible that some birds could temporarily disperse from the foreshore directly around the construction area. Rather than evacuating the area completely, birds would be expected to redistribute to other parts of Church Norton Spit and Pagham Harbour. Should this occur, the effect would only likely be short term with birds expected to return following completion of the construction works.

Overall, with regards to the disturbance created by plant movements, human access and piling during construction, the probability of disturbance occurring is considered to be high. With regards to magnitude it will coincide with the overwintering period and the area is used by species such as Knot, Dunlin, Turnstone and Grey Plover (see Section 8.1.5.3). The 50m disturbance zone around the construction site on the shingle spit will cover an area of around 3

ARUN DISTRICT COUNCIL P/93/15/PL

ha which represents around 3% of the area of Pagham Harbour and approximately 12% of the Church Norton Spit. Within this area around 6% of the harbour's Dunlin and 0.5% of the Grey Plover (based on 2013/14 WeBS low water count) have been recorded.

The area affected by noise and visual disturbance is relatively small when compared to the full Pagham Harbour SPA and the construction activity will only be over a short period at the beginning or end of the overwintering period.. While the probability of an occurrence is high, based on these considerations, the magnitude of the disturbance is assessed as small.

Birds will have to have a low to moderate sensitivity (depending upon species and the degree of established habituation). Many species are likely to be tolerant of the activities taking place and/or become habituated to them such that they will be only partially (not entirely) excluded from the disturbance zone. Habituation will also occur relatively rapidly because the majority of activities on site will be by plant with very little human movements. Some main human movement may occur during the daily site access period and these will occur along fixed routes along established footpaths. If disturbance reactions were to occur, no permanent displacement of birds from the area is predicted with occasional (localised) and mild behavioural responses generally anticipated. As a result there is low vulnerability to disturbance effects.

Based on the evidence relating to bird disturbance, sensitivity to piling and other construction disturbance is assessed as low to moderate (with variations depending upon the species, the levels of habituation). Vulnerability is consequently assessed as low. The importance is scored as high in particular because of the protection afforded to overwintering birds (including Ramsar interest features). Therefore, the temporary disturbance impact during construction has been assessed as minor adverse significant.

8.2.7 Impact Pathway 15: Effects of Loss/Change of Shingle Habitat During Operational Phase

8.2.7.1 General scientific context

A generic review of shingle habitat and its tolerance to physical loss is presented in Section 8.2.1.1 and is therefore not repeated here. The anticipated post-breach evolution of the spit is described in Section 6.3.1 which is used to underpin this assessment (and is summarised below). To further inform this assessment (alongside this preceding information) it is noted that dynamic change, with cycles of growing and breaching, is a typical characteristic of coastal spit features. Some examples are described below.

The best descriptor of the changeable nature of spit evolution and breach morphology in front of a tidal inlet is the frontage at Pagham Harbour itself. This is because this frontage has been well studied over a long period of time. It has not existed in a fixed shape but has instead exhibited a variable morphology over time having natural and man-made breaches of varying sizes, and also once occurring as an (artificially) closed shingle barrier. Therefore understanding how these past configurations have responded over the last decades and centuries will provide the best indication about how it is likely to function. These historical changes have been examined in greater detail in Section 6.2.6.

ARUN DISTRICT COUNCIL P/93/25/PL

Away from Pagham Harbour there are many of examples (nationally and globally) of other shingle spits and barriers evolving and breaching over time. One well documented example of the future evolution of the distal portion of the spit following a breach is in the north end of South Beach, a barrier island in Chatham, Massachusetts (Weidman and Ebert, 2013). This spit exhibits a cyclic pattern of accretion, breaching, and shoal generation. This spit is within a large developing tidal inlet system that was formed when Nauset Beach was breached in 1987. Five cycles of spit growth and breaching have been observed in two years. Each cycle is characterized by: 1) elongation of spit for several months; 2) gradual narrowing and eventual breaching of the spit's midsection, which creates a small tidal channel and terminates the growth cycle; and 3) evolution of the detached distal portion of the spit from a supratidal island to subtidal shoals. The growth and breaching of this spit are significant processes causing landward sediment transport within the inlet system.

In the UK, the spit at the mouth of the Deben estuary has exhibited cycles of change while Hurst Spit and Spurn Head have previously breached. Hurst Spit is a shingle bank at the easternmost point of Christchurch Bay and extends 2.5km from the end of Milford beach out into the Solent. It is an important coastal defence, protecting the Western Solent from flooding and sheltering the designated area of saltmarsh to the north (Poole & Christchurch Bays Coastal Group website). Although originally formed by natural processes, Hurst Spit is now maintained by regular shingle recycling operations. The spit has been declining in volume, probably since the 1940s when coast protection works in Christchurch Bay first began to interrupt movement of the shingle that maintains its stability. The reduction in sediment supply led to several breaches and in 1996 major work was undertaken to replenish the spit with shingle and to construct a rock breakwater and new rock revetment and current management includes regular shingle replenishment and monitoring.

The sand and shingle spit of Spurn Head lies on the north side of the mouth of the River Humber. A series of breaches reduced Spurn Head in the 1850s to a string of small islands according to the Admiralty Chart of 1852 (May, 2003b). The development of the spit considerably changed following the closure of these breaches, by the erection and maintenance of groynes and revetments and by the encouragement of dune-colonizing plants (May, 2003b).

Following the storms that occurred in December 2013 there were also a number of unmanaged breaches of gravel ridges at Blakeney/Weybournbe (N Norfolk) and on the Suffolk coast at Benacre/Easton Bavents and between Walberswick and Dunich (Spencer et al., 2015). The Walbersick barrier has been subject to regular breaching in the past and is clearly a vulnerable site. The shingle bank here has been managed for flood risk over the last 40 years, but since the early 1990s it has been increasingly difficult to maintain an effective flood defence and repair the barrier after storms (Pye and Blott, 2009). The barriers at N Norfolk and Benacre closed up naturally in the weeks/months after the storms (Spencer et al., 2015).

Further examples of stable natural and man-made breaches in shingle barriers occurred at Porlock and Medmerry respectively. The lessons from this past work are described in Section 7.2 of the Breach Design report in Appendix A.

ARUN DISTRICT COUNCIL P/93/25/PL

8.2.7.2 Project impact assessment

This pathway considers the change to shingle habitats that will arise over the short, medium and long term as a consequence of the proposed projects. The effects of the geomorphological and geological/palaeobotanical interests of the site are also considered. The main issues for impacts on geology relate to loss or damage of areas designated for their geological interest.

The future evolution of Pagham Harbour as a result of the proposed project is discussed in more detail in Section 6.3.1. In summary this section concludes that once the work is completed, the separated (northern) section of spit will very quickly (over the short term), begin to migrate landwards towards the beach. As the distal end of the spit reconnects to Pagham Beach a lagoon will form behind which will more slowly (over the medium term) recede through over-washing and the shoreward migration. The new spit shape, with a lagoon behind, is expected to persist for a few years.

Over the longer-term (8 to 12 years depending on the drift rate), the separated section of the spit is expected to reintegrate back into the beach and/or into longshore processes. The removal of shingle from this (separated) Pagham Spit is therefore expected to be a gradual process that takes around a decade.

The rate at which the spit on the Pagham side declines and the speed with which a new ebb delta matures in front of the new inlet will influence how, where and when the Church Norton spit will reform. If, as expected, the removal of shingle from the (separated) Pagham Spit is a gradual process that takes around a decade, then any spit formation at the Church Norton side will take an equivalent number of years thereafter and begin by slowly migrating to seaward. If the spit on the Pagham side (the northern section separated by the managed breach) declines more rapidly than the predicted 8 to 12 years, any spit formation at the Church Norton side will probably follow the existing spit alignment. Under either of these two spit decline and regrowth scenarios it is assumed that a new spit will reform in around 10-15 years following the breach

Under either of these two scenarios occurs, the potential exists for there to be no net loss or change to the shingle habitat in the short, medium to long term. Certainly the existing northern end of the spit is not expected to degrade rapidly and is likely to be present for a number of years. The Church Norton Spit may well then re-form with the rate at which the Pagham Spit declines influencing its alignment and speed of growth.

There is a high probability of a future change with the magnitude of this change ranging from anything from negligible to medium depending upon the precise nature of the future spit evolution (all change is however lower than the large changes experienced through natural variation). Taking account of this uncertainty associated with the future evolution of the site, the exposure to change of shingle habitat is considered occur as a range from negligible to medium. The sensitivity of the shingle habitat and its tolerance to the predicted changes resulting from the breach is considered to be low in the context of natural variability. This habitat is inherently variable in its form and has tolerated and recovered after past breaches and, also, there is confidence that a new spit morphology will evolve (see Section 6.3.1). The

ARUN DISTRICT COUNCIL P/93/25/PL

importance of the SPA/Ramsar supporting shingle habitat is considered to be high. Therefore, the worst-case impact is considered to be minor adverse significant.

When considering the impact on the geomorphological interest of the spit the same assessment principles apply with respect to the levels assigned for probability (high) and magnitude/exposure (variable/uncertain from negligible to medium). The sensitivity to change in geomorphology is also considered to be low as the spit is expected to grow and continue being dynamic (as it is now and as it has been in the past) so that any impact can be viewed as temporary. The importance of the SSSI geomorphological feature is considered to be high given its rarity. Therefore, the impact on the geomorphological interest of this site during operation is considered to be minor adverse significant.

With regard to the geological interest of Pagham Harbour SSSI, the London Clay areas appear to be exposed mostly along the eastern extent of Pagham Beach, where it adjoins the 'Bognor Foreshore' RIGS/'Bognor Reef' SSSI (Section 8.1.8). Following the breach, the increased supply of shingle to the currently eroding section of Pagham Beach will protect any underlying palaeobotanical features that might be present in London Clay and reduce the likelihood of their potential exposure. All material comprising the shingle spit should be relatively recent and relatively small (i.e. of a size which can be moved by currents and waves), and therefore no significant London Clay exposures would be expected within the spit either. The exposure of large erratics (boulders) is also unlikely although not possible to completely rule out given that they were often used in reinforcing coastal defences (David Bone, Sussex Geodiversity Partnership, pers. comm.).

Taking all these considerations into account, the exposure of the change to the geological interest feature value of the Pagham Harbour SSSI is considered to be negligible (with a low probability of a small change occurring). The sensitivity of these features is considered to be low given that if they were to be present they are likely to remain buried (and thus protected) by the increased shingle supply to Pagham Beach over time. SSSIs are a nationally designated site and therefore the importance of the geological interest is assessed as moderate. Overall, the impact on the geological interest feature value of Pagham Harbour SSSI is considered to be insignificant.

8.2.8 Impact Pathway 16: Effects of Loss/Change of Little Tern Breeding Habitat During Operational Phase

8.2.8.1 General scientific context

Information on Little Tern breeding habitat was reviewed previously in Section 8.2.2 and is therefore not repeated here. This included a review of the habitat preferences of Little Terns and also the sensitivity of Little Tern colonies to a range of different pressures. The review of the potential future evolution of the spit features in front of Pagham harbour were described in Section 6.3.1 and was also summarised in Section 8.2.7.2. This information provides the evidence base for the assessment below.

ARUN DISTRICT COUNCIL P/93/25/PL

8.2.8.2 Project impact assessment

This pathway considers the effects that changes to shingle habitats will have on nesting Little Tern populations (as an interest feature of the Pagham Harbour SPA) during the post-breach (operational) period of the project. As described in Section 5.8, this encompasses the anticipated future changes in the short term after the construction phase has been completed but also the medium to longer-term effects (up to maximum of 20 years) arising from the subsequent evolution of the spit features. This assessment focuses on considering the effects on Little Tern species from the changes in habitat extent alone, the changing morphology will also influence the levels of bird disturbance and predation and this aspect is considered further in Section 8.2.10.

As discussed previously, in Section 8.2.2, the breach (development) footprint does not overlap with shingle habitat that is currently used by Little Terns for nesting. Therefore, the extent of preferred Little Tern nesting habitat towards the distal end of Church Norton Spit is not expected to be directly/immediately affected by the work.

In the short term (first few years) after the breach has been made, this area is still expected to remain viable and potentially valuable as a Little Tern nesting area. The separated spit is expected to remain largely *in situ* for at least this period of time. It will, however, shift and evolve in response to storm events particularly, and it is expected to gradually roll back. As it does move it is likely to create relatively sheltered and vegetation-free 'shelves' of shingle that should continue to be suitable for Little Tern nesting (in the same way as is provided by the spit in its existing morphology). Also, during this initial period the existing tidal inlet behind the separated spit section is expected to become a new lagoonal feature (as the spit integrates with Pagham Beach) that may provide an improved area for Little Tern foraging. In the short term therefore, the quality and quality of potential Little Tern nesting habitat is not likely to be adversely affected and may be improved.

Over the medium term (5 to 8 years) the spit is expected to increasingly degrade and recede shoreward and the extent of suitable tern nesting habitat on the separated section of spit is likely to reduce. In particular there will be less available habitat at higher elevations (which are at lower risk of being flooded through overtopping in storms). During this period the root of the new spit on the Church Norton side is likely to be forming although this will be a comparatively slow process because it will be growing seawards into deeper water. This emergent spit may provide suitable habitat for Little Terns though it will be more exposed on the seaward side of the spit.

In the longer-term 8 to 12 years and beyond, the separated spit is expected to disperse and become completely integrated with Pagham Spit. At this time all tern breeding habitat on the relict spit will probably be lost. There is however a high confidence that there will be an expansion of the Church Norton Spit although the manner and direction of this is subject to a higher level uncertainty

The likelihood exists therefore that there could be no overall loss of shingle habitat and that as the separated spit section degrades (over a period extending up to 8 to 12 years) it is replaced

ARUN DISTRICT COUNCIL P/93/25/PL

by the prograding Church Norton Spit. However, as these predictions move from the short to the medium and then the long term there is an increasing level of uncertainty on this aspect.

Based on the predicted changes described above, the probability of some habitat change occurring for Little Terns is high. However, due to uncertainty over the timescales associated with future shoreline evolution and the high level of variability associated with the number of Little Terns breeding (and subsequent productivity) annually, confidence in predicting future usage of the area by breeding Little Terns is low. Taking account of this uncertainty associated with the future evolution of the site, the magnitude and exposure to change to Little Tern breeding habitat is considered occur as a range from negligible to medium. These changes are likely to increase in scale (but also in uncertainty as to their occurrence) over time such that there should negligible to small changes in the short term becoming medium changes over the medium to long term. These are all less than the large changes experienced through natural variation.

Little Terns are considered to have a moderate sensitivity to habitat loss or change (i.e. nests sites are highly vulnerable to a range of pressures but Little Terns will also readily colonise new habitat, particularly in vicinity of natal nest sites). Consequently, vulnerability is assessed as low in the short term building to moderate over the longer-term. The importance of the feature is scored as high because of the protection afforded to Little Terns. Therefore, the impact of changes in breeding habitat are considered to be minor adverse significant in the short term but potentially up to moderate (though with increasing uncertainty of effect) in the medium to long-term.

In order to account for the potentially moderate effects in the future, mitigation measures should be implemented (see Section 5.6.3). The possibility exists that these might not be needed and there is a high likelihood that they are not essential in the short term. However they should be pursued from the start of the project in recognition of the need to adhere to the precautionary principle and to address issues of uncertainty that are relevant especially when considering projects affecting European/Ramsar sites (i.e. site protected under the Habitats Regulations)

In this case, it is recommended that a new area of potential tern breeding habitat is created/restored within the harbour as mitigation (see Section 11.2.2). It is noted that that this mitigation should now be viewed as 'compensation' under the Habitats Regulations given the recent developments in European case law and in Natural England advice (Natural England, 2015).

Following a visit to the site, it has been concluded that the most suitable area for this habitat restoration work would be on the Church Norton side of the harbour where the old 1910 breach took place. Here there are relict concrete revetments from the previously installed training overlying a bed of shingle and in this location it will be possible to use some of the shingle from the excavations alongside these revetments to improve the area. Also it will be possible to excavate a new channel across this redundant revetment to create an isolated island surrounded by a tidal channel that could be less vulnerable to predation than other areas of Pagham Harbour.

ARUN DISTRICT COUNCIL P/93/25/PL

There will remain a level of uncertainty as to whether Little Terns will then nest on this site once it has been created/restored. However, to help understand the confidence that can be placed in this process, a review of measures that have been and can be undertaken to improve and managed Little Tern nesting sites was undertaken. The result of that review is provided in Appendix L.

Based on the findings from this review, it is considered likely, with appropriate planning in the light of past lessons, that Little Terns can be actively encouraged to use the 'New Tern Island' and that it will provide the necessary habitat to offset any potential loss of available breeding habitat on the spit during operation. Although the island is smaller than the area that could be lost over the longer-term, it is considered that it could be made of a better quality (e.g. with robust predator exclusion fences or cages if required).

The enhancement of this island should take place at the same time as the excavation of the breach and any associated monitoring and management measures can then be taken in the short term thereafter when no significant adverse effects on Little Tern breeding are anticipated. Then over time as the evolution of the spit is better understood and as larger effects might be observed ongoing decisions can be made about the requirements for the management of this new island feature. Thus the mitigation would be pursued in an adaptive manner to address the issues uncertainty that exists for this impact pathway. Further details about this site and the nature of these compensation measures are presented in Section 11.2.2.

On the basis of the application of this adaptive mitigation/compensation work it is concluded that there will be a small to negligible magnitude of change to Little Tern breeding habitat. The exposure to change is considered to be low to negligible and, taking account of the moderate sensitivity of Little Terns to habitat loss or change and their high importance in terms of level of protection, the residual impact following compensation is considered to be minor adverse significant or insignificant.

8.2.9 Impact Pathway 17: Effects on Ecology in Pagham Harbour During Operational Phase

8.2.9.1 General scientific context

The sensitivity of intertidal habitats and associated species to changes in emergence regime and suspended sediment levels are described in Section 8.2.5 and are therefore not repeated here. The physical changes that are expected to occur within the site are also reviewed in Sections 6.3.2 and 6.3.4. This information provides the evidence base for the assessment below.

8.2.9.2 Project impact assessment

This pathway considers the changes that will occur within Pagham Harbour during the operational phase of the works. This includes the effects that arise for benthic habitats and bird species as a consequence of changing water levels (from the installation of the temporary access causeway) and the potential release of sediment from excavations and translocation

ARUN DISTRICT COUNCIL P/93/25/PL

work. Effects on birds are addressed on the basis that the works will not be undertaken during the breeding season but are likely to extend into the overwintering period. Thus, it is the effects of foraging on overwintering waterbirds (especially Ruff, Black Tailed Godwit and Dark-bellied Brent Goose as interest features of the SPA) that are considered.

Changes in Water Levels

Within Pagham Harbour there are expected to some minor changes in water levels. During the initial period of breach adjustment there is likely to be a small reduction in high water levels across the harbour. Once the breach has adjusted and enlarged to a new equilibrium these small reductions are not expected to persist, and the high waters are expected to return to baseline conditions. Hence, the small changes on high waters are considered to be short-term and temporary.

As the breach will shorten the inlet channel, the area within the former inlet which used to store water at low tides will no longer influence and hold up low waters on a spring tide at the seaward end of the harbour, and this local area will be able to drain more efficiently. A marginal reduction in the neap low water levels is also indicated. Whilst this effect is only local to the seaward part of the harbour it is likely to last for the longer-term until there was a further change in spit development.

The initial self-adjustment of the breach to a new morphological equilibrium is expected to be achieved over the course of a few spring tidal cycles. Any subsequent natural readjustment of the breach and inlet channel is likely to either increase (if the breach widened/deepened to a greater degree) or decrease high water (if it narrowed). The changes will be in keeping with the range of conditions experienced previously (given the range of morphologies that previously existed at the site). In other words, future water levels will continue to be variable and an inherent function of the natural dynamic nature of the environment at this location.

The changes in water levels within the harbour following the implementation of the proposed project will result in a temporary and slight reduction in the area of upper saltmarsh habitat and a slight increase in transitional terrestrial habitat in the immediate period after the breach. However, given the short period over which these changes in water levels will occur, there will be no structural or functional changes in habitat (e.g. changes in vegetation). The exposure of these changes in water levels is considered to be negligible (based on a high probability of occurrence but a negligible magnitude of change that is within the range of existing natural variability). The sensitivity of upper saltmarsh and transitional habitat to these changes in water levels is considered to be low given that they have tolerated and adapted to these changes under the present baseline scenario in the immediate term (as a result of changes brought about by spring/neap tidal cycle, storms etc.) and in the short to long term (as a result of the continuous dynamic morphological evolution of Church Norton Spit and tidal inlet channel). The overall impact therefore, taking account of the high importance of saltmarsh as a supporting habitat of the Pagham Harbour SPA/Ramsar site is considered to be insignificant.

The sensitivity of foraging and roosting birds to small temporary changes in the areas of upper saltmarsh habitat following the implementation of the proposed project is considered to be low given that this is not the optimal habitat for feeding and birds are able to roost across the

ARUN DISTRICT COUNCIL P/93/25/PL

boundary of both saltmarsh and transitional habitats. The importance of birds in Pagham Harbour is assessed as high given that foraging and roosting include interest features of Pagham Harbour SPA/Ramsar site. Overall, therefore, the long term effects on functional supporting habitat for foraging and roosting within Pagham Harbour from changes to the tidal environment during operation is considered to be insignificant.

The exposure of DeFolin's lagoon snail to the temporary changes in water levels, where it occurs within the harbour, is expected to be negligible (based on high probability of an occurrence but a negligible magnitude of change given the duration and extent of any change that could influence the relevant habitat). In the short term there will also be beneficial changes in the future from the formation of a temporary saline lagoon feature behind the separated Pagham Spit feature (see below). The sensitivity of this species to the temporary changes following the breach is considered to be low given that these changes will be within the range of existing natural variability. This species is also mobile and will be able to tolerate and change its distribution in response to marginal changes in high water if necessary. Despite its high importance in terms of its rarity and nationally designated status, the overall impact on the DeFolin's lagoon snail is considered to be insignificant. The impact on this species where it occurs within Little Lagoon is considered further below.

Water voles are considered to be insensitive to small temporary changes in water levels that would occur following the implementation of the proposed project given that the intertidal marshes are not a preferred habitat for this species and that any water channels they might be using are unlikely to completely dry out (due to existing daily/lunar/seasonal natural fluctuations in water levels). The importance of water voles in Pagham Harbour is assessed as moderate given that they are a nationally protected species. Overall, therefore, the impact of changes to the tidal environment during operation on water voles is considered to be insignificant.

A small temporary reduction in high water levels has the potential to result in a marginal decrease in the time over which tidal water can percolate into saline lagoons which have a tidal connection to Pagham Harbour, namely Pagham Lagoon and Little Lagoon. The overall exposure of this change is considered to be negligible given the high probability of a water level change by the negligible/de minimus magnitude of the change in the context of the existing restricted flushing regime of these lagoons. Percolation lagoons are considered to have a high sensitivity to changes in water quality (Section 8.2.5). Lagoonal species, including DeFolin's lagoon snail which has been recorded in Little Lagoon, are considered to have a low sensitivity to these changes given that these changes will be gradual and within the range of existing natural variability. The importance of saline lagoons is assessed as moderate given that they are a nationally designated interest feature of the Pagham Harbour SSSI. Overall, the impact of changes to the tidal environment during operation on saline lagoons and associated lagoonal species is considered to be insignificant.

No other habitats (including intertidal mudflat, seagrass and vegetated shingle) or species will overlap with the changes in water levels that will occur within the harbour during operation and will therefore not be impacted.

ARUN DISTRICT COUNCIL P/93/25/PL

Changes in Flow Speeds and Sedimentation Regime

As described in Section 6.3.4, the proposed project is not expected to alter the pattern of sedimentation within the harbour. Marginal changes to the hydrodynamic conditions and the alignment of the breach will not result in any measurable changes to the existing sediment regime (accretion/erosion patterns) within the harbour and the overall exposure to changes in sedimentation is considered to be negligible. Intertidal habitats have a low sensitivity to sedimentation which will continue to occur as a gradual process on annual basis but not as a sudden pulse of imported sediment. The importance of intertidal habitats within the harbour is considered to be high given their internationally designated status. Therefore, the overall impact of changes in sediment regime on habitats within the harbour during operation is considered to be insignificant and not of a scale that would result in an indirect effect on supporting species including invertebrates and foraging birds.

Creation of a Temporary Saline Lagoon Feature

As described in Section 6.3.1.2, in the absence of the strong tidal flows along the closed existing inlet channel, the separated Pagham Spit feature that lies down-drift (north-east) of the breach will no longer be subject to migration constraints placed upon it by the channel. As such, under continued wave action and littoral drift processes, in the short term, the distal end of the spit is likely to reconnect with Pagham Beach forming a more enclosed saline lagoon behind the old spit. Over time, the material within the old spit is likely be winnowed out through ongoing coastal processes, providing a large supply of material to the Pagham frontage and further down-drift. Depending on the drift rate, the old spit may take some 8 to 12 years to completely reintegrate back into the beach and/or into longshore processes. The lifetime of the newly created lagoon will therefore only be temporary.

Although the scale of the lagoon is relatively large in the context of existing saline lagoonal habitat in Pagham Harbour (approximately 7.6ha and 49.6% of existing SSSI saline lagoon habitat[42]), it will only be a temporary feature and therefore the magnitude of change is considered to be medium. Taking account of uncertainty in the predictions, the probability of its occurrence is medium. The overall exposure to change brought about by the new saline lagoon habitat is therefore considered to be low to medium.

A number of receptors could potentially benefit from the creation of this NERC Section 41 habitat, including DeFolin's lagoon snail and foraging birds. The sensitivity of these features to this change will depend on the potential value of this newly created lagoon and taking account of uncertainty is at most considered low. The overall impact of the creation of a temporary saline lagoon feature is considered to be of minor beneficial significant given the high importance of DeFolin's lagoon snail and foraging birds. This will offset the minor adverse impact to these features as a result of changes in water levels during operation (see above).

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42 The existing (baseline) area of saline lagoon habitat within the boundaries of Pagham Harbour SSSI has been calculated using the latest available LiDAR data.

ARUN DISTRICT COUNCIL P/93/25/PL

8.2.10 Impact Pathway 18: Effects from Any Increased Bird Disturbance During the Operational Phase

8.2.10.1 General scientific context

This review focuses specifically on the sensitivity of tern species to disturbance. Disturbance to waterbirds more generally was reviewed in detail in Section 8.2.6.1 and Appendix K.

Terns are vulnerable to the effects of anthropogenic disturbance, particularly when nests overlap with popular tourist or recreation beaches (BirdLife International, 2015; Suffolk Biodiversity Action Plan, 2008; Scarton et al., 1994; Catry et al., 2003; Siebolts, 1998; Van der Winden, 2002).

Most Little Tern nesting sites in England are located along the east and south coasts of England, adjacent to some of the most densely populated areas of Britain. This makes these sites particularly vulnerable to human disturbance. Since the 1970s, wardens have supervised many tern colonies, which has substantially reduced human disturbance, but numbers are still declining (RSPB website, accessed April 2015; Ratcliffe et al., 2008).

Disturbance by humans and dogs has the potential to disrupt courtship, incubation or brooding by tern parent birds. Disturbed birds may increase energy expenditure while lowering feeding rates and energy uptake. Disturbances during incubation, for example, can prolong the incubation period, incurring energetic costs to adults, and affecting the health of chicks (Nisbet and Cohen, 1975; Thomas and Slack, 1982; Gochfeld, 1983; Kotliar and Burger, 1986).

If disturbance events occur in sufficient severity or frequency to cause poor long term reproduction, terns may abandon a colony site completely (Nisbet and Welton, 1984). However, terns have been shown to habituate readily to regular, predictable human activity (such as by wardens) and can become tolerant (Nisbet, 2000).

The temporal timing of disturbances plays an important role in terms of breeding success. In general, reproductive success in terns declines as the breeding season progresses. Therefore, disturbance events which disrupt or delay breeding seasons can have reproductive consequences (Arnold et al., 2004). However, as reproductive investment increases as the breeding season progresses, it takes larger and more frequent disturbances to cause colony abandonment (Whittam and Leonard, 2000).

Nocturnal disturbances are especially harmful because terns do not mount defences at night (Shealer and Kress, 1991). Even low intensity nocturnal disturbances may lead to temporary colony abandonment (Nocera and Kress, 1996).

Humans can also cause physical disturbance through trampling. For example, trampling disturbance was predicted to destroy 74% of clutches over a 23-day incubation period in the absence of other sources of loss at a Little Tern colony in East Anglia (Ratcliffe et al., 2008).

ARUN DISTRICT COUNCIL P/93/15/PL

8.2.10.2Project impact assessment

This pathway considers the effects of the operational phase of works on bird populations as a result of the construction activities on site. It separately addresses the issues that arise from changes in the accessibility of nesting grounds on the shingle spit and in the harbour.

Accessibility of the Shingle Spit

Current access on foot to Church Norton Spit is restricted to walking along the foreshore from the nearest car park at the village of Church Norton (located approximately 1km away) or from Selsey (several kilometres away). The creation of the breach will prevent access on foot from this side of the foreshore but will make access possible from Pagham Spit via the infilled channel location. The proposed project is also likely to increase accessibility onto the separated end of the spit once it connects with Pagham Beach in the short term.

The car park at Pagham Spit is currently closed (See recreational Section 9.1). However, despite this, the separated end of the spit is more likely to be subject to access after the work is completed. This is because the nesting areas become more accessible to the more closely situated populations of Pagham and Bognor Regis. Also more tourist related (seasonal) visitors would be expected. Without intervention, recreational activities such as dog walking, tourism and general beach visitors could therefore increase along the old spit during the summer nesting period.

It is important to note that Church Norton Spit is already used by a relatively large number of visitors for recreational purposes (e.g. dog walking). Therefore, birds using the spit are already regularly exposed to potential disturbance stimuli from a range of activities. Furthermore, in order to reduce the effects of existing disturbance, Church Norton Spit is currently actively managed during the tern breeding season. This includes the use of, fencing, educational signs and wardens.

Based on these considerations, the probability of increased disturbance occurring is considered to be medium. With regards to magnitude, the area is already a popular site for dog walking and other recreation and is therefore already considered to have a relatively high level of disturbance pressure. The site is also evidently accessed by predators. In addition, the area is already actively managed to reduce disturbance and predation, particularly in the nesting bird breeding season. However, the project could open up the main area of little tern nesting (see Figure 8.11) to greater levels of possible activity and predation and, therefore, the scale is considered to be medium in the short term. Over the longer-term it could well reduce towards negligible as the less accessible Church Norton spit regrows and creates new habitat areas in the medium to longer-term.

While existing measures will therefore help to manage any increase in disturbance pressure the exposure to change is medium/low (worst case in the short term especially). Sensitivity to recreational disturbance is assessed as high (based on Little Terns which are considered to be particularly sensitive to disturbance) and the vulnerability is consequently assessed as

ARUN DISTRICT COUNCIL P/93/25/PL

moderate or high. The importance is scored as high due to the protection afforded to waterbirds in Pagham Harbour leading to a moderate adverse significant[43] impact.

In order to reduce the significance of this impact, several mitigation measures are proposed during the breeding season to protect Little Tern and wading bird nests which are discussed in greater detail in Section 11.2. These include the use of new fencing on the landward side of the infilled channel and also once the distal end of the spit connects with Pagham Beach to prevent access. In addition, longer-term management measures will be implemented by the community, such as wardening of the site to reduce access during the breeding season. Following the application of these mitigation measures, the probability of increased disturbance occurring is considered to be low. The magnitude of any potential disturbance will continue to be small and consequently exposure to change will be negligible. Taking account of the high sensitivity to recreational disturbance and high importance of waterbirds in Pagham Harbour, the residual impact is considered to be insignificant.

Accessibility in the Harbour

There is a general right of navigation into the harbour on tidal waters and there is currently some navigational access to Pagham Harbour via the tidal channel. However, strong currents and shallow water can make access difficult for some watercraft. The water is also very shallow in many places in Pagham Harbour and as a result some areas of the harbour, such as Sidlesham Quay (the only public launching and landing facility within Pagham Harbour), are inaccessible except at the highest tides and then only by shallow draft vessels. The local boats visiting Sidlesham Quay include canoes, dinghy sailors, rigid inflatable boats, sailing catamarans up to 6 m and small sea angling vessels (Royal Haskoning, 2013).

The breach will improve navigational access to Pagham Harbour for recreational craft including sailing boats, kayaks and paddleboards (jet skiing is prohibited under Local Nature Reserve bylaws). This is likely to cause an increase in the number of boating and watersports participants using the harbour. However, most sailing and watersports activities are undertaken in the warmer summer months which avoids the peak overwintering period for waders and waterfowl in the harbour. In addition, the RSPB 'Code of Conduct for Boating' in Pagham Harbour provides guidance which will help minimise the impact from recreational boating disturbance.

Sailing activity will also be restricted to within navigational channels. In general, the regular presence of vessels in boat channels causes fewer disturbances than vessels approaching birds at faster speeds and which approach closely to bird aggregations (Chatwin et al., 2013; Rodgers and Schwikert, 2002; Bellefleur et al., 2009; Burger, 1998). Furthermore, existing management and Local Nature Reserve byelaws forbid access to Tern Island during the nesting season.

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43 Based on the definition that these are effects that are "of a local to regional nature, of medium to long term duration and/or where effects are anticipated to potentially be above accepted guidelines/standards" (see Section 5.6).

ARUN DISTRICT COUNCIL P/93/25/PL

Based on these considerations, the probability of some increased recreational boating and watersports in the harbour is considered to be high. However, existing management measures and byelaws will reduce potential disturbance pressure to breeding, roosting and feeding birds. In addition, most recreational activity is seasonal and will avoid the overwintering bird season. On this basis magnitude is therefore assessed as small and consequently exposure to change is low.

Sensitivity to recreational disturbance is assessed as low to moderate (with variations depending upon the species, the levels of habituation and the regularity of noise events and visible movements of boats and people). Vulnerability is consequently assessed as low. The importance is scored as high in particular because of the protection afforded to birds (particularly SPA interest features) under the Habitats Regulations. Therefore, the disturbance impact has been assessed as minor adverse significant.

8.2.11 Impact Pathway 19: Effects from Potential Closure of Breach During Operational Phase

8.2.11.1 General scientific context

A review of the potential effects of a tidal inlet closure at Pagham Harbour on nature conservation interests is included under the future baseline scenario in Section 8.1.9.1 and is therefore not repeated here. Similarly the issues associated with the stability of the breach were discussed in Section 6.3.3 and are not repeated.

8.2.11.2 Project impact assessment

This pathway considers the effects arising from a future closure of the breach and changes that will occur in terms of the likelihood of such a closure when compared with the existing condition. The Site Improvement Plan (SIP) for the Pagham Harbour SPA has noted concerns about the potential closure of the tidal inlet under the current baseline condition (Natural England, 2014) and the changes to habitats and birds as a result of a breach closure have already been reviewed as part of the future baseline (Section 8.1.9). It is noted that Natural England is concerned about how the proposed project may alter this potential risk (see comment within scoping response provided in Appendix B).

Overall, there is considered to be a low likelihood of the tidal inlet closing under either the baseline or proposed project scenario based on historical evidence and recent changes that have occurred at Pagham. This evidence indicates that, despite the multiple coastal configurations that have been experienced at this site in the past according to historic records and the substantial influx of shingle drift across the mouth in recent years, a natural closure has never occurred.

The proposed breach has been carefully designed to be as self-maintaining as possible in order to minimise the risk of it closing and also the need for ongoing maintenance (e.g. maintaining the breach position). Overall, the risk of the tidal inlet closing under the proposed project scenario is considered to be lower than the existing baseline scenario given that the breach has been carefully designed to be as stable as possible and improve drainage and tidal

ARUN DISTRICT COUNCIL P/93/15/PL

flushing of the harbour. In the unlikely event that the breach should close, it is more likely to reopen naturally under the scheme scenario compared to the baseline scenario.

Despite this, as a contingency, one subsequent breach intervention has been included as part of the proposed project (Section 3.2.7). The magnitude of change associated with tidal inlet closure would be potentially large but given the probability of occurrence is negligible, the resulting exposure to change will be negligible. Therefore despite the high sensitivity of a number of protected habitats and species within the harbour to the effects of a breach closure, and their high importance in terms of nature conservation status, the overall impact is considered to be insignificant.

8.3 Conclusions

Table 8.12 below summarises the impact assessment judgements, presents final conclusions on the overall impacts across all nature conservation and ecology impact pathways, and also provides an indication of the confidence in the respective assessments and evidence base. The impact assessment methodology (Section 5.2) provides an explanation of the iterative assessment process, including tables explaining how exposure, vulnerability and finally significance are assessed.

Table 8.12 Nature conservation and ecology impact assessment summary and conclusions

Assessment	Summary
Exposure to change	Exposure of nature conservation and ecology receptors to impacts from the proposed project are considered to range from negligible to medium based on a negligible to high probability of occurrence and a negligible to medium magnitude of change. The magnitude of change for shingle habitat and Little Tern impacts over the operational phase are variable over time as the spit evolves towards a new morphology.
Estimation of vulnerability	The sensitivity of features ranges from none to high, resulting in a vulnerability that ranges from none to moderate.
Estimation of significance	The significance of impacts of the proposed project on nature conservation and ecology is assessed as insignificant to moderate adverse significant.
Conclusion	The main significant effects relate to the effects of the project operational phase on nesting Little Terns. The effects that the project will have on nesting habitat for terns is considered change over time as the environment evolves but also the degree of certainty associated with this change also increases. The increased accessibility onto the spit during operation and thus potential disturbance to nesting birds is considered to be moderate adverse significant in the short term (Impact Pathway 18) and will require specific mitigation to manage access during the summer months (see Sections 8.2.10 and 11.2). Over the longer-term the evolution of the spit and the changes in shingle habitat for nesting terns are expected to be minor in the short term but could become a moderate adverse significant impact (Impact Pathway 16) on a precautionary basis in the longer term. However the level of certainty associated with this decreases over time and impacts could be lower. In order to account for the uncertainty associated with the longer-term future evolution of the site as a result of the proposed project (and whether and to what degree

ARUN DISTRICT COUNCIL P/93/25/PL

Assessment	Summary
	Little Terns might be affected), it is recommended that an isolated New Tern Island is created and managed for these SPA features within the harbour (see Section 11.2.2). All other impacts associated with the proposed project are insignificant to minor adverse significant and therefore not of a level that would necessitate mitigation, apart from ensuring that works are not carried out during the bird breeding season (Impact Pathway 10); that construction access routes are agreed in advance with Natural England and RSPB (Impact Pathway 12) and that appropriate on-site pollution control measures are adopted (Impact Pathway 7).
Confidence assessment	There is a wide range of existing data on the presence and condition of species and habitats within the study area. Scientific understanding on the sensitivity of receptors to the predicted impacts is also considered to be good. There is, however, uncertainty over the future evolution of the shoreline due to the complexity of the environment. Furthermore, there is a high level of variability associated with the number of Little Terns breeding (and subsequent productivity) annually. This uncertainty has been taken into account in the estimations of significance and the proposed adoption of compensation measures. Overall, confidence is therefore considered to be at worst medium.

ARUN DISTRICT COUNCIL P/93/25/PL

9. Marine Recreation

This section reviews the effects of the proposed works on marine recreation and amenity receptors. Baseline information is provided in Section 9.1 followed by an impact assessment in Section 9.2.

9.1 Baseline Review

9.1.1 Data Sources

A range of data sources have been used to characterise marine recreational activities that take place along the Pagham beach foreshore and its environs, including the following:

- Pagham Yacht Club website;
- Parish council website;
- TripAdvisor website.

In addition, a number of residents, interested parties and local businesses have been contacted to seek their views and provide baseline information.

9.1.2 Marine and Coastal Recreation

There are (or at least used to be prior to the recent configuration of Church Norton Spit) a large number of different activities taking place along the Pagham beach frontage. These include: running, walking and cycling, having a picnic, rock pooling at the groynes, shell collecting and a range of water-related activities, including scuba diving, dinghy sailing, windsurfing and kayaking.

During the summer, Pagham Beach is popular for sunbathing and relaxation on warm summer days. The most popular area of the beach is in close proximity to the Pagham Yacht Club (PYC), the café and amusement arcade, which form focal points along the seafront. During the winter, the number of people using the beach typically decreases substantially and the main activity is walking. The foreshore area is also regularly used for sea fishing.

Image 9.1 illustrates some of the coastal and marine recreational features at Pagham.

ARUN DISTRICT COUNCIL P/93/25/PL



Image 9.1 Coastal and marine recreation features at Pagham

9.1.2.1 Sailing

The PYC currently offers recreational sailing and watersports activities all year round, which requires access to the sea along the Pagham Beach frontage. Boats regularly sail from March to October on Sundays, and practice takes place on Wednesdays (some of which are races). Races, trophy races and cruises are also organised from time to time during the year along the coast (PYC website, April 2015). Mono and multi-hull boats are stored on land adjacent to PYC and winches are available to recover boats out of the sea.

There is some navigational access to Pagham Harbour via the tidal channel. The water is very shallow in many places in Pagham Harbour and as a result some areas of the harbour, such as Sidlesham Quay (the only public launching and landing facility within Pagham Harbour), are inaccessible except at the highest tides and then only by shallow draft vessels. The local boats visiting Sidlesham Quay include canoes, dinghy sailors, rigid inflatable boats, sailing catamarans up to 6m, small sea angling vessels and Environment Agency hovercrafts (Ports and Harbours of the UK, 2013).

Boat access to Pagham Harbour has been significantly affected by the recent changes to the harbour mouth as a result of the growth of Church Norton Spit. Furthermore, the number of boats stored by residents and launched along the beach has also dropped dramatically, especially to the southwest of PYC due to the beach erosion, loss of winches, excessive currents and rapidly forming shingle banks resulting in very shallow water at lower tides (therefore high risk of grounding) (Robin Henderson, long term resident and member of

ARUN DISTRICT COUNCIL P/93/15/PL

PFDSG, pers. comm., May 2015). The following specific adverse effects have been reported by the PYC (Peter Atkins, Commodore PYC, pers. comm., April 2015):

- Cancellation of annual sail through Pagham Harbour to Sidlesham Quay. This event has had to be cancelled for 2015 (to be reviewed annually until further notice), as the shallows prevent the safety boats from accompanying the fleet, and as the severe eddies and currents in the harbour entrance pose too high a risk to the club's smaller boats (with the cadets on board).
- Inability to host international sailing regattas due to lack of launch area for 30 or more boats. In 2014, PYC entertained a week-long regatta for (Shearwater) catamarans, and it hoped to hold similar events going forward. This is however no longer feasible as the beach is now too constricted to safely hold enough boats.
- Restriction of regular PYC sailing activities due to shallow water to west of PYC and new hazards being uncovered (including steel remains of two old breakwaters and potential WW1 scrap). What was once a safe sailing area is now problematic on some tides.
- Higher risks due to increase in currents reaching the PYC's beach area due to outflow from Pagham Harbour. The strong currents and eddies around the harbour entrance can cause smaller craft to get into difficulties. Extra safety considerations have had to be introduced, including the relocation of launch and recovery sites eastwards, away from obstacles and currents.
- One of the winches on site has been lost to sea, and another (the club's main winch) is threatened. Relocation is difficult as there is now a lot less beach top to use. Currently only one winch, from the original three, remains in use.
- Constant review and visual survey of new banks and channels is required. Safety officers now have to report/notify sailors of changes on a weekly basis (previously seasonal).
- Safety ribs and fishing boats now need to be launched using four to six men, due to the ramp and remaining beach being too steep. The slipway has been lost, and instead rubber matting is now used on the shingle, which makes launching and recovering more difficult. If the boat and trailer are not set up correctly, launching and recovery can apparently be very challenging for the less experienced members. Recovery of other boats is similarly handicapped, especially in strong winds.

9.1.2.2 Recreational fishing

Many beach front residents store their boats along the beach. It is thought that these are primarily used for recreational fishing, and the number of boats using the beach is thought to be low (Royal Haskoning, 2013). Some angling takes place from the beach, targeting bass and some cod, and the harbour mouth is the focus for those fishing for sea bass (Robin Henderson, long term resident and member of PFDSG, pers. comm., May 2015; Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., May 2015).

Recreational rod-angling at the beach appears to have reduced markedly due to the beach narrowing and becoming steeper, as well as the currents being closer to the beach (Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., May 2015). Anglers

ARUN DISTRICT COUNCIL P/93/15/PL

now prefer other locations such as Littlehampton. Recreational sea fishing is also negatively affected due to launching issues at the PYC's beach (see Section 9.1.2.1).

Less boats are now stored on the beach, due to fears that they could be swept out to sea during storms (Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., May 2015). For example, one dingy was washed away during the 2013/14 winter.

9.1.2.3 Other water activities

High flows near to the entrance of Pagham Harbour have also become dangerous for swimmers, kayakers and other water activities (except for short periods around slack water). Up to the PYC, and certainly up to near Groyne No. 1 (closest to PYC), residents have reported high currents, which are apparently worse between mid and low tides (especially on falling tides) (Brian James, long term resident, pers. comm., April 2015).

Long term residents have reported having to rescue holiday makers, who had become caught up in the currents whilst swimming near Groyne No. 4 (closest to the harbour entrance), on several occasions. There was a near fatality in 2014 when a couple were caught in the currents around the harbour entrance. This is despite the many notices which are now in place warning of the dangers. Some holiday makers have apparently stated that they would not be visiting Pagham again due to the dangerous currents, as well as the erosion, which has made the beach significantly narrower and steeper. Previously, this stretch of beach would have been widely used by residents and holiday makers during the summer months (Brian James, long term resident, pers. comm., April 2015; Robin Henderson, long term resident and member of PFDSG, pers. comm., April 2015; Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., May 2015).

Windsurfing activities have also dropped off significantly at the beach. It has been estimated that travelling windsurfers have all but disappeared (ca. 90% reduction) as a result of adverse conditions brought about by the current configuration of Church Norton Spit, although some residents still sail (Brian James, long term resident, pers. comm., April 2015). Windsurfers tend to now favour alternative locations such as Shoreham, Worthing and Bracklesham.

A popular dive site off the coast of Pagham, the Inner (or Near) Mullberry site, which lies 1 km off the beach, may also be visited less due to currents being stronger, and running closer to the site (Brian James, long term resident, pers. comm., April 2015). However, a Selsey dive centre which organises local dives (Mulberry Divers), reports that, whilst it has not stopped visiting the Inner Mulberry site (as it would generally time dives with slack water), divers had anecdotally noted that currents appear to be stronger at the site (Mulberry Divers), pers. comm., April 2015).

A kite surfing event (The Virgin Kitesurfing Armada, sponsored by Richard Branson), which first took place last year, and is scheduled again for September this year, might not be able to stop at Pagham on its way from Hayling Island to Landing. This attracted some 400+ kite surfers last year. The stopover at Pagham might have to be cancelled due to the safety risks related to dangerous currents and nearshore shingle banks (Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., April 2015).

ARUN DISTRICT COUNCIL P/93/15/PL

9.1.2.4 Search and rescue facilities

The nearest Royal National Lifeboat Institution (RNLI) station is the Selsey Lifeboat Station some 5 km west of Pagham. Changes to the beach and offshore waters at Pagham are now heavily restricting offshore rescues by the RNLI and placing a greater reliance on coastguard helicopters (Robin Henderson, long term resident and member of PFDSG, pers. comm., April 2015). The RNLI has been finding it very challenging to access Pagham Harbour by boat, due to the difficult conditions at the harbour entrance, namely the current orientation of the harbour mouth, the presence of shingle bars, the powerful currents, and also the hazard presented by the collapsed remains of Groyne No. 4. Whilst the crew could walk the inshore lifeboat (D-class) into the harbour in an emergency, this would compromise response times (Clive Cockayne, RNLI Lifeboat Operations Manager, pers. comm., July 2015).

The RNLI has also called into question the viability of the annual rescue demonstration which brings large spectator numbers to Pagham Beach. Helicopters and nearshore recovery may not be seriously compromised, but doubt has been voiced in respect of the hitherto shore proximity demonstrations and parallel runs of the large Tyne class lifeboats and inshore rescue ribs, due to fast currents and shingle banks (Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., April 2015).

9.1.3 Coastal Tourism

Coastal tourism is of substantial importance to the economy of the village of Pagham, which has approximately 6,000 inhabitants (Pagham Parish Council, 2014). The wider area including the harbour, the beach and Pagham Lagoon all have an amenity value as accessible open spaces and these, along with watersports, contribute to the value of the village as a holiday destination.

9.1.3.1 Accommodation

With regard to accommodation, there is one caravan site in the village, behind Pagham Lagoon. This is called the 'Church Farm Holiday Village', and is operated by Haven/Bourne Leisure. It contains 898 caravans and on average, has some 2,500 people staying at the park at any one time over an eight month season (March to October). In total 150 units are owned by Bourne Leisure, and some further 150 of the privately owned units are let through Bourne Leisure. The 300 caravans let through Bourne Leisure tend to have an occupancy rate of some 65% on average. Over the 8 month opening period, some 20,000 families stay in these 300 caravans (for varying lengths of stays; this is equivalent to some 12,000 families staying for one week at a time every year). These figures exclude visitors to those caravans which are owned and not let out through Bourne Leisure (Andy Pope, General Manager, pers. comm., April and July 2015).

Caravan owners and other visitors to the site use the marine and coastal environment around the Holiday Village as follows: visit the beach, walk, run, cycle, enjoy the local wildlife/watch birds, kayak and kite surf. Cycles are available for hire at the Holiday Village, but no other equipment (such as kayaks) is rented out (Andy Pope, General Manager, pers. comm., April

ARUN DISTRICT COUNCIL P/93/15/PL

and July 2015). The park contributes a reported £2.4 million per annum toward the local economy (Pagham Parish Council, 2014).

At least 15 private holiday lets are available in Pagham, many of which are located at the Holiday Village. Furthermore, there are three bed and breakfasts and hotels offering accommodation; one hotel closed down in 2014 (King's Beach, closest to the beach) (TripAdvisor Website, April 2015).

Visitor numbers to the Church Farm Holiday Village caravan park do not appear to have been significantly affected by the changes at the beach, although visitors have noted that the beach is now less attractive and less safe (Andy Pope, General Manager, pers. comm., April 2015).

There is however significant concern by the Owners Association of Church Farm (private owners who have bought their caravans), who expressed "overwhelming interest and concern" about the beach changes at their 2014 and 2015 Annual General Meetings (Robin Henderson, long term resident and member of PFDSG, pers. comm., April 2015). The caravan owners are concerned because the beach is viewed as a very important off-site amenity; it is much used and apparently a key part of deciding whether to buy a caravan or to just holiday at the village.

Since the beach erosion has worsened, many Church Farm visitors have avoided walking alongside the worst-affected, reveted section of beach, thus essentially making a previously pleasant circular walk impossible. Church Farm still promote the beach amenity as part of their selling dialogue (Andrew Day, Church Farm caravan owner and member of the Owners Association, pers. comm., May 2015). Amongst Pagham residents, it is felt that significantly less Church Farm visitors venture to the beach, and that the reveted section of the beach is perceived as an unsafe route, particularly when the water levels are high (Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., May 2015).

9.1.3.2 Visitor facilities

There are a range of facilities available for both day and staying visitors. Within Pagham, visitor facilities include two cafés, four take away shops, a shop selling beach equipment, and an amusement arcade.

The nearby café, club, beach amusements and arcade all predict a poor summer season for their trades. The café reports an approximately 25% drop in business compared to last year, due to the beach now being "in such a state, it's an eyesore" (Maria Griggs, Pagham Beach Café, pers. comm., July 2015). The amenity seats (Parish Council owned) on the beach adjacent to PYC have been lost due to coastal erosion. For over 2 years, seven benches were located on a large concrete slab on the beach which used to be accessed via a wheelchair accessible tarmac path from Beach Road. These were "very popular with both residents and visitors" (Ray Radmall, Pagham Parish councillor and member of PFDSG, pers. comm., May 2015). However, the seats have been removed and the site fenced-off and considered dangerous due to the undermining and subsequent partial collapse of the concrete slab; (pers. comm.

ARUN DISTRICT COUNCIL P/93/15/PL

A watersports shop near the beach (in the Pagham Parade shopping area) rents out kayaks and stand up surf boards. The shop also offers tuition in windsurfing, kayaking and stand up surfing (Lee Ralfe, proprietor LAR Watersports, pers. comm., May 2015). The water sports shop in Pagham has suffered an approximately 50% drop in business due to both the changes to the spit, and the closure of the car park at Pagham Spit. Business relating to windsurfing has been particularly badly affected, due to the westerly beach frontage and spit being the favoured locations for this activity, and due to those locations now being firstly significantly more dangerous (due to rip currents) and secondly less easily accessible due to the car park closure. It was felt that, were the beach erosion to be reversed, and the inlet re-located, significant numbers of windsurfers would return even if the Pagham Spit car park remained closed (Lee Ralfe, proprietor LAR Watersports, pers. comm., May 2015).

9.1.3.3 Parking facilities

Some public parking is available within the village, though this is considered somewhat limited (Pagham Parish Council, 2013). Public parking was formerly also available just outside the village to the west (next to Pagham Harbour, on Pagham Spit), however that parking area is now closed due to maintenance and upgrade issues (Pagham Parish Council, 2013). Prior to the closure of the latter car park, it would have taken an estimated 80,000 vehicle movements/year (Pagham Parish Council Website, 2012).

9.1.4 Summary

In summary, the recreational and amenity value of the Pagham Beach frontage has been diminished greatly over the past decade. Not all the blame for this deterioration can be attributed to the spit development and consequent channel migration, as aspects such as the unusually stormy winter of 2013/14 and the closure of the car park on Pagham Spit have also played a role. However, a large percentage of the deterioration can be assumed to be due to the spit development and channel migration (and associated rip currents close to the beach).

The most popular marine recreational activities along the Pagham Beach frontage, walking, sailing, swimming, angling and windsurfing, appear to have all been significantly affected. It is not clear whether sailing activities have actually diminished, but the sailing club members have certainly been inconvenienced, face increased health and safety risks, and their event calendar is much reduced because of the changes. Walkers appear to be less frequent along the frontage, due to the reveted section now being very narrow and perceived as dangerous by many during high tides. Windsurfer numbers also appear to have dropped drastically, though the closure of the Pagham Spit car park is likely to have had a contributing effect in this respect. Further to the increased risks to human health and safety as a result of the high peak-flow currents experienced around the harbour entrance channel, the RNLI is no longer able to access Pagham Harbour by boat.

It is unclear how visitor numbers to Pagham have been affected by the changes. Anecdotal evidence suggests that these have reduced considerably in recent years, though a definitive cause and effect relationship is difficult to establish due to the lack of official statistics.

ARUN DISTRICT COUNCIL P/93/15/PL

9.2 Impact Assessment

9.2.1 Impact Pathway 20: Effects of Changing Spit Morphology on Marine Recreational Activities

The proposed project would result in the new harbour tidal inlet being a significant distance from Pagham Beach (1 km west of its 2015 position). The proposed project would result in significantly reduced flows around the Pagham Beach frontage. These currents, which can peak at very high values at present, and run very close to the beach, have made the beach frontage near the inlet unsafe for recreational users, including, most notably, swimmers, kayakers, windsurfers and sailors. A dramatically reduced health and safety risk will therefore be an immediate effect of the proposed project. As outlined in Section 6.3, it is anticipated that it would take 10-15 years following the breach or possibly longer, before a reformed spit could again cause similar issues along the Pagham Beach frontage. It is also anticipated that the RNLI would once again be able to access Pagham Harbour with its inshore lifeboat without having to 'walk it in' (pers. comm. Clive Cockayne (RNLI Lifeboat Operations Manager), July 2015). Together with the significantly reduced travel distance along the shore and back into the current inlet channel, this should dramatically improve response times to incidents in Pagham Harbour.

Once the breach has been made, and the current inlet channel infilled, a sheltered tidal channel or 'fleet' would develop behind the spit, between the new breach location and Pagham Beach. Within around a year or two of the proposed breach, and mainly during winter months, wave activity along the front of the separated spit will actively push this spit landwards towards the beach, whilst also driving littoral drift across the front of it. The distal end of the spit is likely to be the first to reconnect to Pagham Beach and once this has taken place, a lagoon will form behind the relict spit which will slowly recede through over-washing and the shorewards migration of the old spit. Depending on the drift rate, the old spit may take some 10 to 20 years to completely reintegrate back into the beach and/or into longshore processes. Both the temporary sheltered fleet and lagoon could be of significant recreational value.

Erosive pressures on the beach will ease following the breaching; firstly because the tidal scouring effect along the existing channel and beach will be immediately removed, and secondly because supply of shingle to the beach is expected to be increased. This is anticipated to, in time, lead to a gentler and wider beach profile to become re-established at Pagham, and along its whole beach frontage. This would not only make the beach more attractive to visitors again, but would also enable important amenity infrastructure to be re-instated, including winches and launch areas at PYC and the visitor seating adjacent to it.

The magnitude of improvements to the marine recreational and amenity value anticipated along the Pagham Beach frontage is considered to be medium for the community of Pagham, and the probability of occurrence medium to high. Consequently, the exposure to change is considered to be medium. Taking account of the anticipated response of the community to the predicted changes, the sensitivity of the amenity and recreational resource to change is considered to be high. The vulnerability of the receptor is hence assessed as moderate. The importance of the receptor is assessed as moderate in terms of its value to the local community and for visitors.

ARUN DISTRICT COUNCIL P/93/15/PL

Overall, therefore, the impact is considered to be moderate/minor beneficial significant for the marine recreation and amenity resource of Pagham.

9.3 Conclusions

Table 9.1 below summarises the impact assessment judgement, presents final conclusions on the marine recreation impact pathway, and also provides an indication of the confidence in the respective assessment and evidence base. The impact assessment methodology (Section 5.2) provides an explanation of the iterative assessment process, including tables explaining how exposure, vulnerability and finally significance are assessed.

Table 9.1 Nature conservation and ecology impact assessment summary and conclusions

Assessment	Summary
Exposure to change	Exposure of marine recreational activities and amenities to impacts from the proposed project are considered to range from medium to high based on a medium to high probability of occurrence and a large magnitude of change.
Estimation of vulnerability	The sensitivity of the amenity and recreational resource is considered to be high, resulting in a vulnerability that is high.
Estimation of significance	The significance of impacts of the proposed project on marine recreation is assessed as moderate beneficial significant.
Conclusion	In the context of the value of marine recreation and amenities to the local community and visitors, as well as the immediate reduced health and safety risk, the effects of changing the spit morphology on marine recreational activities is considered to be moderate beneficial significant.
Confidence assessment	A range of public sources have been taken into account to characterise the baseline environment of this topic. The views from a number of relevant stakeholders have also been considered and therefore the impact assessment is in part based on human perception. Overall, the level of confidence is therefore considered to be medium.

ARUN DISTRICT COUNCIL P/93/25/PL

10. Cumulative and In-Combination Effects

10.1 Baseline Review

The proposed project will take place alongside other plans, projects and activities. These have the potential to result in additional or modified impacts on the same receptors as those identified for the proposed project alone, resulting in a cumulative and/or in-combination impact.

A number of plans, projects and activities have been identified which are potentially relevant in terms of cumulative and in-combination effects. These are listed in Table 10.1 below and an initial scoping exercise has been undertaken to identify those which have potential connectivity with the proposed project and have been considered further in the cumulative and in-combination assessment.

Table 10.1 Summary of plans, projects and activities in the wider study area

Plans, Projects or Activities	Description	Scoping View
Construction of rock revetment, ADC (2013)	A rock armour revetment was constructed along the most significantly eroding part of Pagham Beach between November and December 2013 to protect the residential properties from coastal erosion and subsequent flooding (Section 6.2.6).	These works have already taken place and the changes to coastal processes brought about by the existing rock revetment have already been considered as part of the baseline and are therefore not considered to be within the scope of the cumulative and in-combination assessment.
Urgent remedial works to rock revetment, ADC (2014)	The rock revetment and adjacent groyne were undermined through scour over the 2013/14 winter. Urgent remedial works were undertaken in early January 2014 to stabilise the revetment as a short term repair.	These works have already taken place and the changes to coastal processes brought about by the existing rock revetment have already been considered as part of the baseline and are therefore not considered to be within the scope of the cumulative and in-combination assessment.
Beach recycling at Pagham Beach (2014)	Beach recycling between the end of the Church Norton Spit and Groyne No. 4 was undertaken to increase the width of the beach following the failure of the groyne and thus coastal defence to properties.	These works have already taken place and this material has since been removed through continued beach erosion in this area. There is therefore no potential interaction with the proposed project and this is not considered to be within the scope of the cumulative and in-combination assessment.
Further rock revetment work and beach recycling, ADC (2014-15)	Additional rock was imported to bolster the ends of the revetment and adjacent groyne in November 2014 (completed in February 2015). Beach recycling also took place from the intertidal eastern distal end of Church Norton Spit. In addition to maintaining the existing level of protection, these works have also provided additional protection to the beach between Groyne No.4 and Groyne No.3.	These works have already taken place and the changes to coastal processes brought about by the existing rock revetment have already been considered as part of the baseline and are therefore not considered to be within the scope of the cumulative and in-combination assessment.

ARUN DISTRICT COUNCIL P/93/15/PL

Plans, Projects or Activities	Description	Scoping View
Future rock revetment maintenance or extension work, unknown timescale	The existing rock revetment is considered to be reasonably stable now but may require some further maintenance or enhancement work should it be undermined again in the future. The timescales of any such work are uncertain.	Should any future maintenance or extension of the rock revetment works be required, there is the potential for cumulative impacts should these works overlap with the construction of the proposed project. This is considered to be highly unlikely given that the proposed project will reduce tidal flows and coastal erosion at this location and thus reduce the need for maintaining or extending the rock revetment. Future rock revetment work is therefore not considered to be within the scope of the cumulative and in-combination assessment.
Improving existing defences in Pagham Harbour, Environment Agency, part funded by Caravan Club and Pagham Parish Council (2014-15)	Works to the existing embankment in the eastern part of Pagham Harbour, along the western edge of Pagham near the lagoon commenced in September 2014 and are ongoing (due to be completed October 2015). These coastal defence works will provide 1:20 level of protection for 83 properties.	The construction programme for these defence works within Pagham Harbour does not overlap with the construction of the proposed project. However, the operational effects of the proposed project will change high water levels within Pagham Harbour and thus potentially affect the coastal flood risk potential to properties that have been protected by the Environment Agency coastal defence works. Potential cumulative and in-combination effects during operation have been scoped into the assessment.
Further defence improvement works in Pagham Harbour	Further defence works are proposed on the north west side of the harbour between the Ferry Pumping Station and Sidlesham. These proposals are at the appraisal stage and have not been commissioned yet.	The construction programme for these further defence works within Pagham Harbour are unknown and could potentially overlap with the construction of the proposed project. There could also be cumulative and in-combination effects during operation as the proposed project will temporarily change high water levels within Pagham Harbour. Potential cumulative and in-combination effects during construction and operation have been scoped into the assessment.
Management of Pagham Harbour Reserve by RSPB	A number of management activities are undertaken by RSPB in Pagham Harbour. Tern nesting areas are actively managed during the breeding season to minimise disturbance. This includes the use of fencing, educational signs and wardens. RSPB also manage disturbance caused by boating by posting the boating code of conduct at Sidlesham Quay where people are able to launch into the harbour.	These ongoing management initiatives will interact with the proposed project during both construction and operation. However, given that these management measures are aimed at improving the environmental condition and minimising human pressures on the reserve, the effects of the proposed project will be no worse with these ongoing activities taking place. The management of the harbour is therefore not considered to be within the scope of the cumulative and in-combination assessment.

ARUN DISTRICT COUNCIL P/93/15/PL

10.2 Cumulative/In-combination Assessment

Table 10.2 below identifies any potential overlap of the plans, projects and/or activities that have been scoped into the cumulative and in-combination assessment (namely the current defence works in the eastern part of the harbour and future defence works at the Ferry Pumping Station and Sidlesham) with the receptors that have been scoped into the EIA. Consideration is given to the relevant pathways and an assessment undertaken of potential effects for each receptor.

Table 10.2 Summary of predicted cumulative and in-combination effects

Topic	Receptors	Summary of Predicted Cumulative and In-combination Effects
Physical/Hydrodynamic Environment and Coastal Protection	▪ Tidal heights ▪ Volumes of tidal exchange ▪ Tidal characteristics ▪ Waves ▪ Sediment transport ▪ Coastal erosion and flood protection	Inside Pagham Harbour, high water levels will be reduced for a brief period after the implementation of the proposed project by approximately 0.05 to 0.06 m (5 to 6 cm) over a mean spring tide (see Image 6.25) but by less than 0.02 m (2 cm) over neap tides (Section 6.3.2). Any changes in high water levels (and consequent effects on flood protection) are expected to be temporary and last for only a few weeks/months. In terms of overall coastal erosion and flood risk, both the proposed project and the coastal defence works inside the harbour will provide a combined additive effect on coastal protection to properties in Pagham. Taking these considerations into account, the cumulative and/or in-combination impact on coastal erosion and flood protection will be beneficially significant.
Water and Sediment Quality	▪ Temperature ▪ Salinity ▪ Dissolved oxygen ▪ Nutrients ▪ Suspended solids ▪ Contaminants ▪ Radioactivity ▪ Microbiology ▪ WFD waterbodies	The construction of the proposed project may occur at the same time as the construction of future defence works inside the harbour. However, given that changes in water and sediment quality from the proposed project are largely limited to the immediate spatial extent of the scheme (Section 7.2), there will not be any overlap with the changes brought about by proposed defence works at the Ferry Pumping Station and Sidlesham which are over 2km distance. There will therefore be no cumulative and/or in-combination impacts on water and sediment quality during construction. No longer-term changes in water and sediment quality are anticipated as a result of the proposed project and therefore there will be no cumulative and/or in-combination impacts with the coastal defence works inside the harbour during operation.
Nature Conservation and Ecology	▪ Saline lagoons ▪ Saltmarsh ▪ Mudflat ▪ Seagrass beds ▪ Spits and beaches ▪ Vegetated shingle	The construction timing of the proposed project may overlap with the construction of the future defence improvement works at the Ferry Pumping Station and Sidlesham. This could result in combined disturbance impacts on overwintering birds. Given the distance between the two projects (>2km), the disturbance

ARUN DISTRICT COUNCIL P/93/25/PL

Topic	Receptors	Summary of Predicted Cumulative and In-combination Effects
	▪ Coastal subtidal environment ▪ DeFolin's lagoon snail ▪ Other benthic invertebrates ▪ Ornithology ▪ Other protected species (water voles) ▪ Coastal geomorphology ▪ Geology	zone will not overlap but will temporarily and marginally reduce the area available within the harbour for foraging and roosting birds. Should the construction programmes overlap, therefore, the cumulative and in-combination disturbance impact to birds during construction could potentially be minor adverse significant. The existing and future coastal defence improvement works inside the harbour involve raising the levels of the existing embankment which will not result in any longer–term effects on nature conservation and ecology receptors. There will therefore be no cumulative and/or in-combination impacts with the proposed project during operation.
Marine Recreation	▪ Watersports ▪ Angling	The marine recreational and amenity value of the Pagham Beach frontage will improve as a result of the proposed project. The use of the harbour for marine recreation may also potentially increase via the newly created breach. The coastal defence works inside the harbour, however, will have no impact on marine recreation and therefore there will be no cumulative and/or in-combination impacts on marine recreation.

ARUN DISTRICT COUNCIL P/93/25/PL

11. Assessment Summary (Impacts, Mitigation and Monitoring)

This section summarises the predicted impacts of the proposed project and the necessity for mitigation and monitoring. A summary of impacts is provided in Section 11.1, followed by a review of all the proposed mitigation and monitoring measures in Sections 11.2 and 11.3 respectively, and conclusions in Section 11.4.

11.1 Summary of Impacts

Table 11.1 summarises the predicted impacts associated with the proposed project. The table shows the significance of each potential impact, proposed mitigation measures and the significance of the residual impact (i.e. the impact remaining following the implementation of mitigation measures). Some of these mitigation measures are recommendations of the impact assessment process, whilst others are 'embedded mitigation' measures that were incorporated into the design of the proposed works.

ARUN DISTRICT COUNCIL P/93/25/PL

Table 11.1 Summary of impact pathway assessment, project mitigation measures where required and the residual impact

Topic (Section)	Project Phase	Impact Pathway (Section)	Impact Significance	Mitigation (Section)	Residual Impact Following Mitigation
Physical/ Hydrodynamic Environment and Coastal Protection (6)	Operation	1. Effects of Changing Spit Morphology on Coastal Processes (6.2.1)	These five pathways were reviewed in order to inform the assessments of impact significance across the other 15 pathways in Chapters 7, 8 and 9. They do not of themselves warrant separate judgments about impact significance or mitigation.		
		2. Effects of Changing Spit Morphology on Hydrodynamic Regime in Pagham Harbour (6.2.2)			
		3. Effects of, and Need for, Breach Maintenance (6.2.3)			
		4. Effects on Tidal, Wave and Sedimentary Dynamics in Pagham Harbour (6.2.4)			
		5. Effects on Coastal Protection in Pagham Harbour and Along Pagham Beach (6.2.5)			
Water and Sediment Quality (7)	Construction	6. Effects on Suspended Sediment and Water Quality During Construction (7.2.1)	Insignificant.	None required.	-
		7. Effects on Water Quality of Spillages (e.g. Fuel) During Construction (7.2.2)	Insignificant.	None required taking account of pollution prevention guidance and best practice measures that will be adhered to (11.2.1).	-
	Operation	8. Effects on Status of Water Bodies During Operational Phase (7.2.3)	Insignificant.	None required.	-
Nature Conservation and Ecology (8)	Construction	9. Effects of Loss/Change of Shingle Habitat During Construction (8.2.1)	Insignificant (SPA/Ramsar supporting shingle habitat and SSSI geological interest)	None required.	-
			Minor adverse significant (SSSI geomorphological spit feature).	None required.	-
		10. Effects of Loss/Change of Little Tern Breeding Habitat During Construction (8.2.2)	Insignificant.	None required.	-

ARUN DISTRICT COUNCIL P/93/25/PL

Topic (Section)	Project Phase	Impact Pathway (Section)	Impact Significance	Mitigation (Section)	Residual Impact Following Mitigation
		11. Effects of Loss/Change of Habitat for DeFolin's Lagoon Snail During Construction (8.2.3)	Insignificant.	None required.	-
		12. Effects of Loss/Change of Shingle Habitat Outside Development Footprint During Construction (8.2.4)	Minor adverse significant (SPA/Ramsar supporting shingle habitat).	None required given that access routes will be agreed in advance with Natural England and RSPB to minimise the footprint of impact and any potential damage to vegetated shingle (11.2.1).	-
			Insignificant (SSSI geomorphological spit feature and SSSI geological interest).	None required.	
		13. Effects on Ecology in Pagham Harbour During Construction Phase (8.2.5)	Changes in water levels: Minor adverse significant (intertidal mudflat and foraging birds).	None required.	-
			Changes in suspended sediments. Insignificant (intertidal mudflat).	None required.	-
		14. Effects from Any Increased Disturbance on Overwintering Birds Due to Construction Work (8.2.6)	Minor adverse significant.	None required.	-
	Operation	15. Effects of Loss/Change of Shingle Habitat During Operational Phase (8.2.7)	Minor adverse significant (SPA/Ramsar supporting shingle habitat and SSSI geomorphological spit feature).	None required.	-
			Insignificant (SSSI geological interest)	None required.	-

ARUN DISTRICT COUNCIL P/93/25/PL

Topic (Section)	Project Phase	Impact Pathway (Section)	Impact Significance	Mitigation (Section)	Residual Impact Following Mitigation
		16. Effects of Loss/Change of Little Tern Breeding Habitat During Operational Phase (8.2.8)	Minor adverse significant in the short term but potentially up to Moderate (with increasing uncertainty of effect) in medium to long-term.	Given the uncertainty in future predictions, a new isolated island habitat will be created within the harbour as compensation (11.2.2).	Minor adverse significant or insignificant
		17. Effects on Ecology in Pagham Harbour During Operational Phase (8.2.9)	Changes in water levels: Insignificant (saltmarsh, foraging/roosting birds, DeFolin's lagoon snail, water voles and saline lagoons).	None required.	-
			Changes in flow speeds and sedimentation regime: Insignificant.	None required.	-
			Creation of a temporary saline lagoon feature: Minor beneficial significant (DeFolin's lagoon snail and foraging birds).	None required.	-
		18. Effects from any Increased Bird Disturbance During the Operational Phase (8.2.10)	Accessibility of the shingle spit: Moderate adverse significant.	Fencing will be erected to minimise potential disturbance impacts on nesting terns (11.2.1). Active involvement of community in ongoing management measures (e.g. wardening) (11.2.3).	Insignificant
			Accessibility in the harbour: Minor adverse significant.	None required.	-

ARUN DISTRICT COUNCIL P/93/25/PL

Topic (Section)	Project Phase	Impact Pathway (Section)	Impact Significance	Mitigation (Section)	Residual Impact Following Mitigation
		19. Effects from Potential Closure of Breach (During Operational phase) (8.2.11)	Insignificant Risks of closure after proposed project are very low and considered to be lower than for a future baseline scenario.	None required, although as a contingency, one subsequent breach intervention has been included as part of the proposed project (11.2.1).	-
Marine Recreation (9)	Operation	20. Effects of Changing Spit Morphology on Marine Recreational Activities (9.2.1)	Moderate beneficial significant.	None required.	-
Insignificant impacts shaded in blue.					
Minor adverse significant impacts shaded in yellow.					
Moderate adverse significant impacts shaded in orange.					
Minor beneficial impacts shaded in light green.					
Moderate beneficial impacts shaded in dark green.					

ARUN DISTRICT COUNCIL P/93/25/PL

11.2 Mitigation

A tiered approach to mitigation is proposed as follows:

a) Project mitigation measures to minimise or avoid any potentially significant adverse effects during construction and operation;
b) Compensation for the uncertainty in coastal processes predictions through the creation of a new island for Little Terns; and
c) Long term management measures of Little Terns through community involvement.

Adaptive management of this tiered approach to mitigation, with appropriate feedback mechanisms in response to observed changes brought about by the proposed project over time, is considered appropriate.

11.2.1 Project Mitigation Measures

A number of mitigation measures will be implemented in order to minimise or avoid any potentially significant adverse effects during construction and operation. These are described in the following sections.

11.2.1.1 Vegetated shingle

Access routes from the site compound at Pagham Car Park to the breach and infill channel locations will be agreed in advance with Natural England and RSPB to minimise the disturbance footprint and cause the least damage to vulnerable features, namely vegetated shingle. The agreed un-matted route will be marked with tape and poles providing clear definition and a fixed route. Where required the local community would be able to assist in any re-vegetation initiatives.

11.2.1.2 Nesting birds

The timing of the construction works will be agreed with Natural England and the RSPB to avoid the breeding bird season. Fencing will be erected on the landward side of the infilled channel and also at the landward location of the distal end of the spit once it connects with Pagham Beach to minimise potential disturbance impacts during operation upon nesting terns.

11.2.1.3 Pollution prevention and control

In order to reduce the risk of accidental spillages and/or leaks from construction plant, a range of guidance and best practice measures will be followed as outlined in Section 7.2.2.

11.2.1.4 Closure of breach

The breach has been designed in such a way as to be self-maintaining in order to minimise the risk of it closing and also the need for ongoing maintenance. However, one subsequent breach

ARUN DISTRICT COUNCIL P/93/25/PL

intervention has been included as part of the proposal as a contingency in the unlikely event that the tidal inlet were to close over the design life of the project.

11.2.2 Compensation

In order to account for the uncertainty of whether and to what degree Little Terns (which are an interest feature of Pagham Harbour SPA) are affected by the proposed project (see Appendix C), a new isolated island habitat will be created for these birds within the harbour. Following the Court of Justice of the European Union (CJEU) ruling in the Briels case, there may be issues as to whether the creation of habitat for SPA features within the site fabric of the SPA can be regarded as 'mitigation' under the Habitats Directive. Currently there is no UK specific case law on this point although CJEU case law is binding. Rather it may be considered as 'compensation', an option which is available only after following the 'no alternatives' and 'imperative reasons of overriding public importance' tests under Article 6(4) of the Habitats Directive (see Section 2).

The location of the proposed new tern island is shown on Figure 11.1. A proportion of the shingle from the breach will be translocated onto the unused relict concrete structure at this location (Image 11.1). The shingle will be placed on top of the concrete thus preserving and protecting this relict feature. A new channel will be cut to the south of this feature disconnecting it from the shingle spit and allowing it to become isolated over the tide, thus reducing potential predation. Fixed points for fencing will be placed on the newly created island to allow seasonal fencing to be erected to manage fox predation during the breeding season. Vegetation will also be cleared as required to provide optimal habitat to Little Terns. RSPB will take over the management of this island (e.g. erecting seasonal fencing and clearance of vegetation) once created.



(Taken by ABPmer, May 2015 - Source: ABPmer, 2015)

Image 11.1 Relict concrete training wall structure at location of proposed new tern island

A detailed review of management measures that can be undertaken on established Little Tern nesting areas to improve productivity, as well as the restoration of existing degraded habitat and creation of new habitat for this species is provided in Appendix L. Based on this review, it

ARUN DISTRICT COUNCIL P/93/15/PL

is considered likely that Little Terns will use this newly created island and that it will provide the necessary habitat to offset any potential loss of available breeding habitat on the spit during operation. This is because the new island can offer valuable habitat that is sheltered and isolated from predation and recreational disturbance.

11.2.3 Long Term Management Measures

To address issue of uncertainty especially in respect of the effects of the project on Little Terns and the effectiveness of the compensation measures in addressing this effect, ongoing oversight of the project will be required. This could be viewed as an embedded part of the ongoing adaptive management requirement for the coastline and the ongoing management requirements of the harbour. This management will require funding but will benefit substantially from the volunteer support that will be available from the local community. As described in the Section 1.1, community involvement and re-engagement is an important benefit/component of this project.

It is envisaged that the community will assist the RSPB with management and protection of bird breeding areas during the nesting season e.g. through wardening and forming part of a "Tern watch team". Initial discussions with the local community at Pagham have indicated strong support for this approach.

11.2.4 Enhancement Measures

In addition, to the range of mitigation measures that have been presented above to avoid and/or minimise the predicted effects of proposed project, existing initiatives being undertaken by RSPB are considered to protect and enhance the ecological value of the environment and thus potentially further ameliorate some of the project's effects. These initiatives include ongoing consistent management of the Pagham Harbour nature reserve, such as the clearing of vegetated shingle and erection of fences in existing areas used by terns. In addition, work under the EU Life Project (2014-2018) will provide more anti-predator fencing and also fund community engagement and education which will complement, but not overlap, with mitigation being undertaken for the proposed project.

11.3 Management and Monitoring Proposals

For this project there will also be requirements for ongoing (post-breach) site mitigation/compensation, monitoring and management. Post scheme monitoring in particular is proposed to account for the uncertainties associated with the future evolution of this dynamic coastline as a result of the proposed project.

This will require little new survey work and analysis but may require technical oversight perhaps by a panel of stakeholders. This panel will be able to review ongoing annual surveys under the SRCMP and annual low tide LiDAR surveys undertaken by the Environment Agency. This should take place for up to 8 years post breach i.e. covering the minimum lifespan of the project in terms of coastal defence protection. Evaluation of this data in the context of historical evolution will not only serve to validate the predictions in the ES but also enhance our understanding of how spits develop following a breach and thus provide an important

ARUN DISTRICT COUNCIL P/93/25/PL

contribution to the science of coastal geomorphology. Additional monitoring and evaluation of the compensation measures at the New Tern Island will also be needed.

11.4 Conclusions

The majority of impacts identified in this ES have been assessed as insignificant or of minor adverse significance. Where the potential for more significant adverse impacts has been identified, the mitigation measures provided in Section 11.2 are considered sufficient to reduce the residual impact significance to minor adverse at worst.

There will be many key benefits arising from this project that have been reviewed within this assessment. In particular it offers coastal protection to Pagham Beach and improvements to the amenity value and the health of those residents that live along this shoreline. It offers the opportunity for community engagement in the environment to the benefit of both the environment and the community.

There are issues associated with impact certainty for a project which seeks to mimic, and work with, natural processes at a spatially large scale. These uncertainties have been considered throughout this assessment and can be addressed in an adaptive manner through the ongoing management of the site and the coastline.

This is therefore considered to be a necessary and visionary project achieving multiple benefits while also realising and addressing actual and potential significant adverse effects.

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Figures



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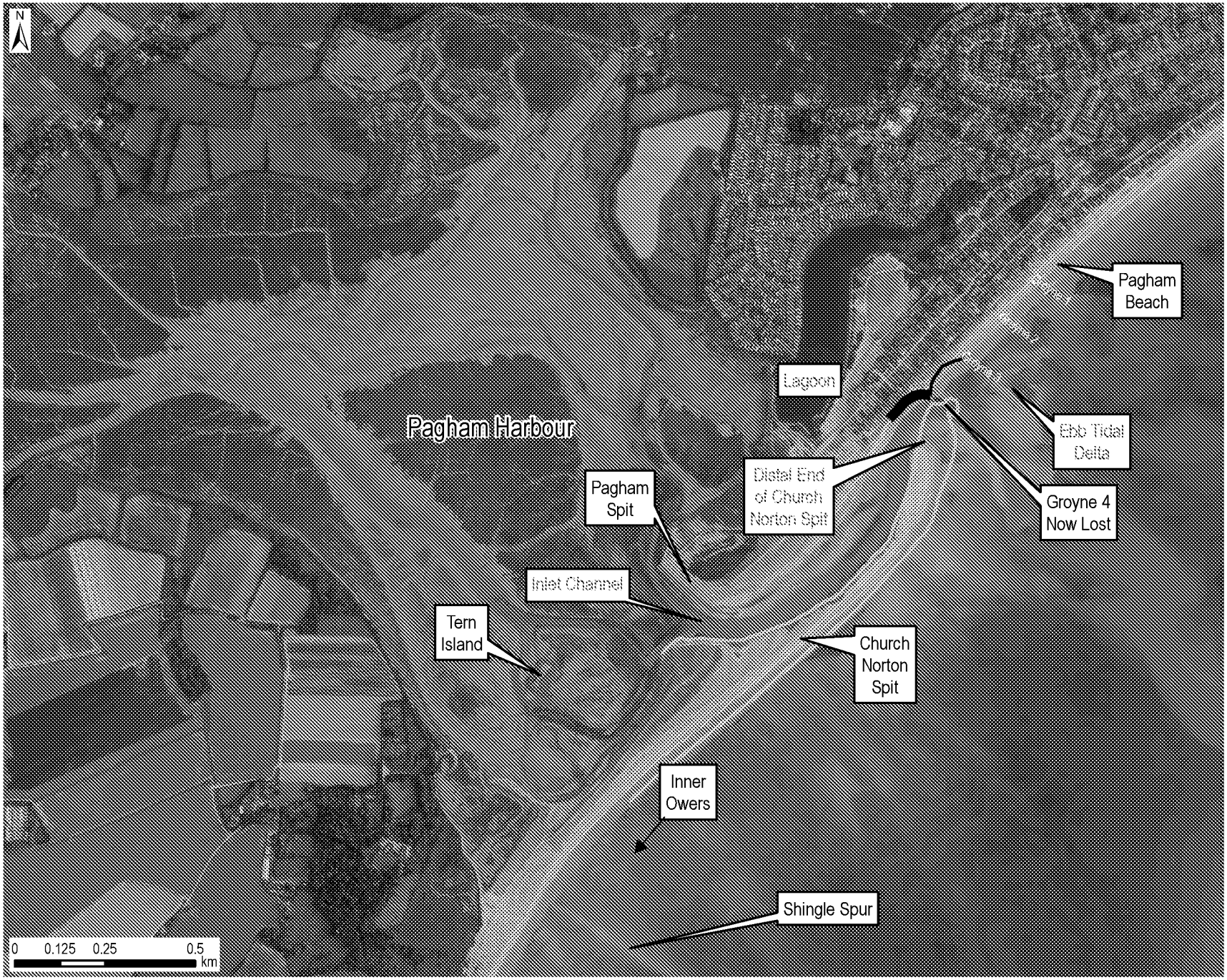


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Location of Pagham Harbour

Figure 1.1



Extent of Church Norton Spit in January 2015

Training Wall

Rock Revetment and Geotextile Bag Protection

Aerial imagery from 26th June 2013

Date	By	Size	Version
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Plan of Key Local Features

Figure 1.2



Extent of Church Norton Spit in January 2015

District Council Boundaries

Aerial imagery from 26th June 2013

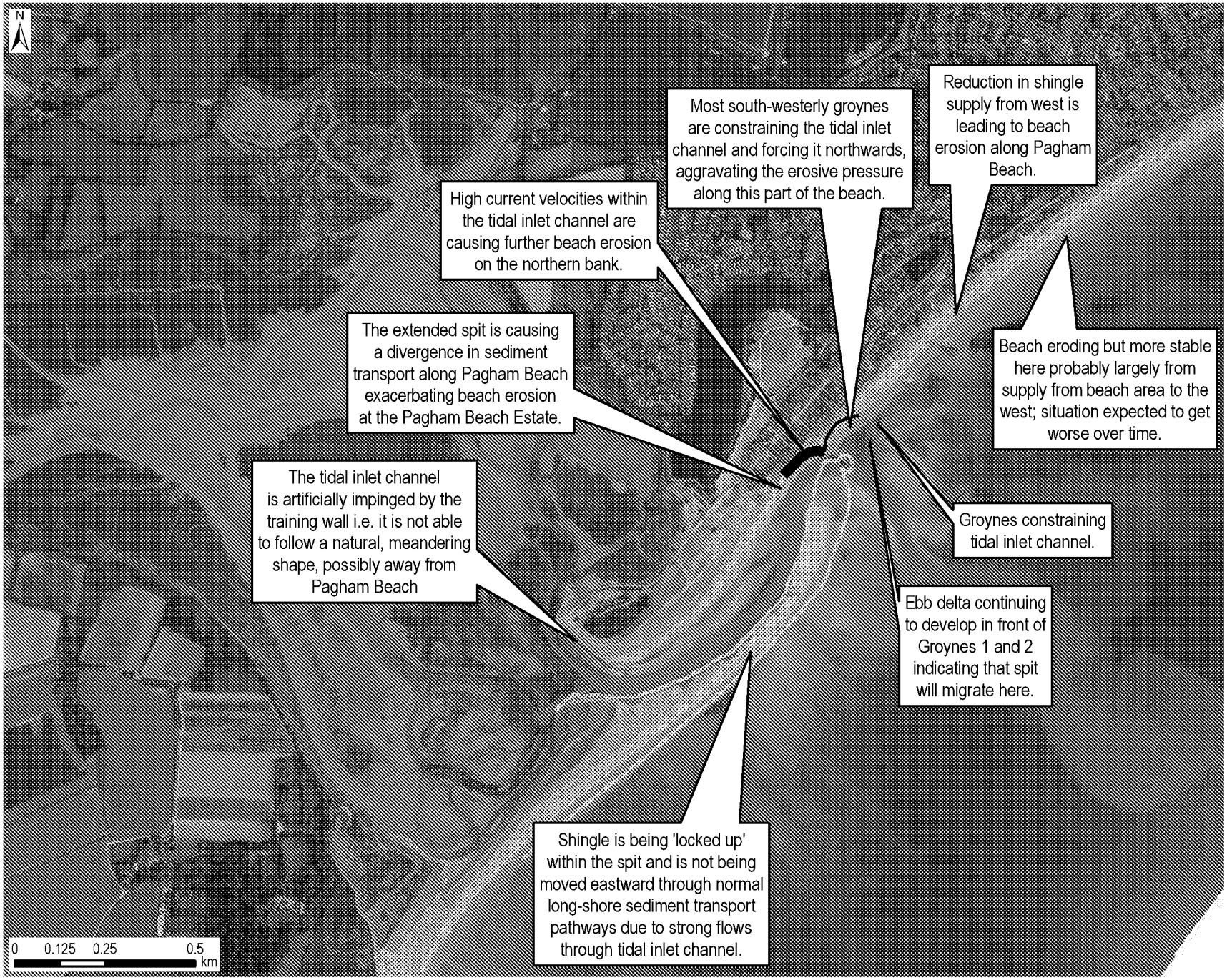
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Boundaries of Chichester and Arun District Councils

Figure 1.3



Extent of Church Norton Spit in January 2015

Rock Revetment and Geotextile Bag Protection

Aerial imagery from 26th June 2013

Date	By	Size	Version
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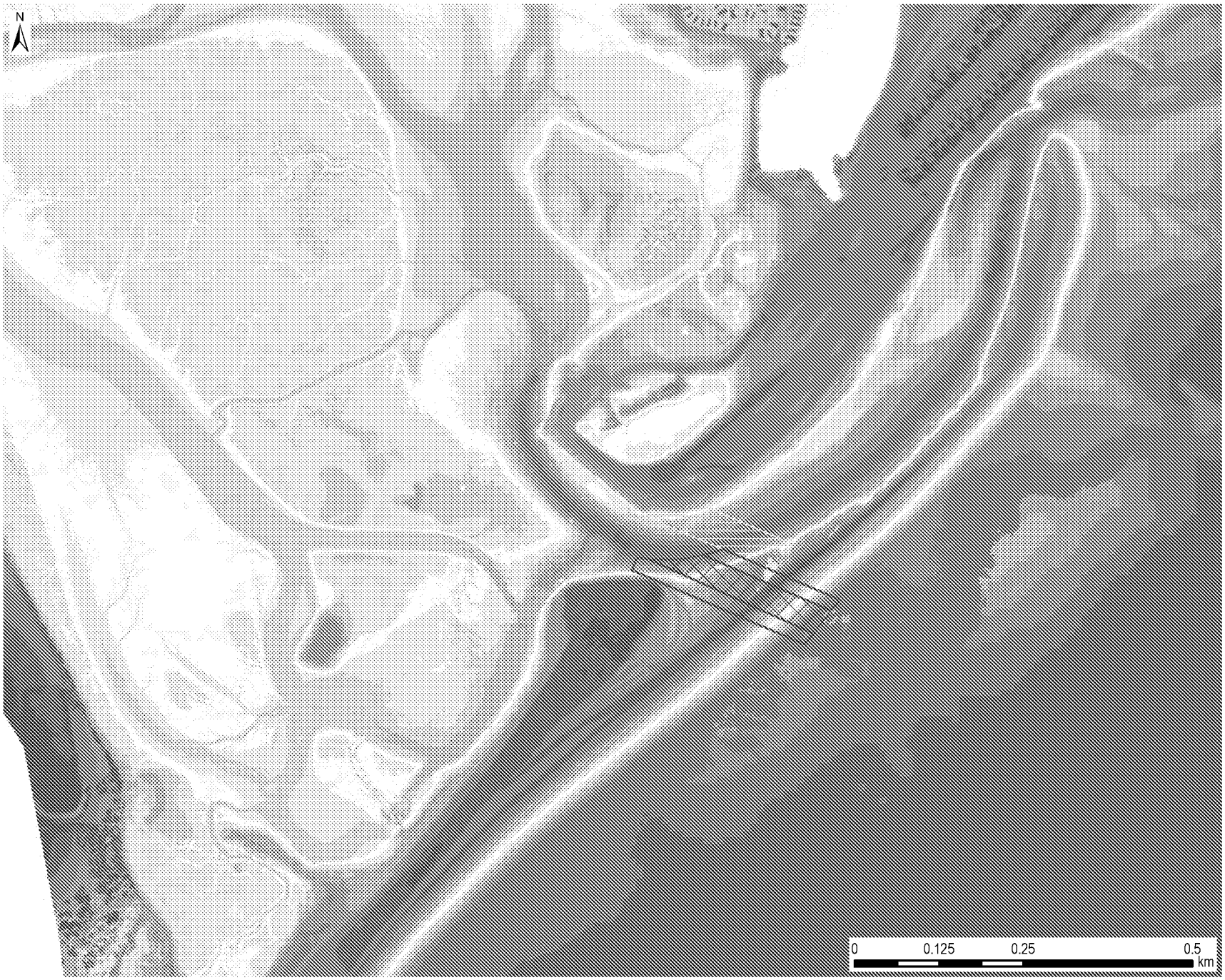


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Factors Influencing Erosion at Pagham Beach

Figure 2.1



40m Wide Base Channel

Breach Side Slopes

Proposed Infill with Excavated Material

Digital Terrain Model

Elevation (mODN)

- < -2.00
- -1.99 to -1.50
- -1.49 to -1.00
- -0.99 to -0.50
- -0.50 to 0.00
- 0.00 to 0.50
- 0.50 to 1.00
- 1.01 to 1.50
- 1.51 to 2.00
- 2.01 to 2.50
- 2.51 to 3.50
- 3.51 to 4.50
- 4.51 to 5.50
- 5.51 to 6.50
- > 6.50

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Location and Design of Proposed Breach and Channel Infill

Figure 2.2



Extent of Church Norton Spit in January 2015

Rock Revetment

Aerial imagery from 26th June 2013

Date	By	Size	Version
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Indication of the Alternative Options

Figure 2.3



Mean High Water Contour

- 2001
- March 2003
- September 2005
- January 2007
- January 2009
- December 2009
- May 2010
- February 2011
- September 2011
- March 2012
- September 2012
- October 2012
- February 2013
- September 2013
- February 2014
- January 2015

Mean High Water Level 1.9mODN

Aerial imagery from 26th June 2013

Date	By	Size	Version
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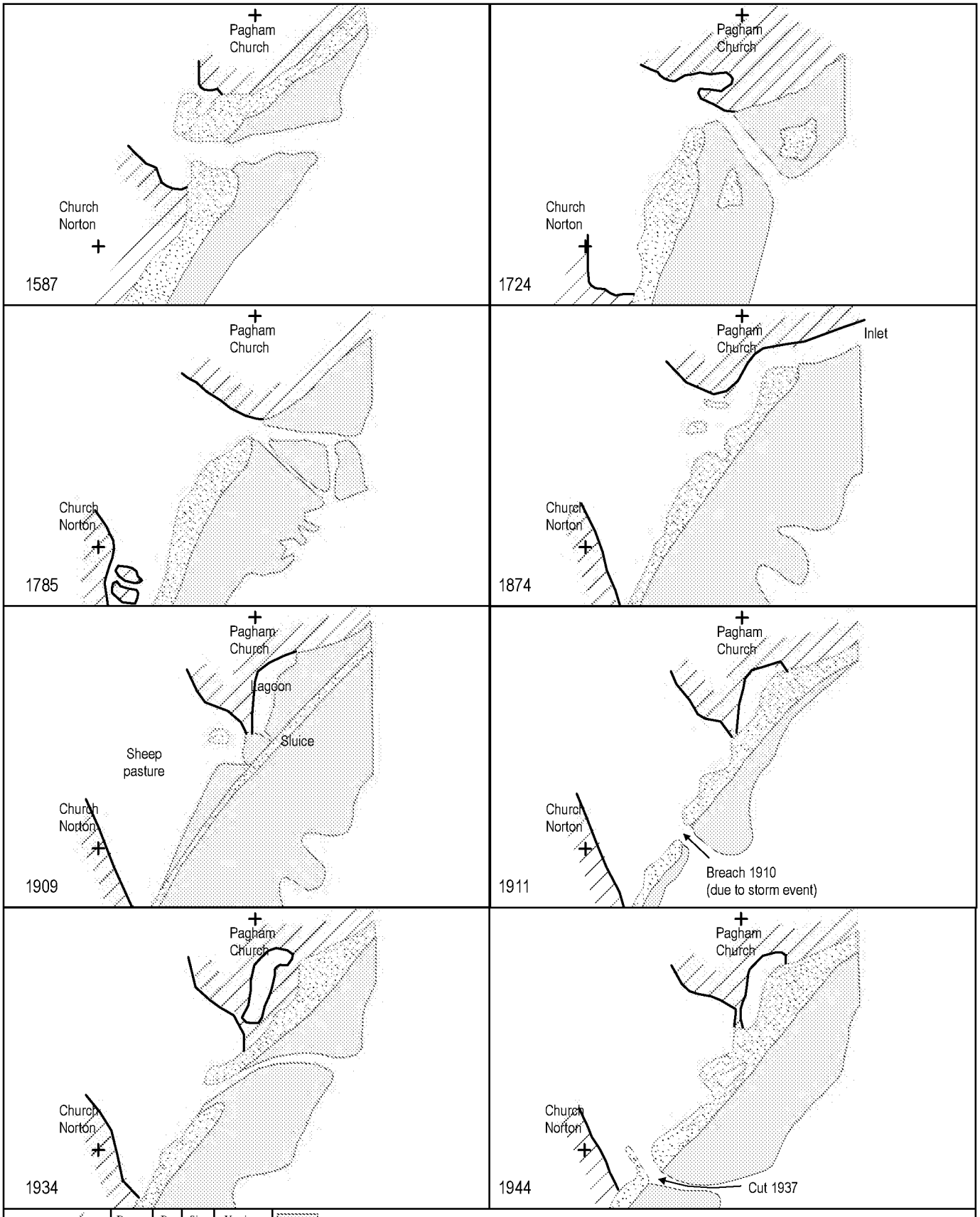


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Recent Evolution of the Church Norton Spit and Pagham Beach Frontage

Figure 6.1



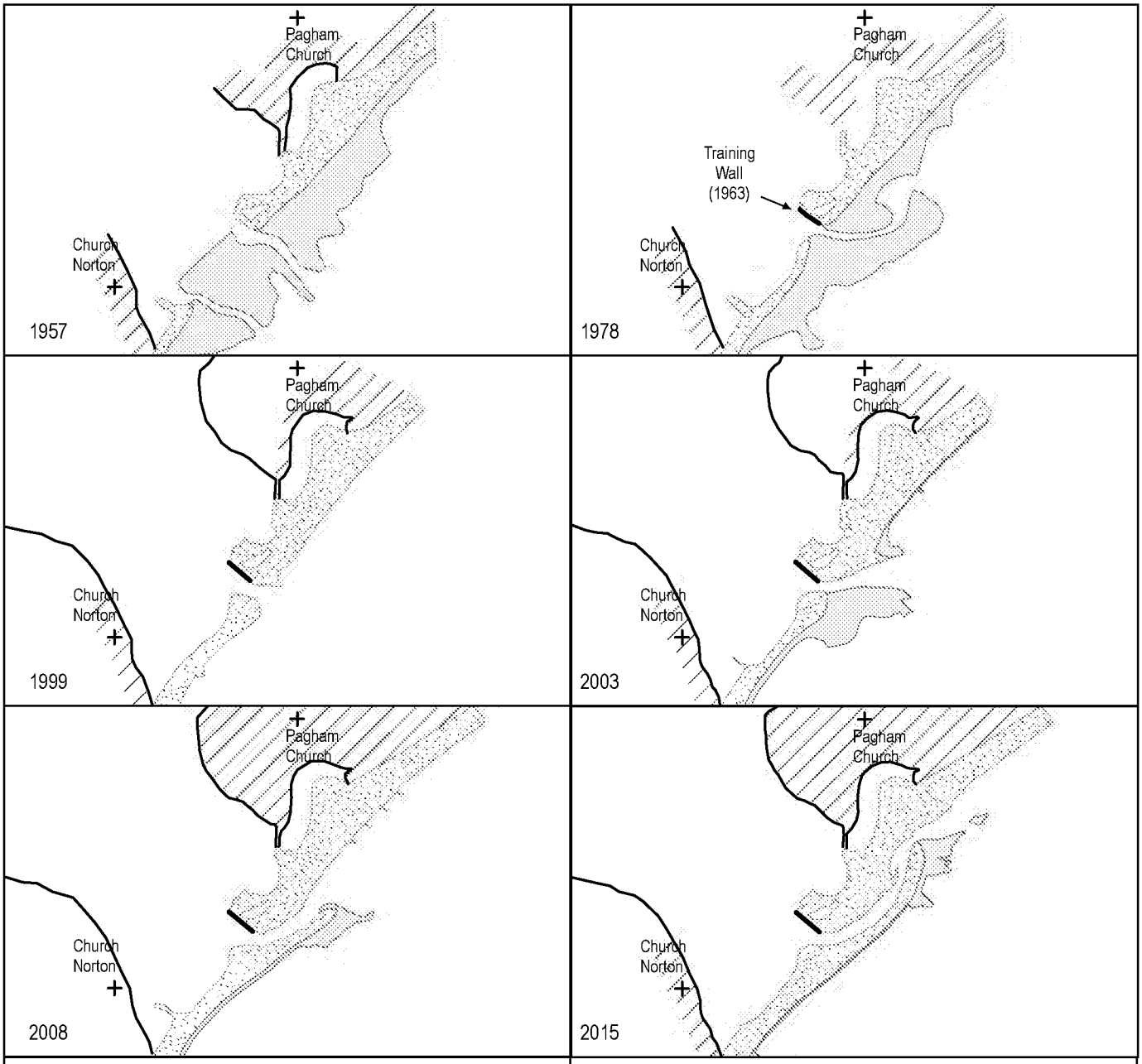
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Interpreted from Robinson, DA & Williams RBG (1983). The Sussex Coast Past & Present

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Schematic Illustration of Coastal Features Mapped Between 1587 and 1944

Figure 6.2



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Left Blank

Date	By	Size	Version
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Coordinate System	British National Grid		
Projection	Transverse Mercator		
Scale	1:40,000		
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'Sand' (Sand, Shingle and Ebb Delta)

'Shingle' (Spit/Beach)

Land

Churches (used for georeferencing)

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Schematic Illustration of Coastal Features Mapped Between 1957 and 2015

Figure 6.3



Contours

- 4.9 mODN - 2001
- 4.9 mODN - 10/03/2003
- 4.9 mODN - 08/03/2012
- 4.9 mODN - 26/03/2013
- 4.9 mODN - 20/02/2014
- 4.9 mODN - 27/01/2015

Aerial imagery from 26th June 2013

Date	By	Size	Version
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Changing Position of 4.9 mODN Elevation Along Pagham Beach (2001 to 2015)

Figure 6.4



1874 Meander
1978 Meander
2015 Meander
Identified by Dornbusch 2014
Identified for this EIA

Aerial imagery from 26th June 2013

Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
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Projections for Future Spit Development Alongside Past and Present Channel Meanders

Figure 6.5



15 properties protected by existing emergency revetment (already claimed under FDGiA) which will require less maintenance following proposal

10 properties between Groyne 4 (lost) and Groyne 3 which have some emergency defences already but will be further protected from tidal channel erosion following proposal

43 properties between Groyne 3 and Yacht Club area which will have reduced risk (in short term) from future encroachment of spit and enhanced shingle supply to stabilise/restore eroding beach

34 properties between Yacht Club area and the end of East Front Road which will have enhanced shingle supply to stabilise/restore eroding beach and reduced risk (in longer term) from future encroachment of spit if it were to continue growing

23 properties in the Beach Road and Sandy Road area that will have reduced risk of future wave over-topping

Date	By	Size	Version
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Aerial imagery from 26th June 2013

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Properties that are Vulnerable to Erosion and Flooding Risk

Figure 6.6



Extreme water levels

mODN

1 in 1	3.17
1 in 10	3.41
1 in 20	3.49
1 in 50	3.58
1 in 100	3.66
1 in 200	3.74
1 in 500	3.85
1 in 1000	3.93

Aerial imagery from 26th June 2013
2014 EA LiDAR used to determine land elevations

Date	By	Size	Version
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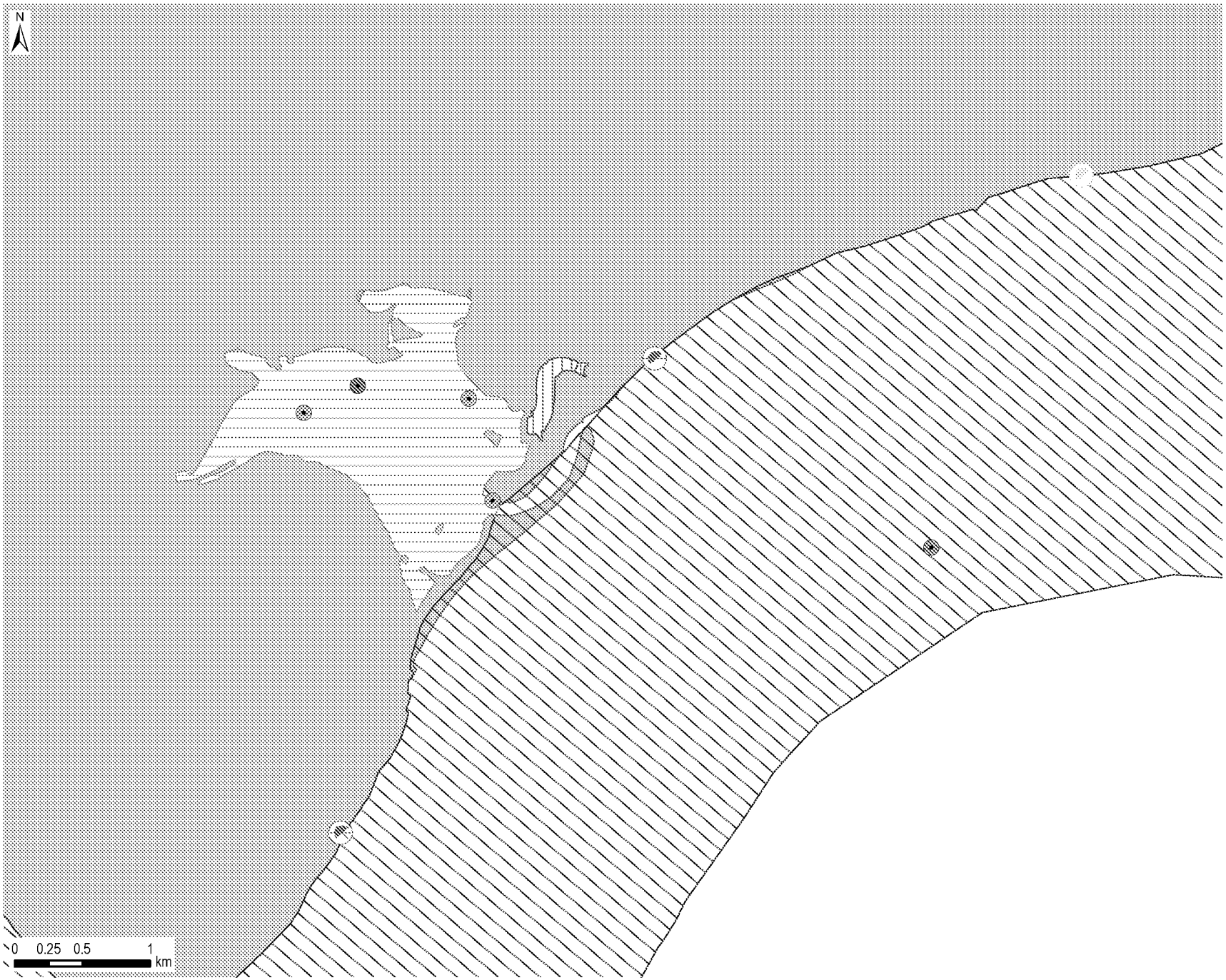


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Land Elevations Around Pagham Harbour Equating to Projected Extreme Water Levels

Figure 6.7



Pagham Harbour Transitional Water Body

Pagham Lagoon

Sussex Coastal Water Body

Bathing Waters

Bognor Regis (Aldwick)

Pagham

Selsey

Environment Agency Monitoring Data

Sediment Quality

Water Quality

Suspended Solids

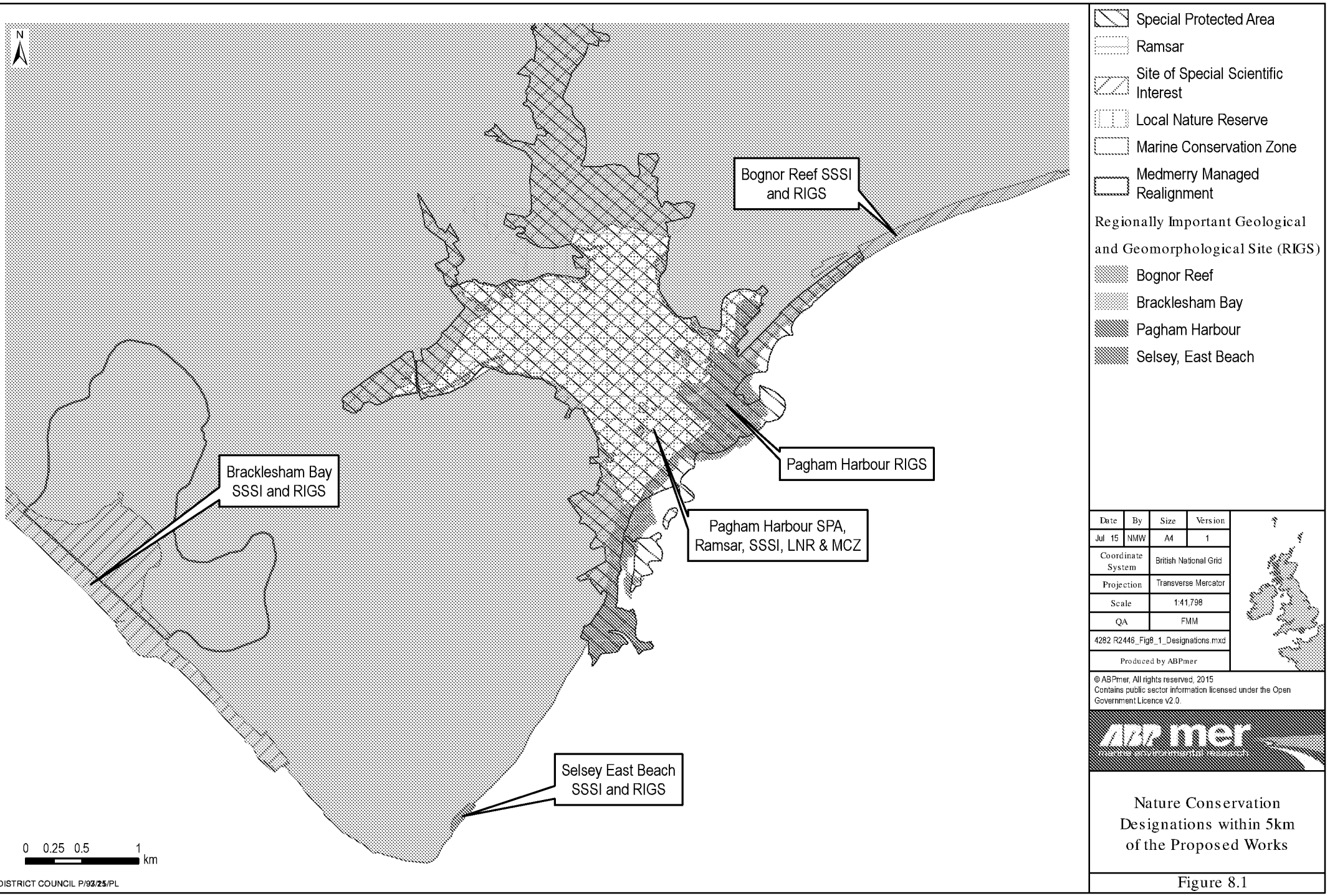
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Water/Sediment Quality Designations and Monitoring Sites

Figure 7.1

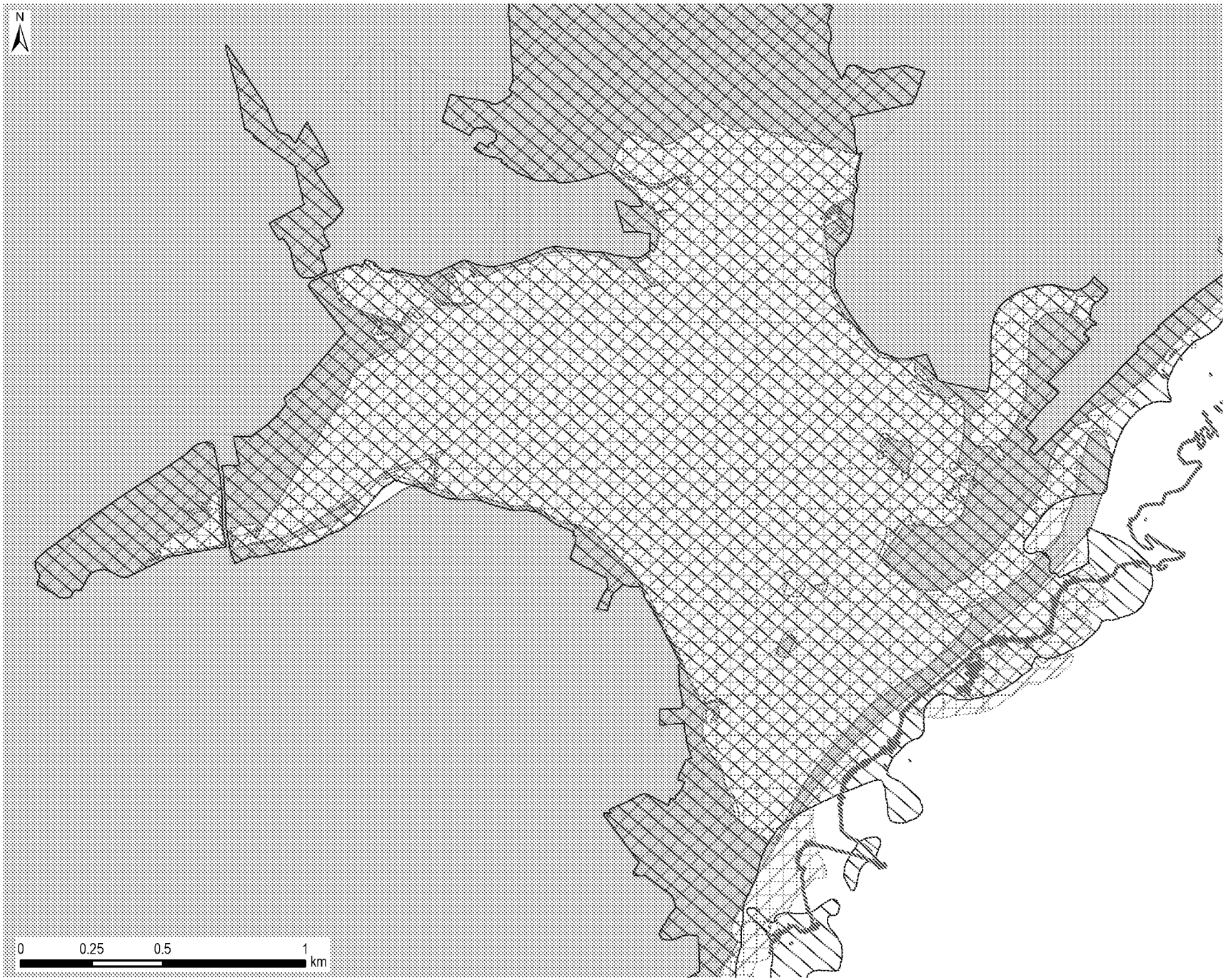


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Nature Conservation Designations within 5km of the Proposed Works

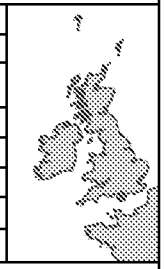
Figure 8.1



Mean Low Water
Special Protected Area
Ramsar
Site of Special Scientific Interest
Local Nature Reserve
Marine Conservation Zone

Mean Low Water line defined from 27 January 2015 topographic survey

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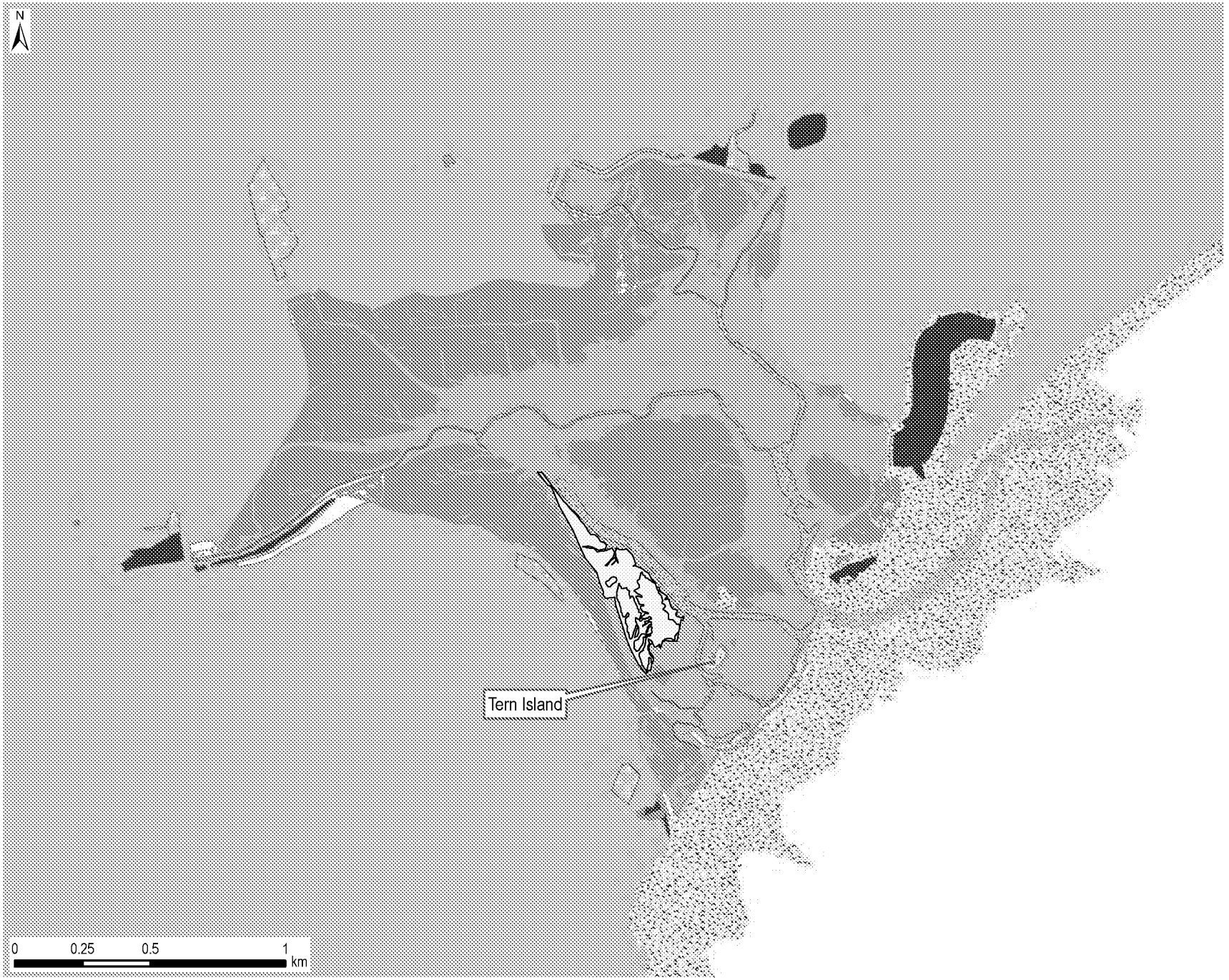


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Pagham Harbour
Designated Sites and
2015 MLW Line

Figure 8.2



Zostera Beds Extent 2014
Zostera Beds Extent 2011
Saltmarsh
Shingle
Tidal channel
Mudflat
Fresh water
Saline lagoon/scrape
Reedbed

Date	By	Size	Version
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Coordinate System		British National Grid	
Projection		Transverse Mercator	
Scale		1:20,000	
QA		FMM	
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Marine and Coastal Habitats of Pagham Harbour

Figure 8.3



Marine Conservation Zone

Zostera Beds Extent 2014

Zostera Beds Extent 2011

DeFolin Snail Find Locations

Date	By	Size	Version
Sep 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
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The Pagham Harbour MCZ and its Feature Records

Figure 8.4



DeFolin's Snail Survey Locations

- Church Norton Spit
- Pagham Spit Lagoon

Date	By	Size	Version
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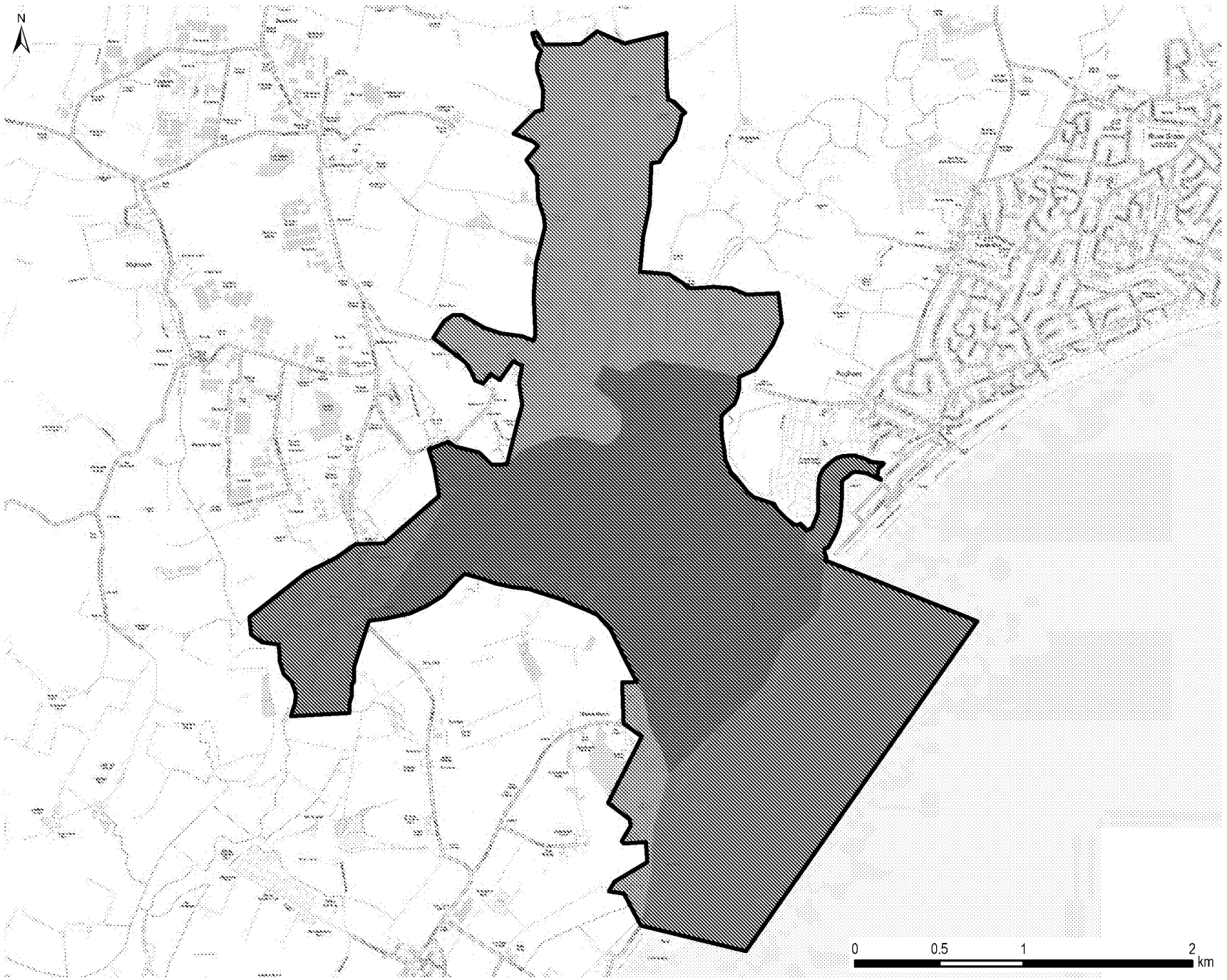


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Data Sources - Natural England, 2013; Aerial (2013) Image/Data courtesy of Channel Coastal Observatory

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DeFolin's Lagoon Snail Survey Results

Figure 8.5



Pagham Harbour Major WeBS Site

Sectors within Pagham Harbour WeBS Site

- Pagham Harbour
- Pagham Lagoon
- Pagham Sea
- North Fields
- Severals
- Sidlesham Ferry

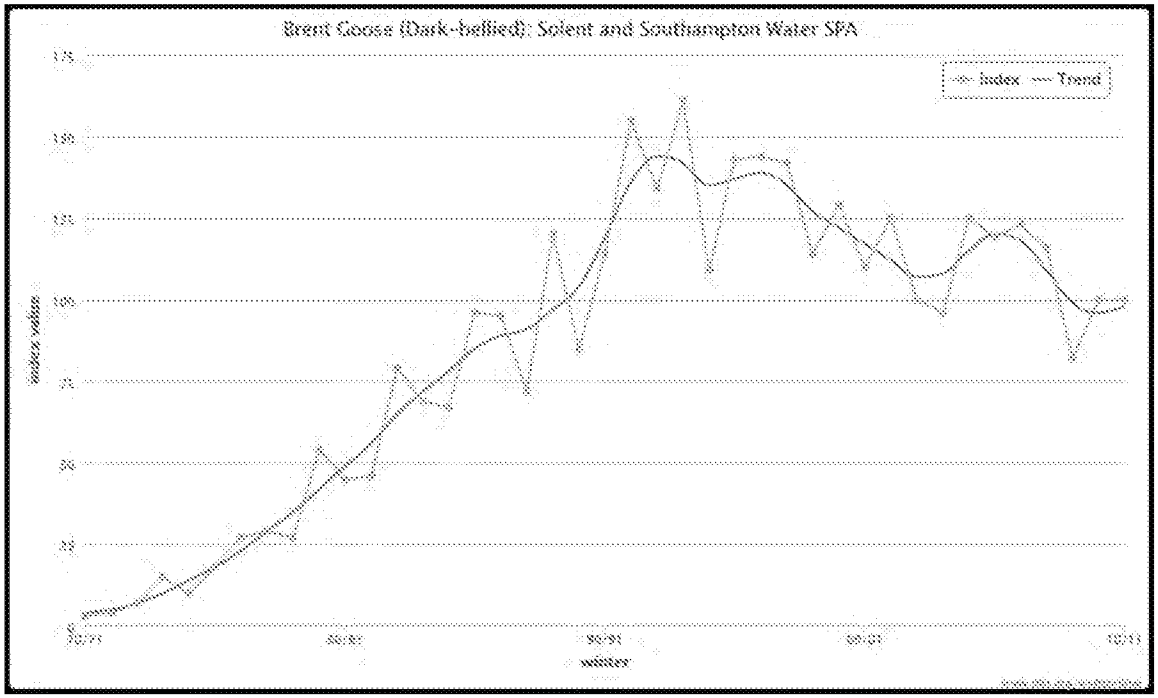
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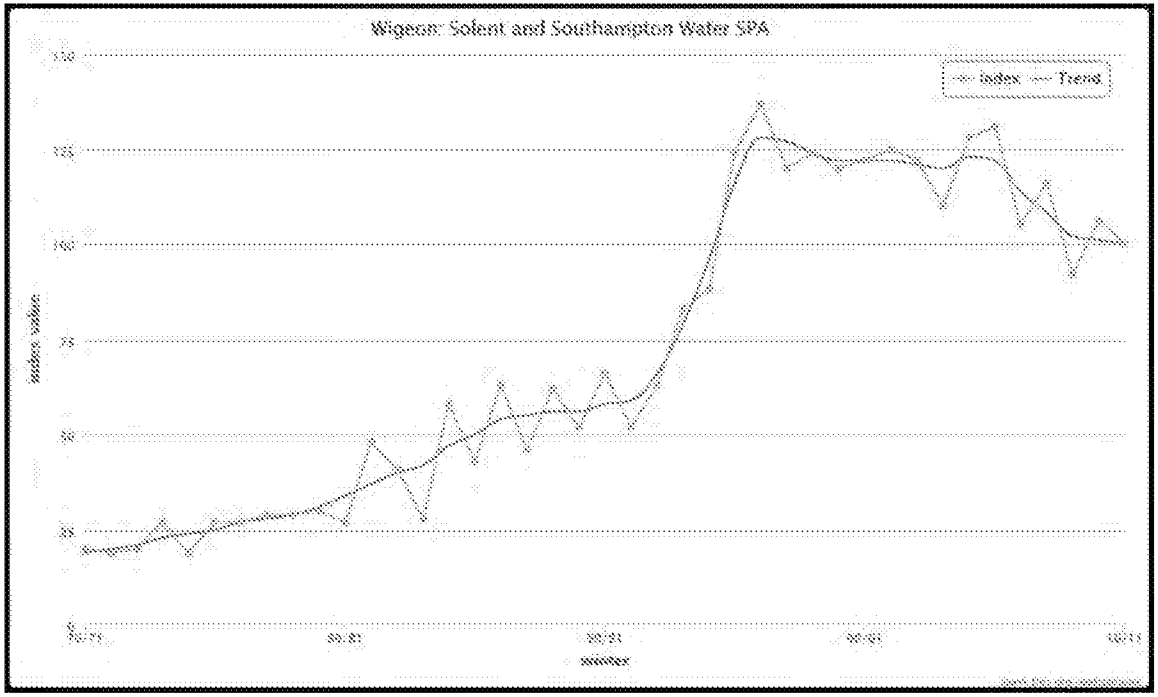
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WeBS Core Count Sectors in Pagham Harbour

Figure 8.6





Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
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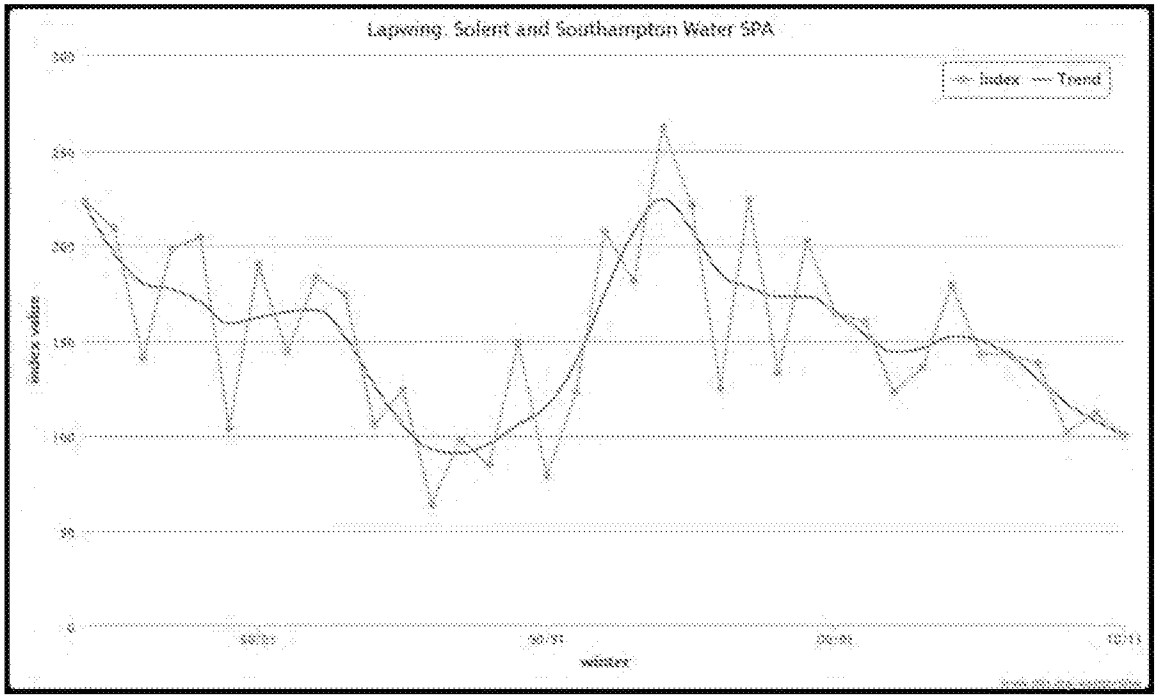


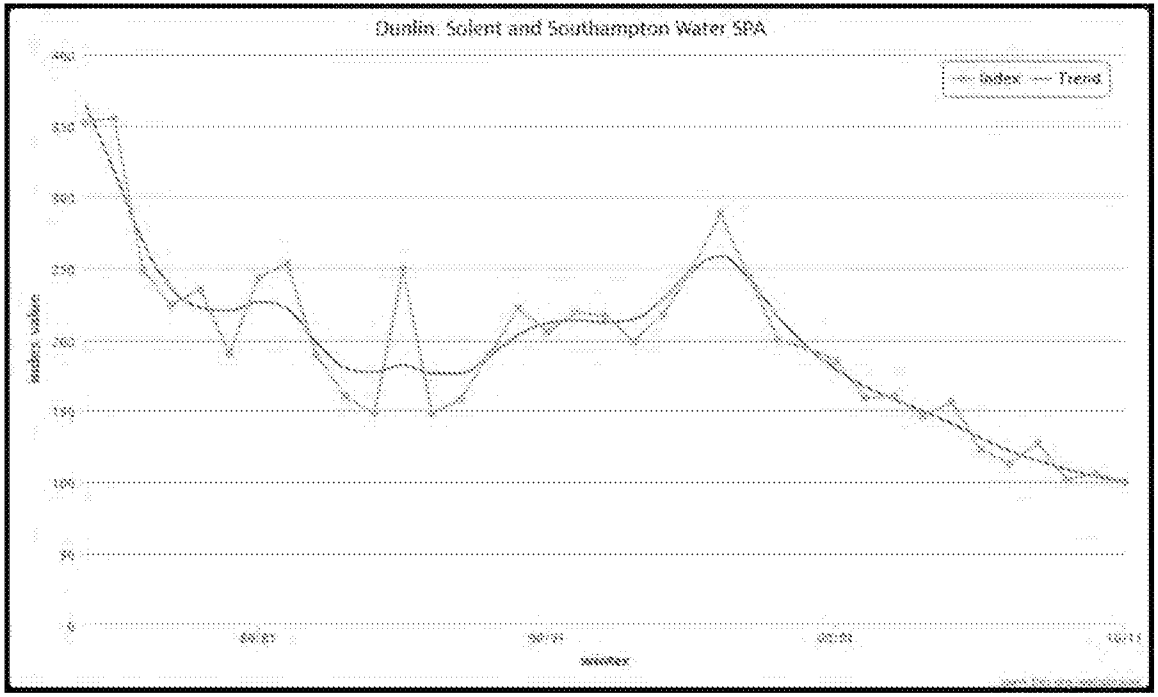
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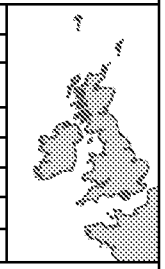
WeBS Alert Graphs for Dark-bellied Brent Goose and Wigeon in Southern England

Figure 8.7a





Date	By	Size	Version
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Projection		Transverse Mercator	
Scale		n/a	
QA		DLW	
R2446_Fig8_7b_WeBS_Lapwing			
Produced by ABPmer			



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WeBS Alert Graphs for Lapwing and Dunlin in Southern England

Figure 8.7b



Dunlin, Grey Plover and Knot low high tide

Dunlin, Grey Plover and Knot very high tide

Grey Plover and Curlew on rising tide

Lapwing and Golden Plover on rising tide

Oystercatcher

Redshank

Various species

Various species in small numbers

Aerial imagery from 26th June 2013

Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
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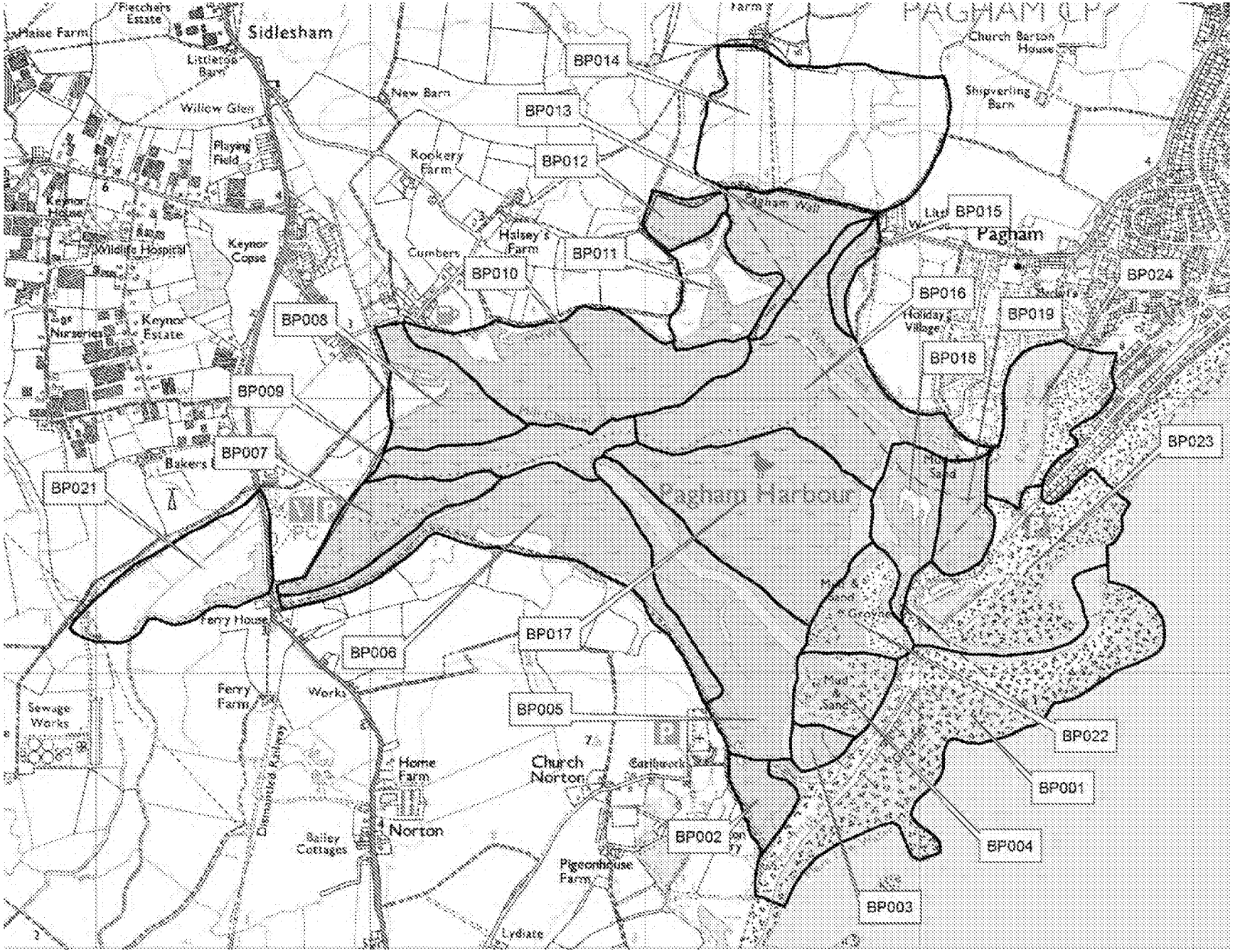


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The Location of Major Wader Roosts in Pagham Harbour

Figure 8.8



Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
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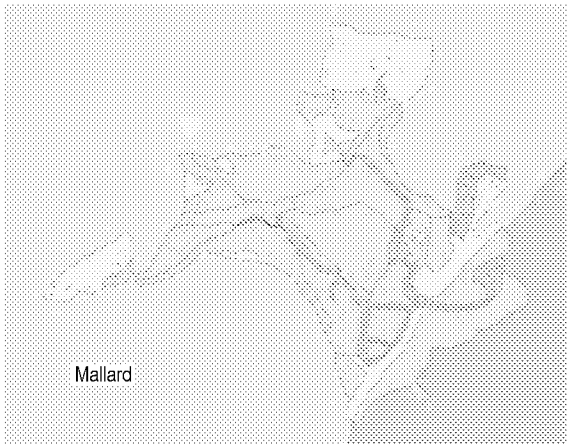
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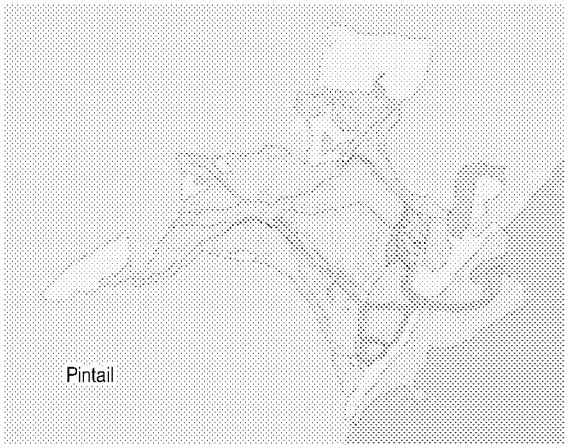
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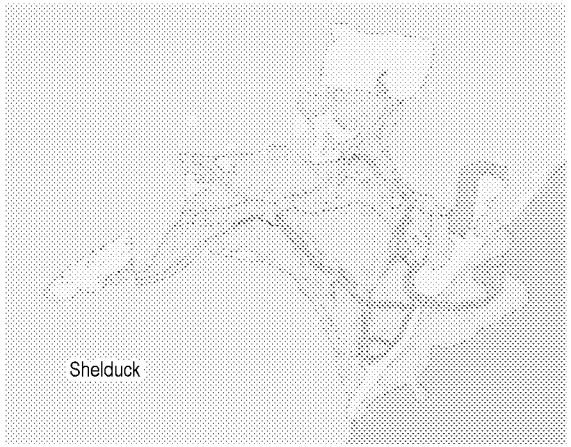
WeBS Low Tide Count
Sectors in Pagham Harbour

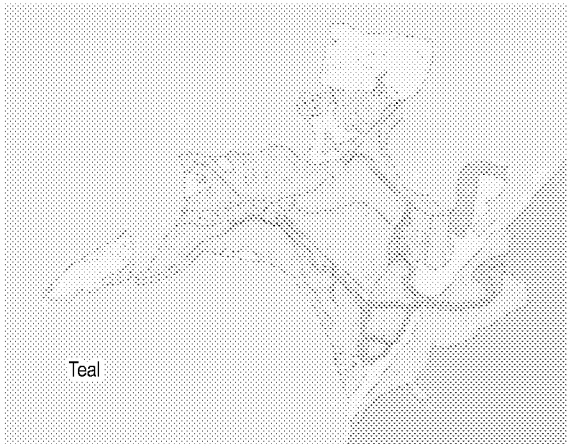
Figure 8.9

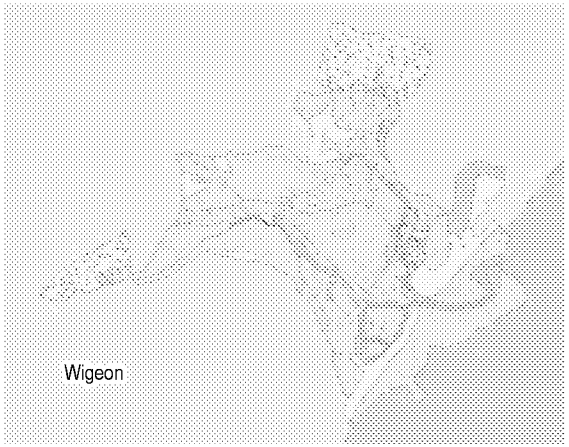






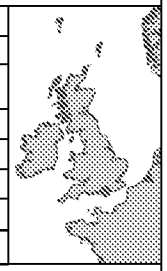






Images taken from the WeBS Low Tide Counts online portal. (http://blx1.bto.org/webs-reporting/?tab=lowtide)

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Scale	n/a		
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Produced by ABPmer			



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Data Source: WeBS, 2015.

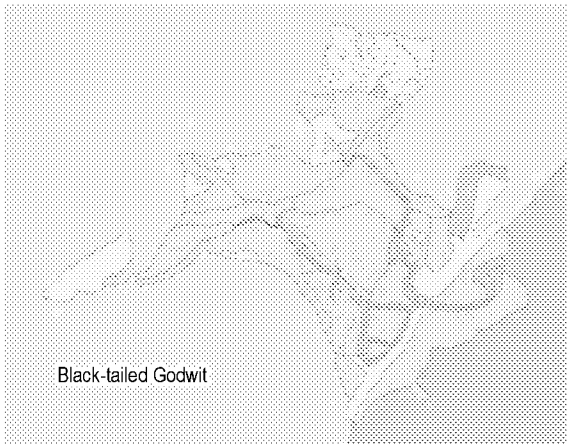
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WeBS Low Tide Count Maps for Wildfowl Species in Pagham Harbour (2013/2014)

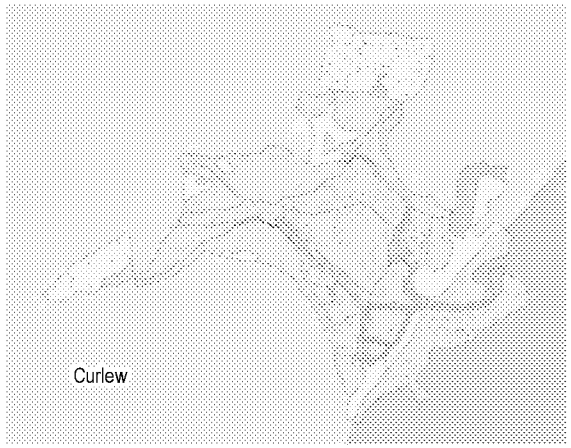
Figure 8.10a



Bar-tailed Godwit



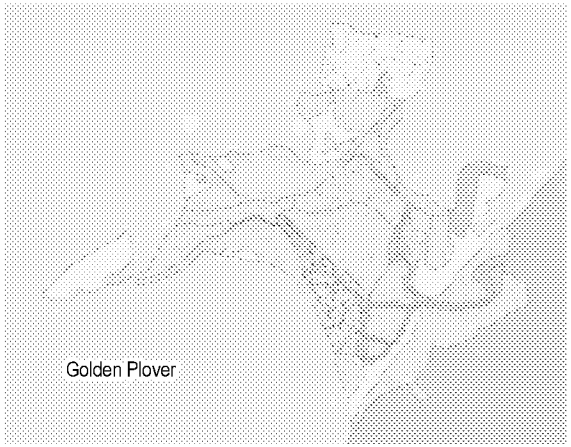
Black-tailed Godwit



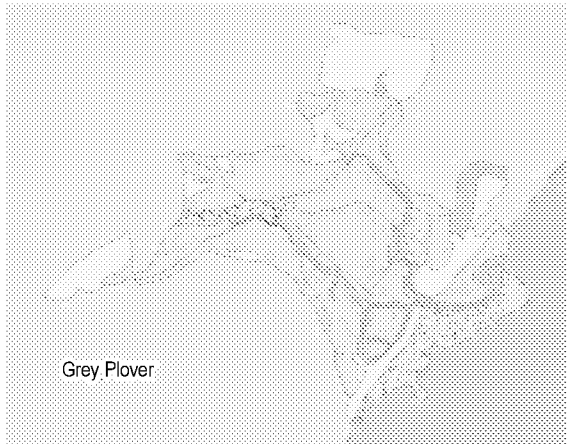
Curlew



Dunlin



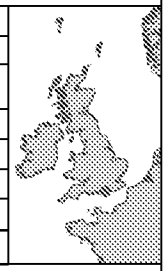
Golden Plover



Grey Plover

Images taken from the WeBS Low Tide Counts online portal. (http://blx1.bto.org/webs-reporting/?tab=lowtide)

Date	By	Size	Version
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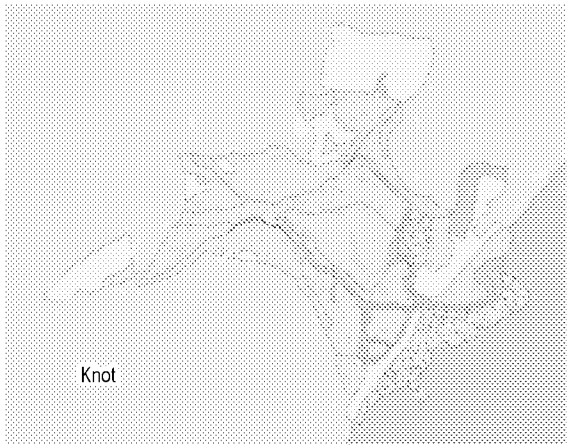


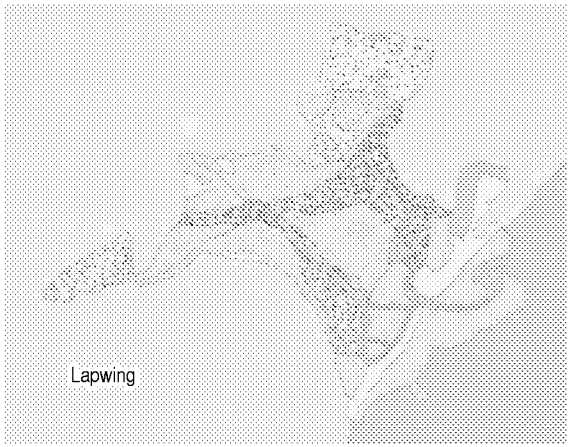
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Data Source: WeBS, 2015.

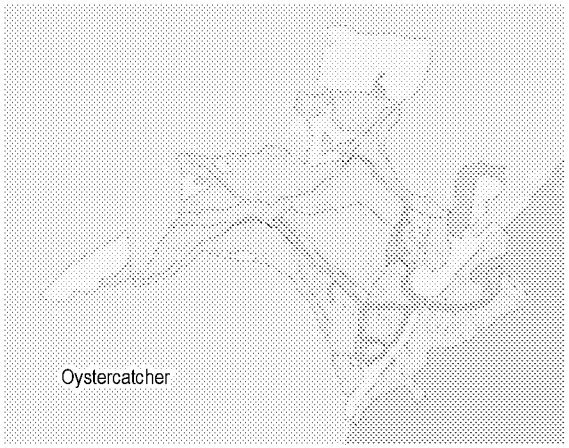
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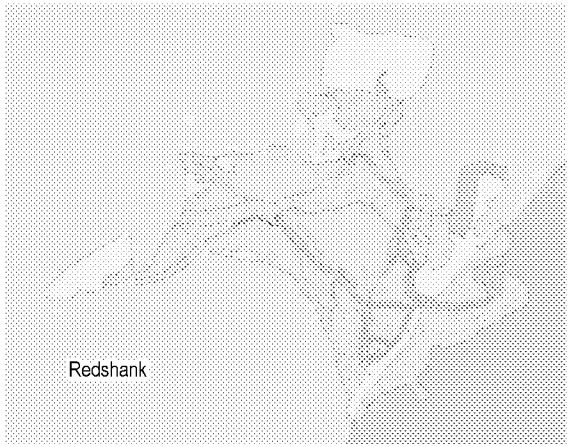
WeBS Low Tide Count Maps for Wading Bird Species in Pagham Harbour (2013/2014)

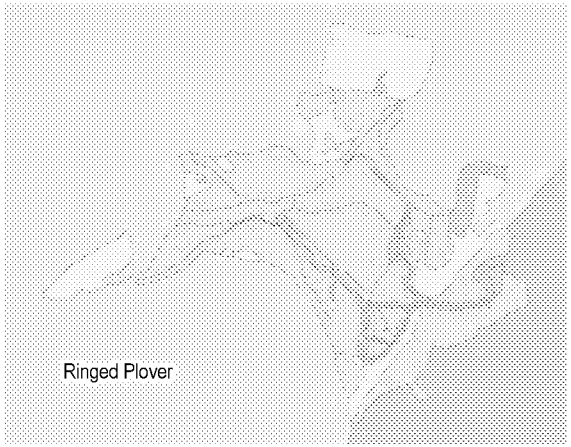
Figure 8.10b

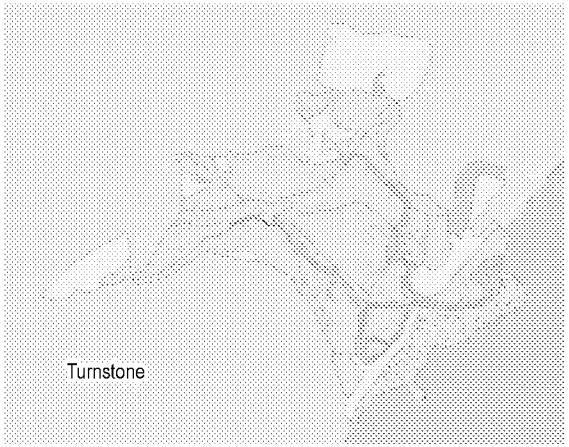






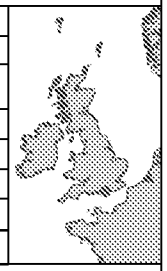






Images taken from the WeBS Low Tide Counts online portal. (http://blx1.bto.org/webs-reporting/?tab=lowtide)

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Produced by ABPmer			



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Data Source: WeBS, 2015.

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WeBS Low Tide Count Maps for Wading Bird Species in Pagham Harbour (2013/2014)

Figure 8.10c



Extent of Church Norton Spit in January 2015

Breeding Colonies

- 2008 & 2009
- 2010
- 2011
- 2011 & 2012
- 2013
- 2014

Aerial imagery from 26th June 2013

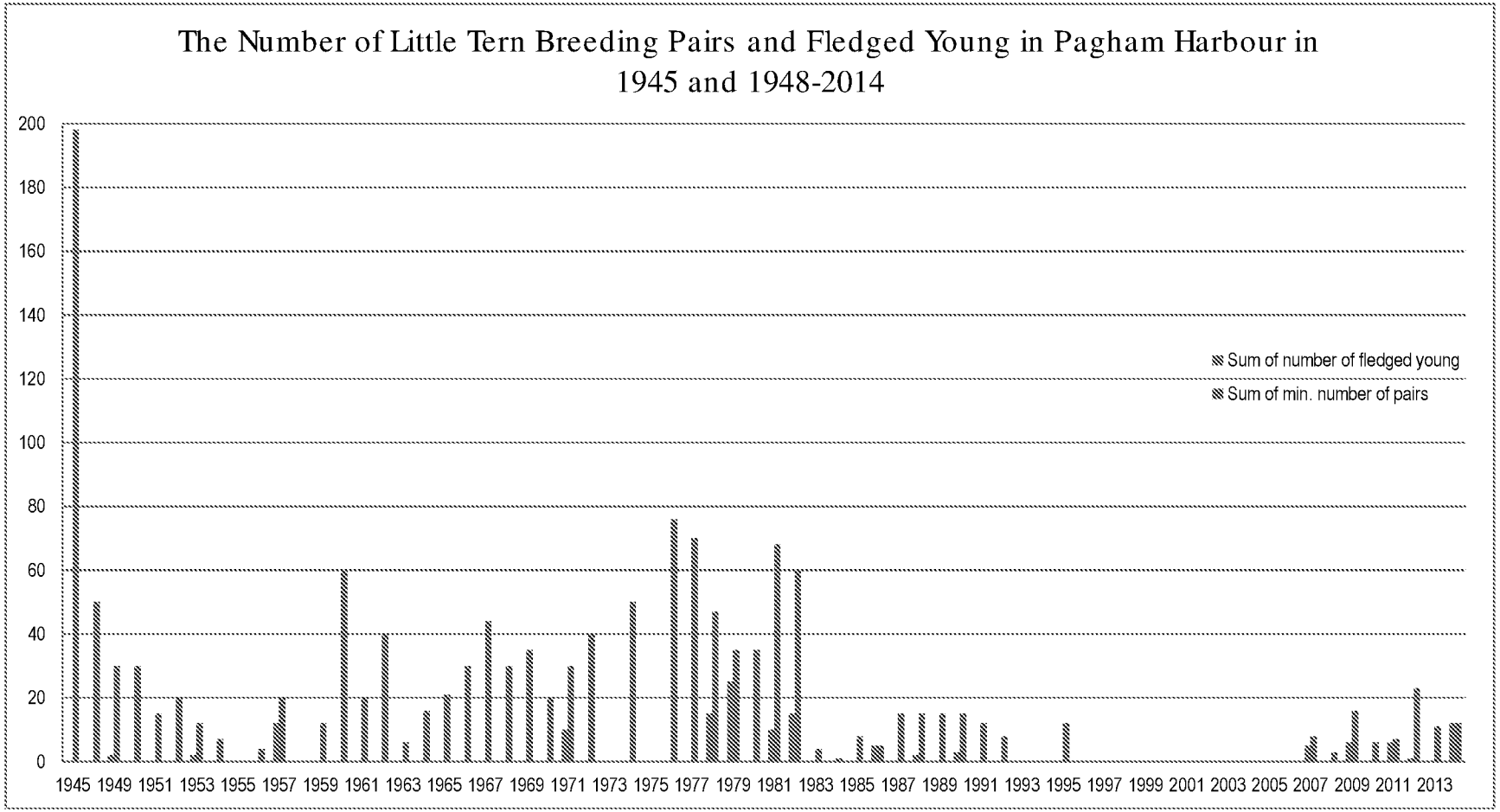
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4282 R2446_Fig8_11_Tern_Nests.mxd			
Produced by ABPmer			

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The Location of Little Tern Breeding Colonies in Pagham Harbour from 2008 to 2014

Figure 8.11



Date	By	Size	Version
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Coordinate System		British National Grid	
Projection		Transverse Mercator	
Scale		n/a	
QA		DLW	
R2446_Fig8_12_Tern_Graph.mxd			
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The Number of Little Tern Breeding Pairs and Fledged Young in Pagham Harbour in1945 and 1948-2014

Figure 8.12



Shorebird Nesting Area

Aerial imagery from 26th June 2013

Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
Scale		1:10,000	
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4282 R2446_Fig8_13_Shorebird.mxd			
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The Location of Shorebird Nesting Areas in Pagham Harbour

Figure 8.13



Water Voles Recorded

Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
Scale		1:27,787	
QA		FMM	
4282 R2446_Fig8_14_Water_Voles.mxd			
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Records of Water Vole in and around Pagham Harbour

Figure 8.14

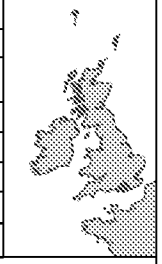


Proposed Location of a New Tern Island

Excavation to Create Isolated Island

Aerial imagery from 26th June 2013

Date	By	Size	Version
Aug 15	NMW	A4	1
Coordinate System		British National Grid	
Projection		Transverse Mercator	
Scale		1:9,000	
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4282 R2446_Fig11_1_Tern_Island.mxd			
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Location of Proposed New Tern Island

Figure 11.1

Appendices

(See Volume 2)

A. Proposed Design and Modelling Report
B. Scoping Consultation Log
C. Information for an Appropriate Assessment Signposting Document
D. Construction Maps Provided by Mackley
E. Legislation and Policy
F. Review of Nature Conservation Designations
G. Marine Conservation Zone Assessment
H. Water Framework Directive Compliance Assessment
I. Transport Statement
J. The Ecology of the DeFolin's Lagoon Snail
K. Review of Bird Disturbance
L. Little Tern Habitat Creation and Management Review

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