Improvement Programme for England's Natura 2000 Sites (IPENS) – Planning for the Future IPENS009

Humber Estuary Clay Pits - Water Quality Briefing (2013 – 2014)

Humber Estuary Special Protection Area (SPA)

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Foreword

The **Improvement Programme for England's Natura 2000 sites (IPENS)**, supported by European Union LIFE+ funding, is a new strategic approach to managing England's Natura 2000 sites. It is enabling Natural England, the Environment Agency, and other key partners to plan what, how, where and when they will target their efforts on Natura 2000 sites and areas surrounding them.

As part of the IPENS programme, we are identifying gaps in our knowledge, and where possible, we are addressing these through a range of evidence projects. Results from these projects will feed into Theme Plans and Site Improvement Plans. This project forms one of these studies.

Within the Humber Estuary Special Protection Area (SPA), underpinned by the Humber Estuary Site of Special Scientific Interest (SSSI), water quality monitoring in 2012/13 of a sample of the Humber Clay Pit lakes found that several lakes are failing targets for phosphate and nitrogen, causing undesired effects such as blooms of toxic algae and reduced aquatic plant populations. This study focussed on the lakes with the highest phosphate levels which were at Far Ings National Nature Reserve (NNR) and Pasture Wharfe Nature Reserve. A conceptual model of the hydrological system was developed in order to better understand the water and nutrient sources and pathways into the lakes within the study area. This was followed by a targeted monitoring programme assessing water quality, and lake bed sediment sampling.

Results from lake bed sediment sampling showed high phosphate concentrations, indicating that lake bed sediments are an important secondary source of nutrients to the water column, through remobilisation pathways. Based on bird count data over the last 12 years, it is considered that birds (particularly Canada goose, Greylag goose and coot) have been the most significant source of nutrients to the lakes, contributing on average 1,020 kg total phosphate per year.

During the study, a tidal surge in December 2013 breached the flood banks, severely flooding a large extent of Far Ings NNR with water from the Humber Estuary. The focus of the study became to assess the impact of the surge on phosphate, nitrogen and salinity, making comparisons between pre and post surge concentrations. As a result of the tidal surge, salinity rose dramatically at Far Ings NNR. Although it has declined, it is still above pre-surge levels. The surge temporarily led to elevated nitrogen levels, but had little consequence for phosphate. Prior to the storm surge, phosphate was the key driver affecting the water quality of lakes. The high level of salinity resulting in brackish conditions is now the driving parameter.

The report includes a range of broad-scale future management and monitoring recommendations. These include monitoring the speed of recovery in salinity and the factors that drive it, such as rainfall; active management to reduce salinity (e.g. flushing); and active management to reduce phosphorus concentrations (e.g. by immobilising phosphorus in the sediment).

The report has identified the main sources of phosphate and the impact of the storm surge on salinity. Issues and recommendations identified within the report have been incorporated into the Humber Estuary Site Improvement Plan and are being considered by Natural England in assessing the future objectives for the lakes. Monitoring recovery of salinity to pre surge levels is continuing. The key audience for this work is the staff within Natural England and the site managers.

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EXECUTIVE SUMMARY

The standing waters of the Clay Pits within Far Ings National Nature Reserve (NNR) are notified features of the SSSI, and the conservation objectives for the Humber Estuary include maintaining the standing open waters in favourable condition, with reference to the macrophyte community composition and water quality. Previous studies including aquatic plant surveys undertaken in 2007 and 2008 showed that very few macrophytes were present, with a loss of loss of characteristic species since 1987. As a result most of the pits are recorded as being in unfavourable declining condition. Prior to this study, a two year project (undertaken in 2012 and 2013) focused on a sample of the lakes present within the designated site, to investigate the reasons for the low number of macrophytes. Possible causes put forward included poor water quality, the fine and unstable clay substrate and the presence of introduced fish (particularly carp). These studies highlighted that three former Clay Pits are failing favourable condition targets for phosphate. Based on a previous study in 2012-2013 those lakes failing Common Standards Monitoring (CSM) targets for phosphate, and also nitrogen, were Ness Pit and Pursuit Pit, lying within the Far Ings NNR, which is managed by Lincolnshire Wildlife Trust, and Pasture Wharf which is to the east.

Phosphate and nitrogen occur naturally in the environment and are essential to the growth of aquatic life. However, when higher than natural levels occur they can have undesired effects, such as blooms of toxic algae and reduced water quality. The NNR is recognised as a key area in the UK for the conservation of reedbeds and a stronghold for one of Britain's rarest birds, the bittern.

The first step of this study developed a conceptual model of the hydrological system in order to better understand the water and nutrient sources and pathways into the lakes within the study area. This was followed by the completion of a targeted monitoring programme assessing water quality and bed sediment quality, undertaken between November 2013 and March 2014.

A storm surge on 5 December 2013, measuring ~2m above normal levels moved up the Humber Estuary and breached the flood banks along the northern edge of the Far Ings NNR, severely flooding a large extent of the reserve with brackish water. The focus of the study became to assess the impact of the storm surge on phosphate, nitrogen and salinity, making comparisons between pre and post surge concentrations. This was supported by assessment of nutrient sources relevant to long-term nutrient management planning - bed-sediment sampling of the three pits and a preliminary assessment of bird guano input.

The lakes are on a natural spectrum of salinity, however the tidal surge, as a one off extreme event, has altered the salinity well beyond that generally measured at the site. Based on water quality sampling undertaken as part of this study; Pursuit Pit (salinity of 7.3‰ in March 2014), Hotel Pit (4.0‰), Ness Pit (4.2‰) and Target Lake (3.8‰) are considered brackish. For these lakes, the level of salinity is now the key water quality driver affecting favourable condition of these SSSI units and the SPA locally.

Prior to the storm surge, phosphate was the driving parameter. The surge temporarily led to elevated levels of nitrogen, beyond those concentrations recorded in the 2012-2013 study. The surge had little consequence for measured concentrations of phosphate in the lakes. Ness Pit and Pursuit Pit are confirmed by sampling for this study to exceed the CSM threshold for phosphorus. Data for this study indicate that Pasture Wharf did not fail the CSM target for phosphorus until March 2014. In terms of compliance with CSM water quality targets, phosphorus remains a long term issue for Ness Pit and Pursuit Pit.

Lake bed sediment samples, taken from all three lakes, indicate high phosphorus concentrations. Pursuit Pit has the most (1,490mg/kg) followed by Ness Pit (1,315mg/kg). Although one of the individual values measured in Pasture Wharf exceeds 1,000mg/kg the other two values are equal or slightly less. These results indicate that lake bed sediments are an important secondary source of nutrients to the water column, through remobilisation pathways.

Based on maximum bird count data (for the Far Ings NNR as a whole), it is estimated that birds could be contributing on average 1,020 kg total phosphate each year. Although this is considered a high estimate, the preliminary guanotrophic assessment suggests with confidence that birds are the most significant source of nutrients to the lakes. Phosphate and nitrogen nutrient loadings are considered to be mainly driven by populations of Canada Geese, Greylag Geese and Coot.

Following the monitoring programme and assessment, a range of broad-scale future management and monitoring was considered and recommendations made by this study. These recommendations are made on the understanding that Natural England will continue to assess the condition of the study area lakes in accordance with the current citation and water quality targets set for them – as a series of eutrophic standing waters which are broadly freshwater but with variable amounts of saline influence. The tidal surge has shifted the pits away from the salinity the pits have been since notification, and which support the interest feature (eutrophic standing water). This will have impacted the habitat and its flora, (despite this being a 'natural' event) so a return to pre surge conditions and a recovery from the surge will be the management priority alongside any measures to manage phosphate in the two high-nutrient lakes. Equally any consideration of management will need to take into account the long term sustainability and cost effectiveness of any measures. Three tiers of management action are recommended for consideration by Natural England and by Lincolnshire Wildlife Trust who actively manage the four relevant lakes. These are set out as:

1) **Watching brief** - to oversee and monitor the speed of recovery in water quality and the factors that drive it such as rainfall.

2) **Actively manage a reduction in salinity** - recommended to be achieved through any practical, cost-effective and realistic means available. This is recommended to be initially set out as enhanced management of the use of water from the blow wells to flush brackish water from the affected lakes through existing surface water connections or additional connections. If the lakes remain brackish for an extended period, this will adversely affect their ecological condition and also protract the ecological recovery once freshwater has been returned.

3) **Actively manage a reduction in phosphorus concentrations** - following further understanding of the key sources and pathways of phosphate into the water column of the relevant lakes identified in this study. We recommend consideration of resolving elevated phosphorus concentrations through a combined strategy of immobilising phosphorus currently in the sediment (e.g. the use of Phoslock^{TM}) and then maintaining a low concentration by routine active management of flushing/ dilution using blow wells water or repeat dosing of Phoslock^{TM} when concentrations have risen again towards high levels. We consider this approach to be the least intrusive for the NNR and its users.

In the long term, there are risks associated with the lack of future maintenance of the flood defences on the Humber Estuary. This potentially heightens the risk and frequency of inundation of brackish water from storm surge waters from the Humber Estuary in the future. This potentially compromises any management actions implemented that are tailored to address water quality issues in the short term. The Clay Pits provide supporting habitat for breeding, wintering and passage birds which are SPA and Ramsar features. Macrophytes are an important food source for species such as pochard, tufted duck, wigeon and teal. The Clay Pits are also SSSI features, with the interest being the complex of lakes with variation of salinities from freshwater to brackish.

Contents

1. INTRODUCTION

1.1 IMPROVEMENT PROGRAMME FOR ENGLAND'S NATURA 2000 SITES

Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) are collectively known as Natura 2000 sites and are protected under European legislation for their important wildlife and habitats. In England there are 337 Natura 2000 sites covering 2,077,276 hectares. Whilst many sites are well on the path to recovery, a significant number are not yet in a healthy state and have appropriate management measures in place (termed "favourable condition").

The Improvement Programme for England's Natura 2000 Sites (IPENS) programme developed a strategic approach to achieving favourable condition on England's Natura 2000 sites by reviewing, for each site:

- issues that are impacting on and/or threatening the condition of the site
- which mechanisms (i.e. actions and measures) could be used to address them
- how much it will cost and where the money could come from.

As part of the IPENS programme, Natural England has identified that several of the Humber Clay Pits lakes (from a sample of 16 lakes monitored in 2012/13), lying within the Humber Estuary Special Protected Area (SPA) and Ramsar Site, are failing nutrient targets for phosphate.

Nitrogen and phosphate occur naturally in the environment, including in lakes, and are essential to the growth of plant and animal life. However, when higher than natural levels occur in lakes they can have undesired effects, such as blooms of toxic algae and reduced water quality.

1.2 BACKGROUND

Natural England identified the study area as three flooded Clay Pits within the SPA and Humber Estuary Site of Special Scientific Interest (SSSI)[1]. These are: Ness Pit, Pursuit Pit and Pasture Wharf, which are each failing favourable condition targets for phosphate. The Clay Pits provide supporting habitat for breeding, wintering and passage birds which are SPA and Ramsar features. Macrophytes are an important food source for species such as pochard, tufted duck, wigeon and teal. The Clay Pits are also SSSI features, with the interest being the complex of lakes with variation of salinities from freshwater to brackish.

Ness Pit and Pursuit Pit are located within Far Ings National Nature Reserve (NNR), near Barton-upon-Humber and are managed by Lincolnshire Wildlife Trust (LWT), (Figure 1.1). Pasture Wharf is located ~2.5km to the east of the NNR.

In terms of the appropriate target baseline nutrient concentrations each lake is required to

[1] http://www.sssi.naturalengland.org.uk/citation/citation_photo/2000480.pdf

maintain for it to be of favourable status. Common Standards Monitoring (CSM) Guidance[2] state that the target for these lakes (which are categorized as eutrophic lakes (shallow lakes of high alkalinity) is 0.05mg/l total phosphate and the target for brackish lakes is also 0.05mg/l total phosphate. This is the benchmark that was used in the 2012 to 2013 nutrient study[3]. It is important to note that a threshold of 0.1mg/l total phosphate has been identified for lakes which are just designated for their bird interest[4], which is to prevent a shift to algal dominated states. It is noted that in certain situations, available nitrogen may be a limiting nutrient, although the guidance suggests no nitrogen target. Elevated levels of total phosphate are likely to lead to enhanced algal growth and increased biomass (JNCC 2005)[5]. It is noted that the lakes are not specifically classified as lake waterbodies in the Water Framework Directive (WFD) as they do not meet minimum surface area qualification standards. Consequently no WFD lake nutrient standards apply, and those WFD targets listed in this report are indicative, for comparative purposes, and do not imply compliance or failure with the WFD.

The lakes are on a natural spectrum of salinity and most can be considered brackish. There are various standards for identifying brackish water as opposed to freshwater or full salinity sea water. The JNCC standing water classification[6] identifies brackish as greater than 1.3‰. For comparative purposes the WFD lake standard[7] identifies brackish as greater than 0.6‰. The level of salinity is a driver affecting favourable condition of these SSSI units and the SPA locally.

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[2] Natural England (2008) Common Standards Monitoring: Generic guidance on objective setting and condition assessment Freshwater.

[3] Natural England (2013) Clay Pits Nutrient Sampling, Final Report. Report prepared by JBA Consulting

[4] Clarke, S and Drewitt, A (2004) Applying water quality standards to standing waters designated for bird interest features. Natural England report.

[5] JNCC (2005) Common Standards Monitoring for Ditches. Version March 2005.

[6] The JNCC standard is described, using measurement of conductivity, as 2,000µS/cm². Salinity, reported in parts per thousand (‰), can be derived from conductivity measurement using a conductivity ratio. This is water temperature specific and 2,000µS/cm² at 15°C equates to 1.3‰.

$$R = \frac{C(S,t,p)}{C(35,15,0)} = \frac{C(S,t,p)}{4.2914S*m}$$

R = Conductivity ratio

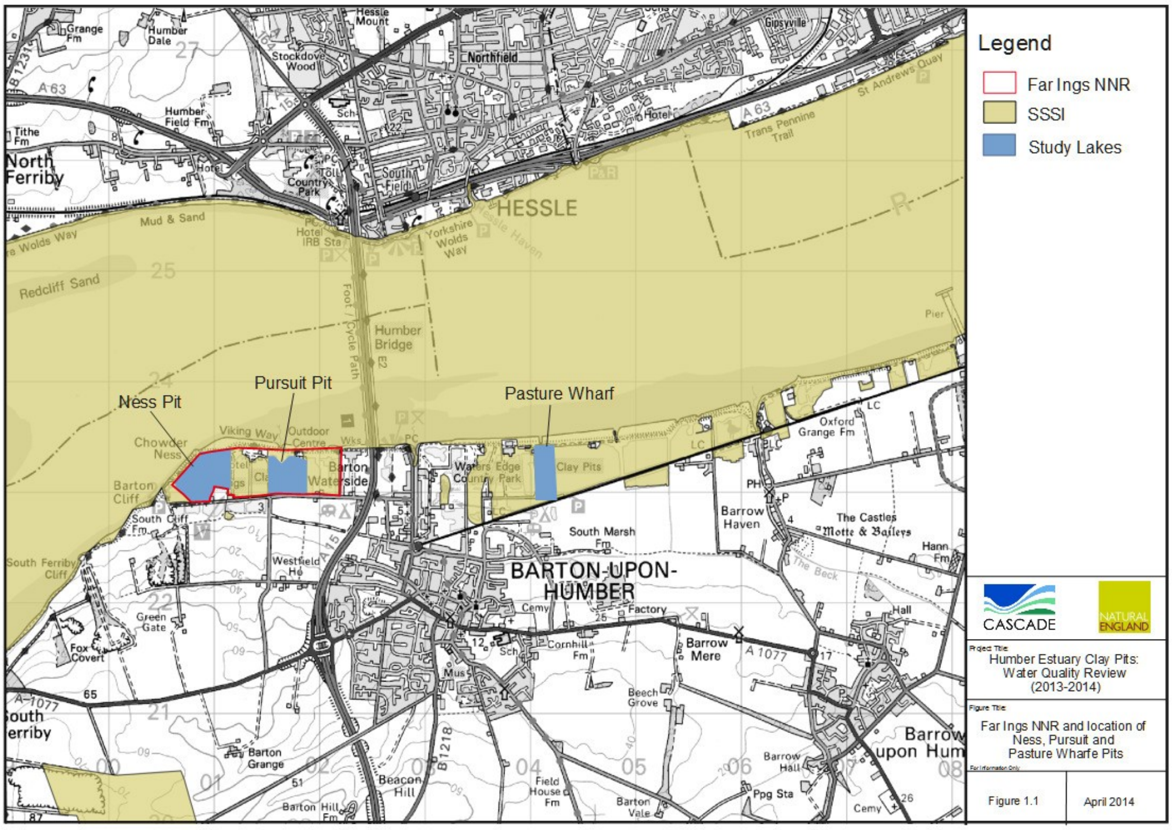
C = Measured electrical conductivity

S = Electrical conductivity of standard seawater

Fofonoff and Millard Jr. (1991). Calculations of physical qualities of seawater. http://cchdo.ucsd.edu/manuals/pdf/91_1/algo6.pdf

[7] The JNCC standard is described, using measurement of conductivity, as 1,000µS/cm². Using the Fofonoff and Millard (1991) equation, at 15°C equates to 0.6‰.

Figure 1.1 Location of Far Ings NNR and the lakes under assessment (Ness, Pursuit and Pasture Wharf)

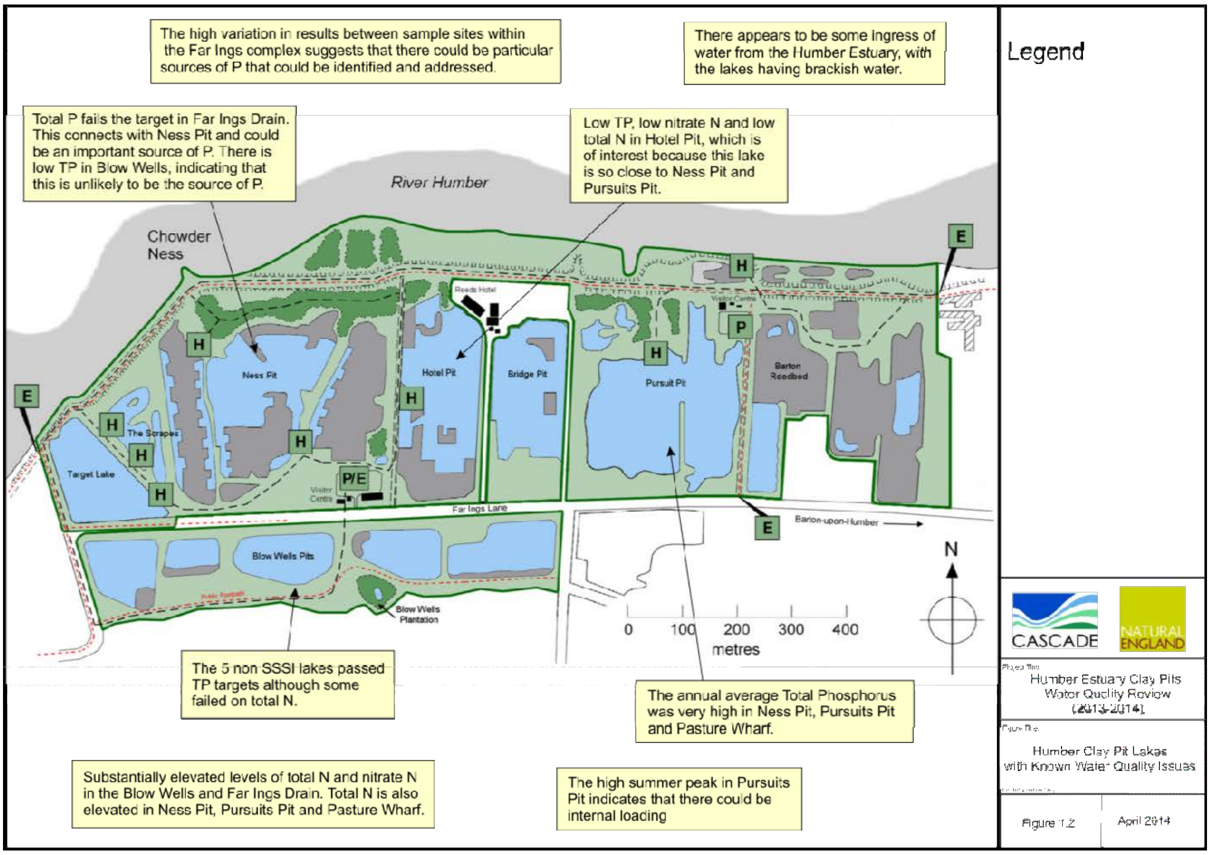


1.2.1 Known Water Quality Issues

A Natural England study in 2013[8] highlighted a number of water quality problems at Ness Pit, Pursuit Pit and Pasture Wharf (based on nutrient monitoring from 2012 to 2013). The key findings from the 2012-2013 study are summarized for the western area in Figure 1.2 and described below for the three lakes relevant to this study. The 2012-2013 study concluded that elevated levels of total phosphate are likely to lead to enhanced algal growth and increased biomass in Ness Pit, Pursuit Pit and Pasture Wharf. Data from the 2012-2013 nutrient study are re-presented in Appendix A.

[8] Natural England (2013) Clay Pits Nutrient Sampling, Final Report. Report prepared by JBA Consulting

Figure 1.2 Humber Clay Pit lakes (western area) with known water quality issues (from the 2012-2013 study)



Ness Pit

The 2012-2013 nutrient study reported that Ness Pit failed to achieve the appropriate CSM and WFD targets for total phosphate, which combined with high concentrations of total nitrogen may be promoting the extent and density of observed mass stands of filamentous algae. Such mass stands may be out-competing the aquatic macrophyte feature of interest in the standing waters. The slightly brackish conditions in Ness Pit may be further limiting macrophyte abundance and diversity.

Despite high total nitrogen levels in Ness Pit, the exceptionally high concentrations of nitrate-nitrogen observed in both the East Pits (now scrapes and referred to in this study as East Ness pit scrapes) were not seen in Ness Pit. Such levels, along with total phosphate concentrations that exceed both CSM and WFD targets, were thought to be encouraging algal blooms. Although such blooms weren't observed during the study period, both the former East Pits returned high concentrations of suspended solids (failing to achieve the WFD target) and higher concentrations of chlorophyll-a than the control (non-SSSI) lakes, suggesting blooms may have been occurring. The extensive stands of reedbeds within both the former East Pits provide further evidence of high nutrient levels. Algal blooms and the scale of reedbeds in both the former East Pits may have limited aquatic macrophyte abundance and diversity by limiting light levels and direct competition.

Pursuit Pit

Pursuit Pit failed to achieve the appropriate CSM and WFD target for total phosphate and exhibited extensive stands of filamentous algae. Pursuit Pit also contained unacceptable levels of suspended solids (failed WFD target), and returned consistently low Secchi Disc readings across the entire duration of the JBA study (August 2012 to April 2013). High chlorophyll-a levels in Pursuit Pit suggest that high concentrations of algae may be contributing to low water clarity issues. The reduced water quality and brackish water (as indicated by elevated conductivity measurements) may well be contributing to limited density and diversity of aquatic macrophytes in Pursuit Pit.

Pasture Wharf

Pasture Wharf exhibits elevated orthophosphate, total phosphate (fails to achieve CSM and WFD targets) and total nitrogen concentrations - the annual average of the first being statistically significantly different to the combined annual mean of the combined control (non-SSSI) lakes. This nutrient enrichment seemingly results in concentrations of chlorophyll-a (indicative of algal blooms) higher than the control (non-SSSI) lakes. Furthermore, Pasture Wharf had high salinity (quote salinity values). These parameters are likely to combine to limit achievement of appropriate macrophyte abundance and diversity.

1.2.2 Additional Environmental Considerations

Groundwater is supplied from the Chalk aquifer, located to the south of the Far Ings NNR, via the blow wells. The 2012-2013 study reported this was having an observable influence on water quality in the lakes due to elevated levels of nitrate in the groundwater. It was suggested that these elevated nitrate levels are associated with agricultural activity on land overlying the aquifer groundwater catchment.

The lakes themselves support a wide range of bird species, including important breeding populations of marsh harrier and bittern, while also comprising one of the principle roosting and feeding areas of the waterfowl distribution in the SPA, Ramsar site and SSSI. The lakes were identified as being in unfavourable condition in 2008 following macrophyte surveys which showed very few macrophytes present compared with the baseline data from 1987. The most recent assessment of the habitat condition as reported in the SSSI Condition Assessment (undertaken in 2011) identified that the component units comprising the Humber Clay Pits are largely in an unfavourable declining condition as a result of the annual average phosphate levels and elevated nitrogen levels.

Pre surge salinity reported in the 2012-2013 nutrient study highlighted there is some influence of salinity at these pits and that inputs of estuarine water could influence macrophyte targets due to impacts on the abundance and diversity to some degree.

Observations on fish populations carried out for the 2012-2013 nutrient sampling study were inconclusive. It concluded that if fish species and/ or population densities were deemed to be a factor limiting appropriate vegetation communities in the Humber Clay Pits, complete biomass removal would not be possible by mechanical fishing methods, for example, electric fishing or netting. The 2012-2013 study recommended that a fuller assessment of the fish population of the lakes should be undertaken.

1.3 SCOPE OF STUDY

The original aim of this study was to monitor water quality and develop phosphate budgets and Lake Management Plans for Ness Pit, Pursuit Pit and Pasture Wharf. However, the scope of the study was altered dramatically when on 5 December 2013 a storm surge caused significant flooding of the east coast, Humber Estuary and Far Ings NNR.

1.3.1 Storm Surge December 2013

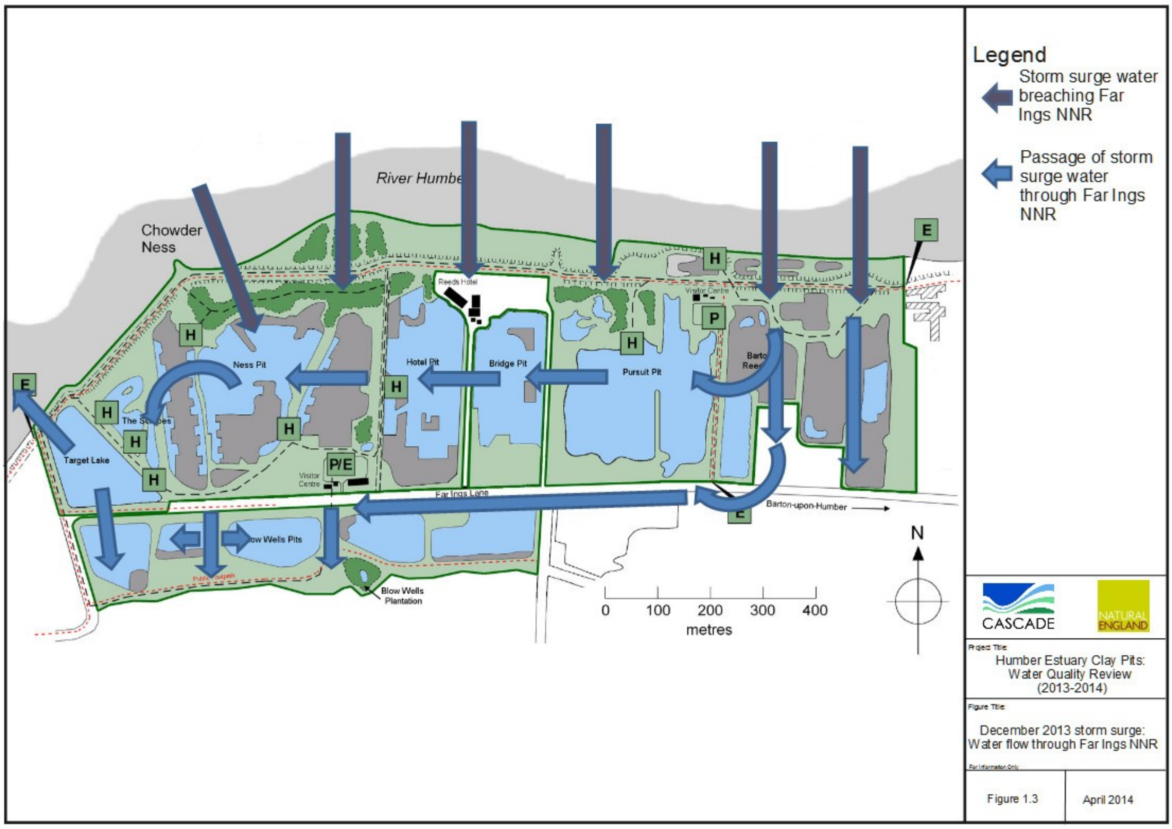
On 5 December 2013, a storm surge measuring ~2m above the predicted high water (measured at Lowestoft, Suffolk[9]) moved up the Humber Estuary and breached the flood banks along the northern edge of the Far Ings NNR, severely flooding a large extent of the NNR. Prior to this event, Far Ings NNR had been overtopped on three occasions (1922, 1953 and 1988). The storm surge was caused by a combination of unusually low pressure, strong onshore winds and high 'spring' tides and was described by the Environment Agency as the highest since 1953[10].

The influx of brackish water from the storm surge inundated the freshwater habitats of the NNR threatening all ecosystems within the nature reserve. In order to evaluate the impact of the storms and the implications for this study, a fieldwork reconnaissance visit was undertaken on 18 December 2013. Figure 1.3 outlines the locations where the NNR was breached and the subsequent directions the flow of water took. All the lakes within the NNR were impacted to varying degrees however Pasture Wharf, outside the NNR, was unaffected.

The storm surge caused significant damage to the flood bank at the northern margin of the NNR, particularly towards Hotel Pit, Bridge Pit and Pursuit Pit. Much of the damage to the flood banks was located on the lee side of the flood banks due to erosion as water overtopped the banks. Apart from localised re-deposition of material eroded from the flood banks and flooding of the new nature reserve visitors centre, no other significant structural damage occurred within the NNR.

[9] Met Office, 2014, Winter storms, December 2013 to January 2014. http://www.metoffice.gov.uk/climate/uk/interesting/2013-decwind Accessed March 2014.
[10] BBC, 2013, Lincolnshire Wildlife Trust storm-hit reserves 'shut down'. http://www.bbc.co.uk/news/uk-england-lincolnshire-25317228 Accessed March 2014.

Figure 1.3 December 2013 storm surge water flow through Humber Clay Pit lakes (western area)



Based on water level data (recorded since 1991), the lakes were at a historically low level (in particular Hotel Pit) immediately prior to storm surge flooding. Given these low levels, the spatial extent of flooding and the potential impacts across the site were lessened as the lakes had capacity to store the storm surge waters that inundated the lakes.

1.3.2 Scope Revisions Following Storm Surge

As a result of the impact of the storm surge, the original scope had to be iteratively replaced with an alternative approach that provided the opportunity to: 1) assess the impact of the storm surge on each lake and the surrounding habitats; and 2) provided a route to recommend a strategy that would aid Natural England's management of the site in terms of recovery to pre surge salinity levels. The storm surge event on the 5 December brought about chemical changes to the study area and increased the volume of water in the impacted lakes, raising their levels by up to 1m. The focus of the study therefore changed to:

- monitor the water quality at 12 selected lakes over four months (between December 2013 and March 2014) in order to determine the changes post storm surge.
- learning how the ecosystems responded in terms of transient environmental conditions.

In addition to water quality measurements at Ness Pit, Pursuit Pit and Pasture Wharf, water column water quality measurements were also taken at East Ness Pit Scrape, West Ness Pit Scrape, New Scrape, Target Lake, Hotel Pit, Blow Wells Pit 3, Blow Wells Pit 4, Blow Wells

Pit 5 and Barton Reedbed. These additional lakes were impacted by the storm surge to varied extents and as such the lakes chosen represent a spectrum and provide a broad understanding of the response and recovery of the lakes.

Additional lake bed sediment samples were taken at Ness Pit, Pursuit Pit and Pasture Wharf for nutrient analysis given there was no understanding of the levels of P contained within the sediments. This approach mirrors the IPENS framework approach and allows integration into that strategic framework permitting:

- identification of the key issues currently impacting on and/or threatening the condition of the site.
- recommendations of mechanisms (i.e. actions and measures) that could be used to address them.

Appendix B provides a timeline for the duration of the monitoring programme of the study (November 2013 to March 2014) and outlines the events, actions and decisions taken by the project team. As a result, the following key outputs were agreed:

- A comparison of water quality before (including the 2012-2013 study) and after storm surge – this is discussed further in Section 4.
- An assessment of the impact of the storm surge and likely recovery of the sites to pre surge salinity levels and to meeting water quality targets – this is discussed further in Section 4 and Section 8.
- Utilising the water quality and sediment data (Section 5) to make recommendations about future management and monitoring of the sites (see Section 8).

1.3.3 Partnership working with Lincolnshire Wildlife Trust

LWT has been consulted throughout this study and has provided both on the ground knowledge and insight with respect to the functioning and management of the lakes within the Far Ings NNR (see Appendix C for further detail). It is acknowledged that the outputs from this study will feed into the future management of the lakes, therefore LWT, as the owners and managers of the NNR, has been actively engaged in the monitoring undertaken and the recommendations (Section 8) outlined in this report.

2. CONCEPTUAL MODEL OF SOURCES AND PATHWAYS OF NUTRIENTS IN THE STUDY AREA

In order to better understand the water and nutrient sources and pathways in the study area and their interactions, a conceptual model of the hydrological system has been developed. It is important to note that certain pathways are only enabled at certain times of year or under certain conditions.

2.1 SOURCES

The key potential sources of nutrients to the study area lakes are:

- **Guanotropy –** Bird faeces (guano) are rich in nitrogen and phosphate and can be important sources of nutrients in standing waters, particularly where large flocks or colonies of birds gather.
- **Blow wells –** the main source of water to the site. Water quality of the groundwater inputs are monitored by the Environment Agency, while LWT monitor flow rates from the aquifer.
- **Lake sediment stores –** serve as a potential sink and source of phosphorus. The sediment may act as a store of phosphorus bound within compounds in the sediment. This phosphorus may become available for biological uptake, especially in summer, as bound P is made more soluble under anaerobic conditions which become more likely to occur in summer.
- **Humber Estuary –** estuaries are sinks for organic matter and nutrients entering both from their catchments and also from the adjacent lands and urban areas and in turn they are sources of such materials to the adjacent coast.
- **Vegetation Management –** there is a potential pathway regarding onsite management of the reedbeds. The management of the designated site included ongoing maintenance in particular the removal of encroaching reeds, which if left unmanaged can block and or bury the surface water connections, however this can lead to reeds falling into the lakes and settling on surface of the lake bed, contributing to elevated concentrations of P being released. The reedbeds stabilize sediments with their roots, support attached algae which take up phosphate from the water and provide cover for zooplankton (which emerge at night to feed on suspended algae).
- **Localised agricultural inputs –** There is only a single potential source of input from agricultural sources, namely a small ditch input to the western blow well lakes (Blow Wells Pit 4), which carries runoff from the agricultural land at the southern edge of Far Ings NNR. No other agricultural inputs to the site are known.
- **Fisheries –** fish has been historically stocked at some of the Clay Pits (e.g. Pursuit). Fish can make phosphorus more bioavailable through feeding and sediment disturbance, however they are not a source of phosphorus unless they are stocked or fed. This potential increase in bioavailable phosphorus is not accounted for in most mass-balance models used to determine nutrient load reductions.
- **Atmospheric deposition –** atmospheric nutrients have recently gained increased attention as significant additional sources of new nitrogen and phosphorus loading to aquatic ecosystems.

- **Underlying aquifer –** elevated concentrations of nitrogen and phosphorus (to a lesser extent) may be attributable to groundwater within the underlying aquifer at Far Ings NNR.

2.2 PATHWAYS

The key potential pathways transferring nutrients into the water column in the study area lakes are:

- **Surface water connections –** there are a number of these within the site (see Figure 2.1) between each of the lakes and the drainage system.
- **Remobilisation from lake sediments –** nitrogen and phosphorus contained within lake sediments can be remobilised. Organic matter in sediments is continuously being decomposed and is released back into the water column as soluble reactive phosphorus and dissolved inorganic nitrogen. Physical and chemical processes can also lead to remobilisation, such as disturbance of sediment through wind mixing, and deoxygenation leading to low redox potential in and near the sediment, causing phosphorus to become more soluble and be released into the lake water.
- **Flooding from the Humber Estuary –** flood events (such as that on the 5th December 2013), can lead to the introduction of sediment and nutrient rich water. These flood events are rare however the risk is widely acknowledged to be increasing due to the impacts of climate change.
- **Surface run-off –** there are very few sources of diffuse pollution around the study area however these could include the use of fertiliser in agriculture and, contaminants from roads. These polluting substances can mobilise and leach into surface waters and groundwater as a result of rainfall, soil infiltration and surface runoff.

2.2.1 Surface water connections

There are a number of surface water connections within the site between each of the lakes. It terms of drainage, water only enters into the Far Ings Drain from the lakes and is not a source of water for the lakes. The movement of water between the lakes is primarily via these. Following a site visit on 24 October 2013, it was concluded that, due to the spread of marginal lake vegetation, the flow rates between surface water connections could not be reliably measured, preventing any further assessment of these connections. Information regarding surface water connections in the study area was provided by LWT and is shown in Figure 2.1.

The main source of water for Ness Pit is an artesian blow well fed by the Chalk aquifer. Pursuit Pit is largely fed from Barton Reedbeds and rainfall. There are also surface water connections between the lakes and Far Ings Drain (Figure 2.1). The only known outflow from the site is situated in Target Lake which drains into the Humber Estuary via a tidally flapped valve. There is a surface water connection between Pasture Wharf and adjacent lakes. In all lakes there may be upward seepage from the underlying chalk aquifer, which is difficult to quantify, and there is most likely seepage from the Humber Estuary, as indicated by the brackish conditions in some of the lakes. The blow well and surface water connections are seen as key sources and pathways in terms of the hydrological regime of the site.

2.2.2 Remobilisation from lake sediments

Sediments play an important role in the retention or release of phosphate in shallow lakes (e.g. Moore et al., 1998[11]; Egemose et al., 2011[12]). Nutrient availability, in particular phosphate, is a key factor for the structure and functioning of lakes, and sediment plays an important role by acting as both a nutrient source and sink (Søndergaard and Bjerring, 2013[13]).

The concentration of phosphate in the lake water is not only determined by the external phosphate loading, but also by internal dynamics. Phosphate could be released from the sediments under anoxic conditions that occur if the lake stratified and oxygen is depleted from the lower layer. It should be noted that anoxia can develop in shallow lakes which don't stratify, as anoxia will probably develop in and at the sediment surface due high microbial respiration. Even when external sources of phosphate have been curtailed by best management practices, the internal recycling of phosphate can continue to support excessive algal growth. The nutrient study 2012-2013 stated the lakes are shallow – no lake is more than 5m deep - and is considered too shallow to stratify. Even if the lakes did stratify, stratification would be for insufficient time for anoxia to develop. It is most likely that the turnover of water results in the release of phosphate from the sediments Søndergaard et al., (2013) carried out an investigative study into the phosphate concentrations within six shallow lakes (between 1.2 and 3 metres deep, which is comparable to the study lakes). In a similar approach to this study, sediment samples were taken from the surface of the lake beds and phosphors concentrations calculated based on three sampling locations. The phosphate concentrations derived ranged from 740 mg/kg to 3,290 mg/kg. Søndergaard et al., (2013) concluded that the external nutrient loading is determining the overall water quality of lakes, but the sediment plays a central role for the internal cycling of phosphorus in the lakes. They considered above 1,000 mg/kg to indicate poor phosphate quality in a waterbody. The study by Søndergaard et al., (2013) concluded that external nutrient loading was driving the overall water quality of lakes, however the sediment was found to be playing a central role for the internal cycling of phosphate in the lakes. Phosphorus release from the sediment into the lake water may be so intense and persistent that it prevents any improvement of water quality for a considerable period after the loading reduction (Søndergaard et al., 2003[14]).

2.2.3 Flooding from the Humber Estuary

The south bank of the Humber Estuary around the Clay Pits lies within Flood Zone 3.

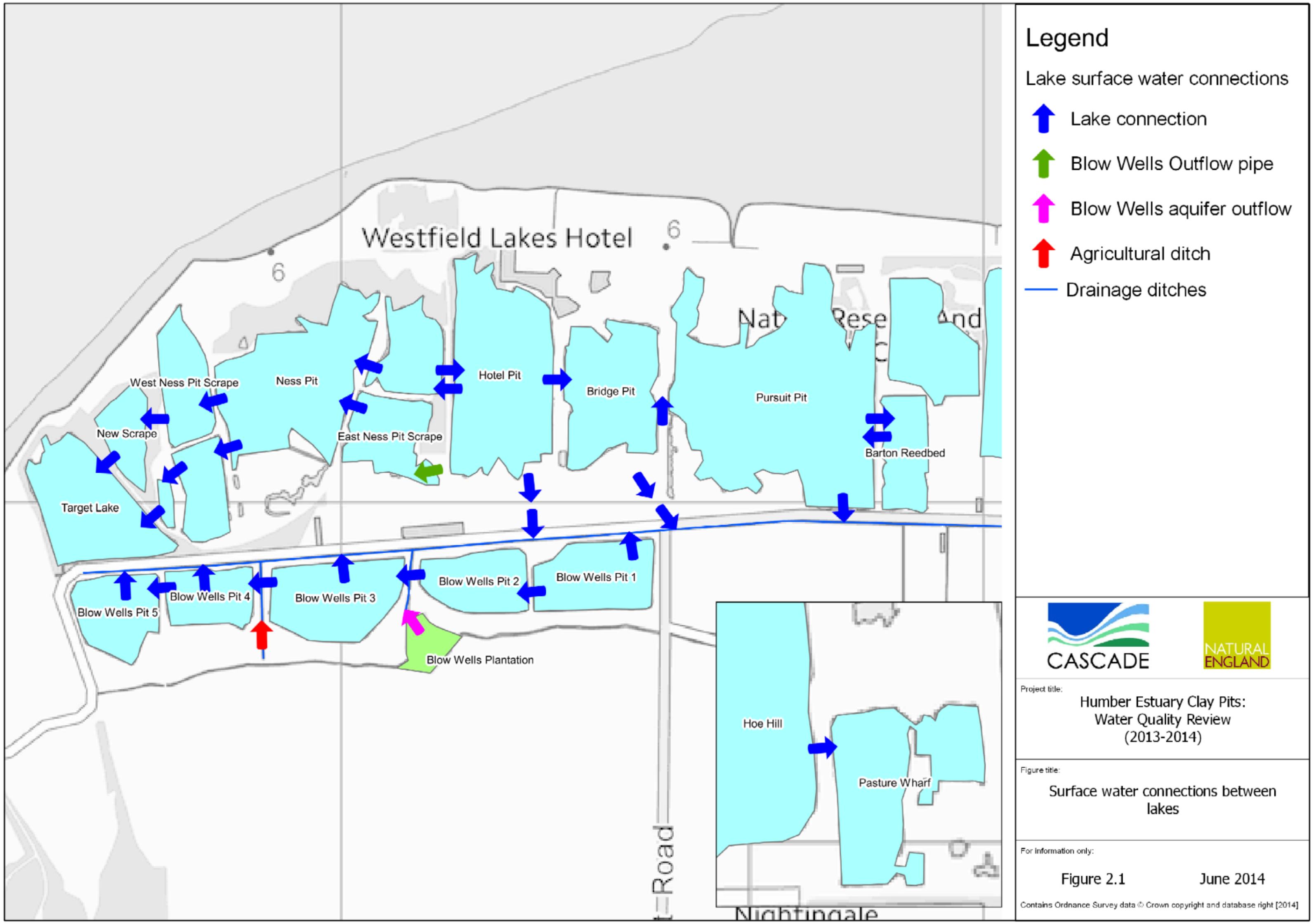
[11] Moore, P. A., K. R. Reddy & M. M. Fisher, 1998. Phosphorus flux between sediment and overlying water in Lake Okeechobee, Florida: Spatial and temporal variations. Journal of Environmental Quality 27: 1428–1439.
[12] Egemose, S., I. de Vicente, K. Reitzel, M. R. Flindt, F. O. Andersen, T. L. Lauridsen, M. Søndergaard, E. Jeppesen & H. S. Jensen, 2011. Changed cycling of P, N, Si, and DOC in Danish Lake Nordborg after aluminum treatment. Canadian Journal of Fisheries and Aquatic Sciences 68: 842–856.
[13] Søndergaard. M, Bjerring. R. and Jeppsen E. 2013. Persistent internal phosphorus loading during summer in shallow eutrophic lakes. Hydrobiologia. 710:95–107.
[14] Søndergaard. M, Jensen. J.P. and Jeppsen E. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia. 506–509: 135–145.

2.3 MONITORING STRATEGY APPROACH

The monitoring strategy undertaken provided a greater understanding of this conceptual model specific to Ness Pit, Pursuit Pit and Pasture Wharf in terms of:

- The impact of water quality at the three lakes
- Sources and pathways of nutrients to the lakes
- The level of phosphate and nitrogen contained within the sediments of lake beds of the lakes, which was previously unknown
- Ground truth potential management actions (see Section 8).

Figure 2.1 Surface Water Connections Known within Humber Clay Pit lakes (western area)



3. MONITORING PROGRAMME

This section documents the monitoring programme undertaken for this study during November 2013 to March 2014. The results of this sampling have been used to inform water quality and lake sediment assessments in Section 4 and Section 5 respectively. The water quality assessment also utilises results from previous monitoring undertaken for Natural England from August 2012 to April 2013 reported in the 2012-2013 study.

3.1 WATER QUALITY MONITORING

Water quality monitoring was undertaken on five occasions, once per month. These can be considered temporally as pre- and post-storm surge monitoring given the change in scope due to the surge (Section 1.3):

- **Pre-storm surge –** 20 November 2013: in-lake sonde measurements and water sampling undertaken at the centre of Ness Pit, Pursuit Pit and Pasture Wharf from a boat.
- **Post-storm surge –** 18 December 2013, 23 January 2014, 19 February 2014 and 20 March 2014: sonde measurements and water column sampling taken from the margin of each of the 12 selected lakes.
- **Blow wells outflow –** In addition to the post-storm surge sampling sites a single water sample was taken from the Blow Wells Outflow (Figure 3.1) on 20 February 2014 as this was the first time the Blow Wells had flown during the study.

Sonde measurements were taken using a handheld YSI 6920v2 sonde to measure a range of determinands in situ (Table 3.1). Water samples were decanted into 1 litre and 250 ml plastic bottles which were then analysed by the National Laboratory Service for a wide range of determinands, including nutrients (Table 3.1).

Table 3.1 Water quality determinands measured and analysed

In situ sonde measurements	Laboratory analysis of water samples
pH	pH
Temperature (°C)	Conductivity (µS/cm)
Conductivity (µS/cm)	Salinity (‰)
Salinity (‰)	Total phosphate (mg/l)
Turbidity (NTU)	Orthophosphate (mg/l)
Dissolved Oxygen saturation (%)	Total nitrogen (mg/l)
Dissolved Oxygen concentration (mg/l)	Total Oxidized Nitrogen (mg/l)
	Ammoniacal Nitrogen (mg/l)
	Nitrate (mg/l)

Table 3.2 provides a list of the sample sites and the water quality monitoring undertaken at each site. Pre-storm surge in-lake monitoring was undertaken in November 2013 with post-storm surge sonde measurements and water samples undertaken from December 2013 to March 2014. The results from the programme of pre-surge monitoring in this study are combined with those undertaken in the 2012/2013 study in Section 4 to provide an extended baseline for interpretation. The locations of individual water quality sample sites used in this

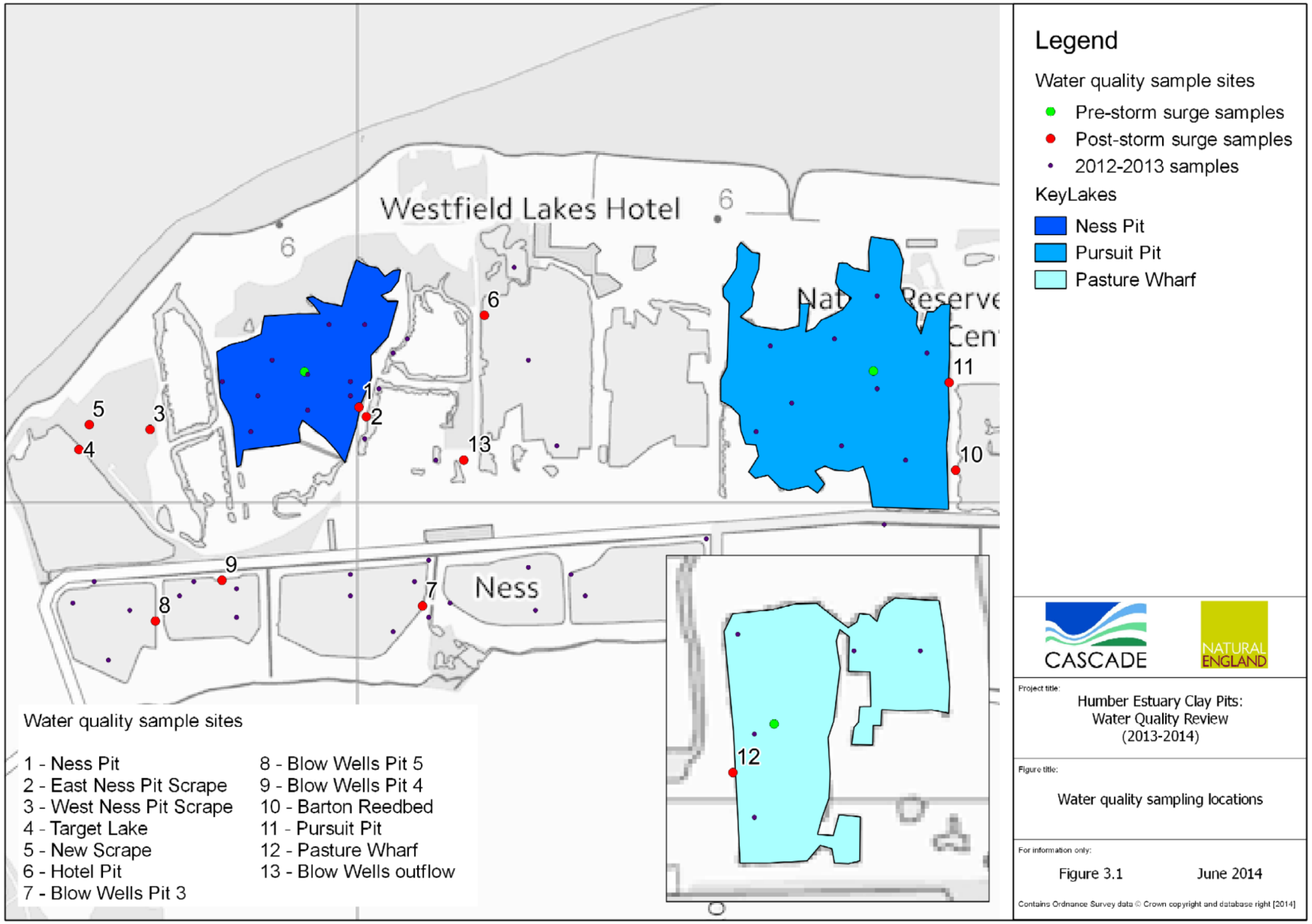
study are shown in Figure 3.1. in additionally to those sites used in the 2012-2013 study.

Table 3.2 Water quality monitoring undertaken (2013-2014)

Lake	Pre-storm surge in-lake monitoring (sonde and water sample)	Post-storm surge sonde measurements	Post-storm surge water samples
Ness Pit	✓	✓	✓
Pursuit Pit	✓	✓	✓
Pasture Wharf	✓	✓	✓
East Ness Pit Scrape		✓	
West Ness Pit Scrape		✓	
Target Lake		✓	
New Scrape		✓	
Hotel Pit		✓	✓
Blow Wells Pit 3		✓	✓
Blow Wells Pit 4		✓	
Blow Wells Pit 5		✓	
Barton Reedbed		✓	✓

Water quality samples taken in November 2013 were taken in the centre of each lake from a boat. After the storm surge, and through discussion with Natural England, in order to sample all chosen lakes within a single site visit and allow analysis of laboratory samples before holding times were exceeded for specific key determinands it was agreed to sample from the margins of each of the lakes, rather than in the centre from a boat. This decision was supported by a review of water quality samples (at Ness Pit, Pursuit Pit and Pasture Wharf) taken for the 2012-2013 study which demonstrated there was very little variation between lake centre and lake margin water quality samples when phosphate and nitrogen levels were compared.

Figure 3.1 Water quality monitoring locations (2013 to 2014)



3.2 LAKE SEDIMENT MONTORING

Lake bed sediment sampling has been undertaken at Ness Pit, Pursuit Pit and Pasture Wharf. This monitoring allowed an understanding of the current nutrient levels (both phosphate and nitrogen) in the lake bed sediments to be obtained.

The determinands analysed from the lake sediment samples taken from each of the three lakes are outlined in Table 3.3.

Table 3.3 Lake sediment quality determinands analysed

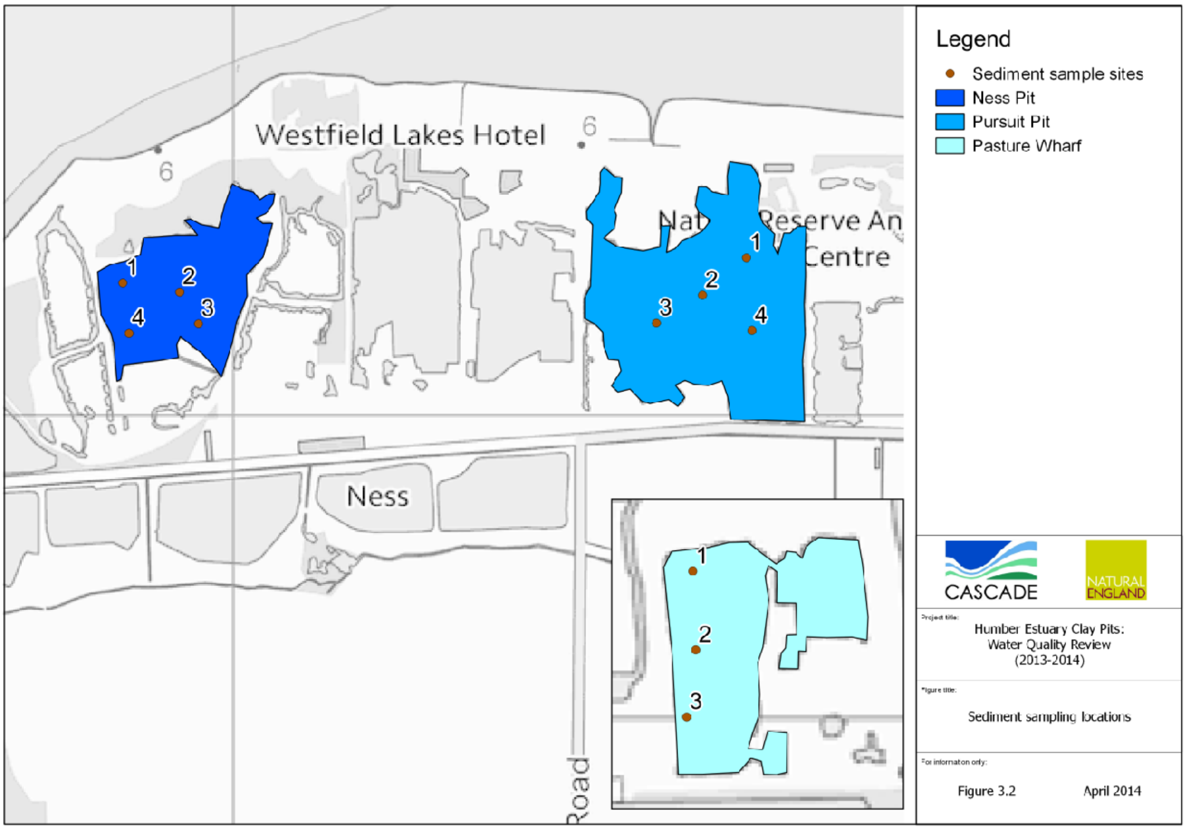
Lake Sediment Determinand	Units
Ammoniacal Nitrogen	mg/kg
Nitrite	mg/kg
Total Oxidized Nitrogen	mg/kg
Orthophosphate	mg/kg
pH	pH units
Aluminium	mg/kg
Calcium	mg/kg
Iron	mg/kg
Total phosphate	mg/kg
Dry Solids at 30°C	%

Using the bathymetry data of the study lakes captured during the 2012-2013 Study, four sample points were selected on each of Ness Pit and Pursuit Pit and three on Pasture Wharf (a total of 11 sample sites). The locations of individual sediment sample sites are shown in Figure 3.2. Sample sites were selected ensure that a range of bed sediments were captured from the deepest to shallowest points across each lake.

Using a boat, the selected sampling point was reached and the boat kept on station by means of an anchor and a GPS reading recorded. A Van Veen grab was lowered over the side of the boat and the sample hauled back to the boat, sieved through a 2mm sieve to remove vegetation and placed into a sample pot. All sampling equipment was washed after sampling prior to moving onto the next sample site. Depth to the lake bed at the sample site was measured and recorded.

Sediment sampling was undertaken on 20 February 2014 and 25 March 2014. Sampling in February was hampered by a combination of high winds (preventing sampling altogether on Pursuit Pit) and thick weed growth on the bed of Ness Pit. Due to the sheltered nature of Pasture Wharf good samples were obtained during the February 2014 visit. Pursuit Pit and Ness Pit were successfully sampled in March 2014.

Figure 3.2 Sediment sampling locations



4. WATER QUALITY ASSESSMENT

This section presents the results from the water quality monitoring (Section 4.1) for each lake in terms of phosphate, nitrogen and salinity, where appropriate. Results are set out as: pre surge; pre-post storm surge recovery; and post storm recovery. A discussion of the results is provided in Section 4.2.

4.1 WATER QUALITY RESULTS

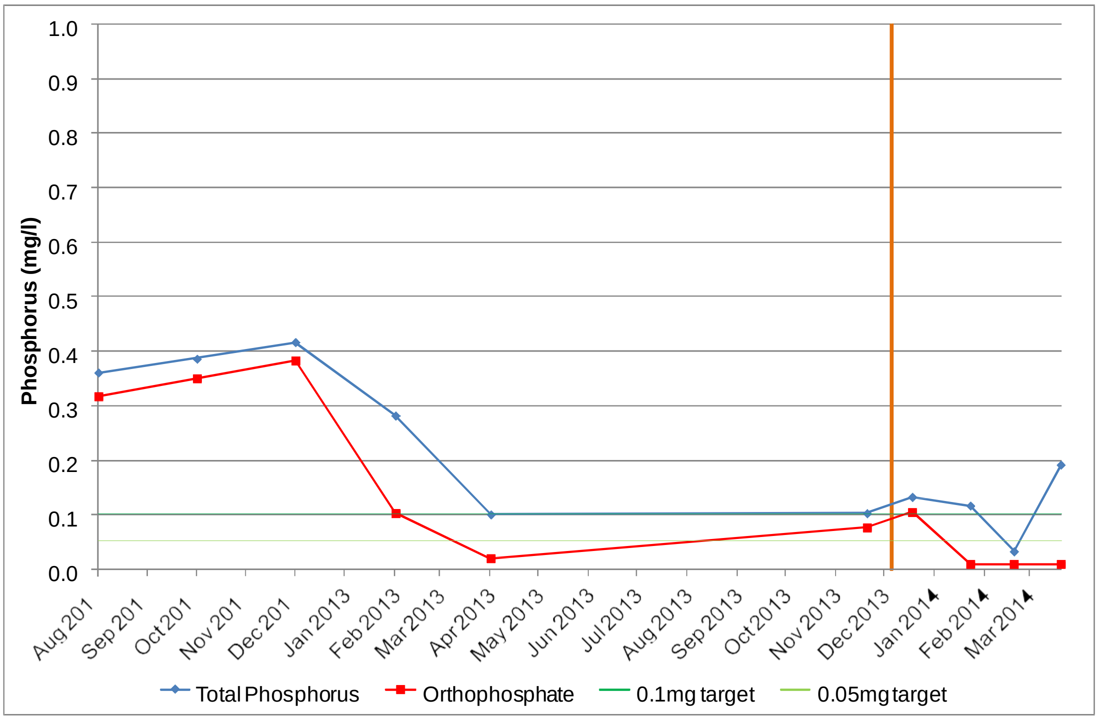
This section presents the results of the water quality monitoring (phosphate, nitrogen and salinity) for Ness Pit (Section 4.1.1), Pursuit Pit (Section 4.1.2), Pasture Wharf (Section 4.1.3). Further data were collected to support the evidence base, including from other lakes within the Far Ings NNR, presented in Appendices D and E. Salinity data for these other lakes are presented in Section 4.1.4.

4.1.1 Ness Pit

Phosphate

Figure 4.1 shows the phosphate concentrations recorded in Ness Pit. The graph includes data collected from the 2012-2013 study and from this study (November 2013 - March 2014). The 2012-2013 study data are reported from the sample point closest to this study's sampling point on Ness Pit. The vertical orange line on Figure 4.1 represents the date of the storm surge.

Figure 4.1 Phosphate concentrations measured in Ness Pit



Pre-storm surge: After gradual increases from 0.36mg/l and 0.32mg/l in August 2012, total phosphate and orthophosphate peaked at 0.42mg/l and 0.38mg/l in December 2012 respectively, their highest values measured during both studies. After December 2012 they total phosphate and orthophosphate declined sharply to 0.10mg/l and 0.02mg/l respectively in April 2013. Values recorded in late November 2013 were similar to the last values recorded in April 2013, with a slight increase in orthophosphate to 0.08mg/l.

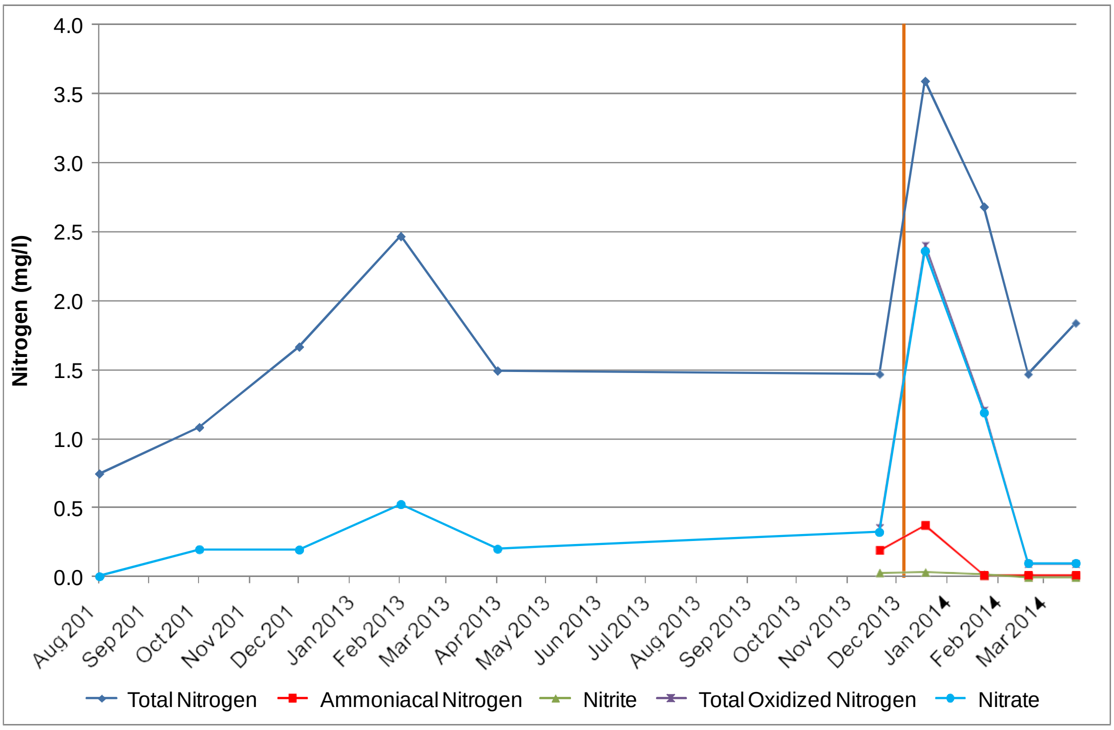
Storm surge: Immediately after the storm surge total phosphate and orthophosphate increased slightly to 0.13mg/l and 0.11mg/l respectively in December 2013.

Post-storm surge: After the surge a rapid decline in orthophosphate was observed from December 2013, with values dropping below the limit of detection from the end of January 2014 onwards. Total phosphate declined slightly in January 2014 to 0.12mg/l and rapidly in February 2014 to 0.03mg/l. However, in March 2014 total phosphate levels increase markedly to 0.19mg/l, concentrations not recorded in Ness Pit for over a year.

Nitrogen

Figure 4.2 shows the concentration for various forms of nitrogen recorded in Ness Pit. The graph includes data as for the phosphate graph (Figure 4.1).

Figure 4.2 Nitrogen concentrations measured in Ness Pit



Pre-storm surge: Total nitrogen and Nitrate rose sharply between August 2012 and February 2013, peaking at 2.5mg/l and 0.5mg/l respectively. This was followed by declines in both nitrogen determinands between February 2013 and April 2013 to 1.5mg/l and 0.4 mg/l respectively.

Storm surge: Immediately after the storm surge values of total nitrogen and nitrate increased significantly to 3.6mg/l and 2.4mg/l respectively, most likely in response to the inundation of saline waters as a result of the storm surge.

Post-storm surge: Between December 2013 and January 2014 total nitrogen and nitrate decreased markedly, with total nitrogen declining to 1.47mg/l (similar to the levels measured before the surge) and nitrate declined to 0.1mg/l. As noted for total phosphate, total nitrogen also displays an increase in concentration in March 2014, increasing from 1.47mg/l to 1.84mg/l.

Salinity

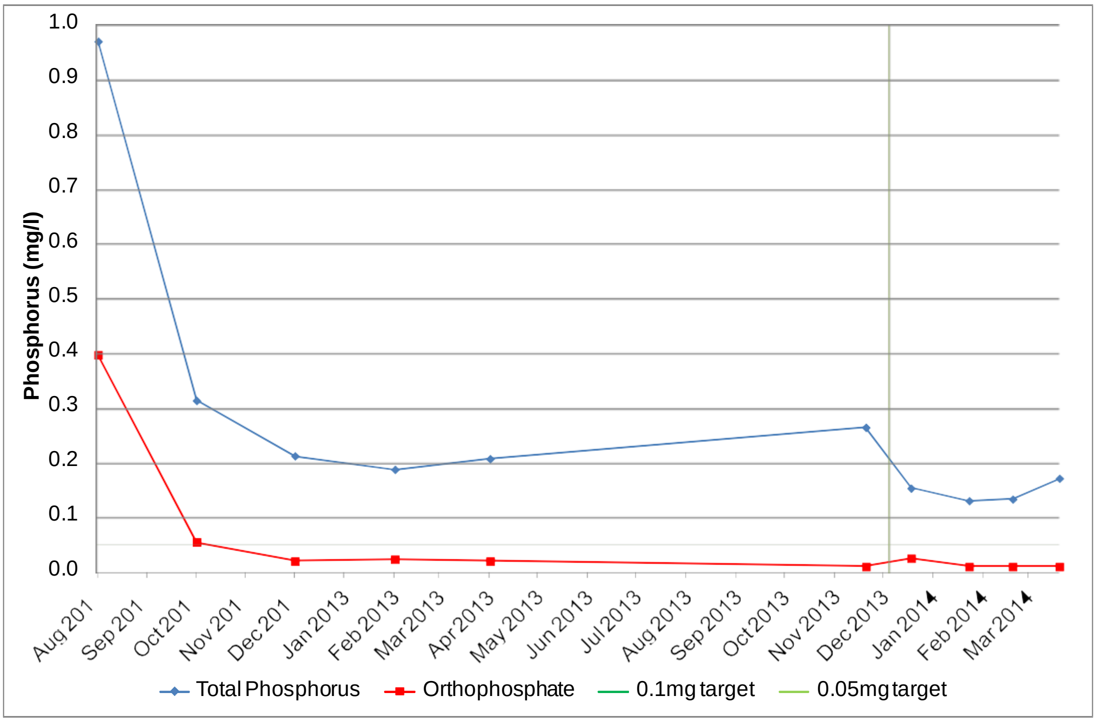
Salinity at Ness Pit was 0.89‰ prior to the storm surge, increasing to 4.84‰ in December in response to the surge. Post storm surge, salinity decreased steadily to 4.0‰.

4.1.2 Pursuit Pit

Phosphate

Figure 4.3 shows the phosphate concentrations recorded in Pursuit Pit. The graph includes data as for the Ness Pit phosphate graph (Figure 4.1).

Figure 4.3 Phosphate concentrations measured in Pursuit Pit



Pre-storm surge: Total phosphate and Orthophosphate declined sharply between August 2012 and December 2012, dropping to 0.21 mg/l and 0.02mg/l respectively. Total phosphate concentrations increased slightly to 0.26mg in December 2013, while orthophosphate remained fairly constant between December 2012 and 2013.

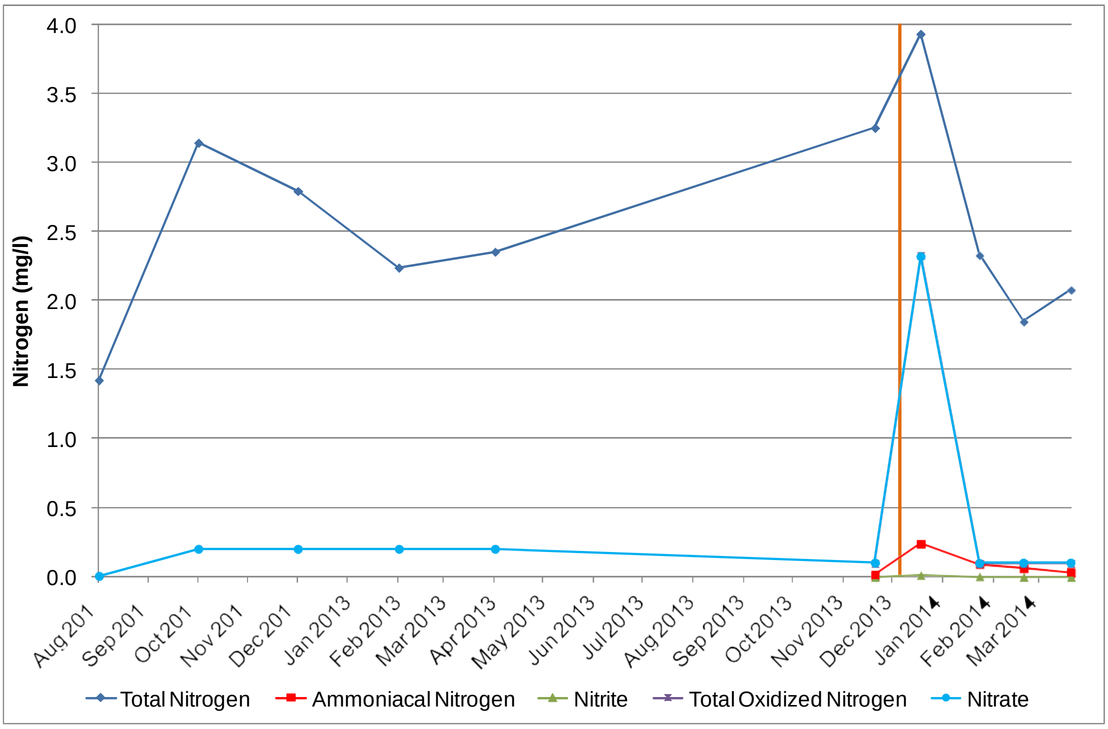
Storm surge: Immediately after the storm surge orthophosphate from 0.01mg/l to 0.025mg/l. In contrast total phosphate declined from 0.26mg/l before the surge to 0.15mg/l after the surge.

Post-storm surge: After the surge total phosphate was shown to remain fairly constant between January and February 2014 and increase in March 2014 to 0.17mg/l. Orthophosphate declined and remained constant around 0.01mg/l (below the limit of detection).

Nitrogen

Figure 4.4 shows the concentration for various forms of nitrogen recorded in Pursuit Pit. The graph includes data as for the Ness Pit phosphate graph (Figure 4.1).

Figure 4.4 Nitrogen concentrations measured in Pursuit Pit



Pre-storm surge: Total nitrogen levels rose from 1.4mg/l in August 2012 to 3.1mg/l in November 2012 before dropping to 2.3mg/l in February 2013. Concentrations rose again between the last recorded value in April 2013 and November 2013, total nitrogen peaking at 3.3mg/l before the storm surge. Nitrate remained relatively constant staying below 0.5 mg/l from August 2012 to November 2013.

Storm surge: After the storm surge, values recorded in December 2013 showed significant increases in total nitrogen and nitrate, with peaks 3.9mg/l and 2.3mg/l respectively. These were the highest peaks measured since monitoring began.

Post-storm surge: After the storm surge total nitrogen and nitrate concentrations dropped rapidly. In January 2014 nitrate declined to 0.09mg/l and remained constant until the end of the monitoring in March 2014. Total nitrogen declined rapidly to 1.85mg/l in February 2014; however this was followed by a slight increase in March 2014 to 2.08mg/l.

Salinity

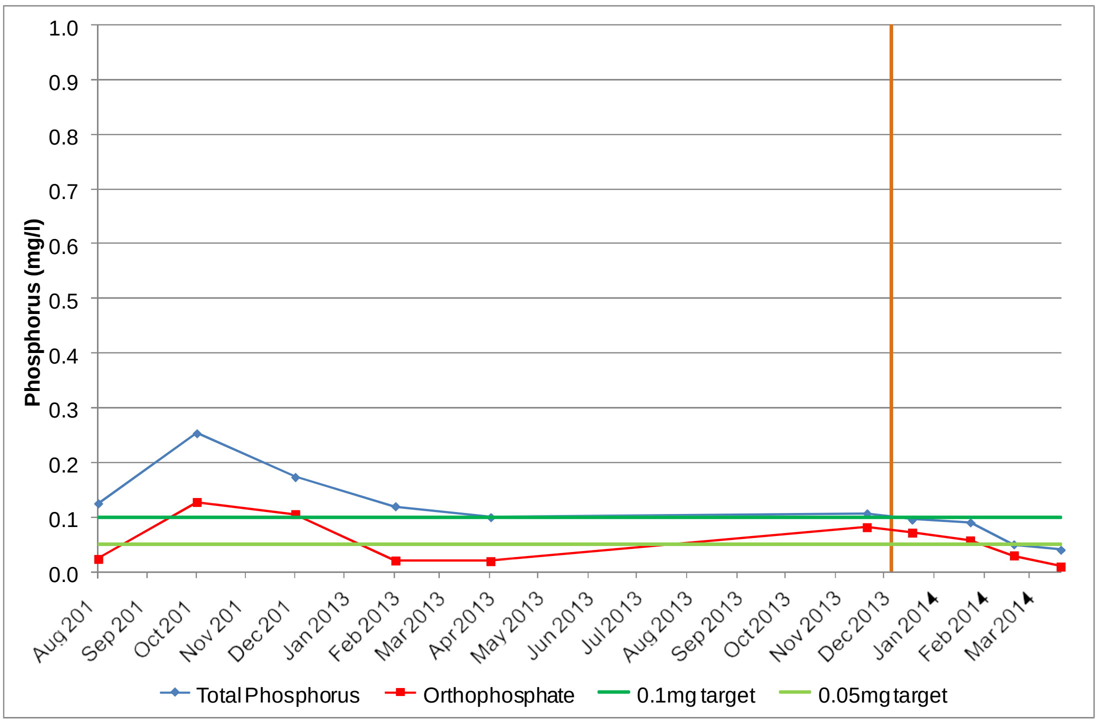
Salinity at Pursuit Pit was measured as 1.44‰ prior to the storm surge, increasing to 9.02‰ in December 2013 in response to the surge. Post storm surge, salinity levels have markedly decreased to 7.28‰, however this is still very high in comparison to salinity levels prior to the storm surge.

4.1.3 Pasture Wharf

Phosphate

Figure 4.5 shows the phosphate concentrations recorded in Pasture Wharf. The graph includes data as for the Ness Pit phosphate graph (Figure 4.1). It is noted that Pasture Wharf was not directly impacted by estuarine water input from the storm surge.

Figure 4.5 Phosphate concentrations measured in Pasture Wharf



Nitrogen

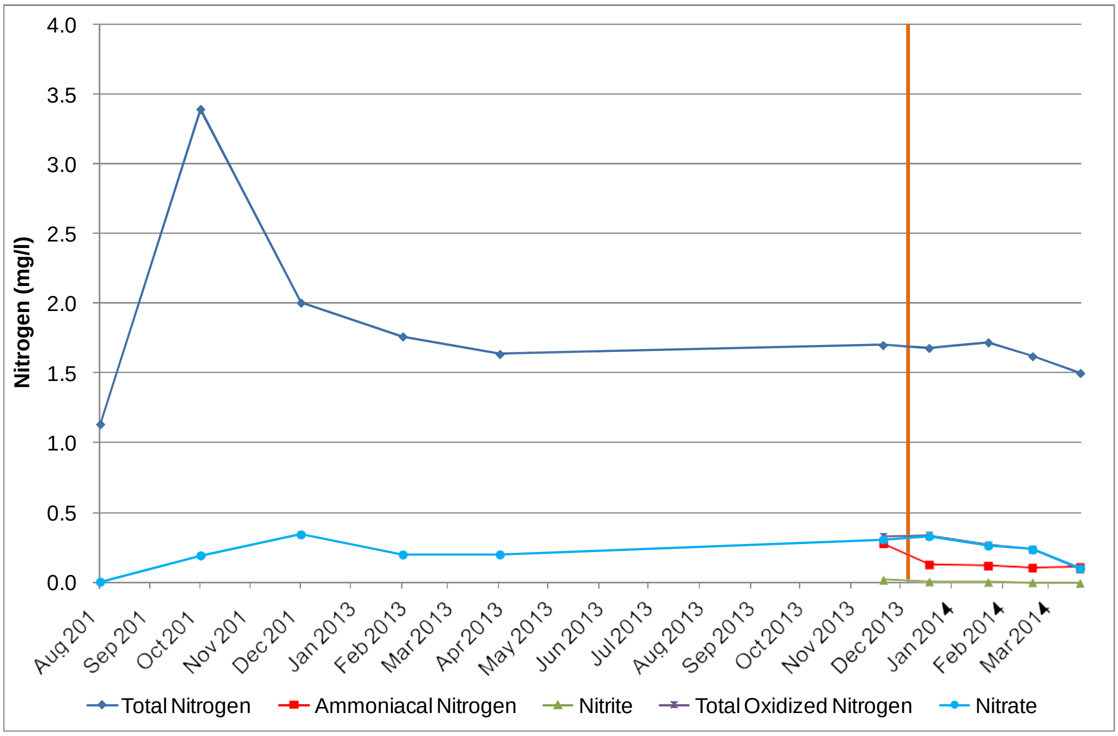
Figure 4.6 shows the concentration for various forms of nitrogen recorded in Pasture Wharf. The graph includes data as for the Ness Pit phosphate graph (Figure 4.1). It is noted that Pasture Wharf was not directly impacted by estuarine water input from the storm surge.

Pre-storm surge: Total nitrogen rose sharply from 1.13mg/l in August 2012 to a maximum of 3.39mg/l in October 2012. Total nitrogen decreased thereafter to 1.64mg/l in April 2013. At the first measurement of this project in November 2013, total nitrogen was slightly higher at 1.70mg/l. Nitrate showed an increase, although the maximum did not occur on the same date (considering the limited dataset), increasing from 0.004mg/l in August 2012 to 0.34mg/l in December 2012. Thereafter nitrate remained constant at 0.20mg/l but had increased slightly to 0.31mg/l in November 2013.

Storm surge: Pasture Wharf was not affected by the storm surge, hence no change in determinands can be attributed to the surge.

Post-storm surge: With the exception of peak of 1.72mg/l in January 2014, total nitrogen declined from November 2013 to 1.50mg/l in March 2014, its lowest measured value with the exception of August 2012. Nitrate followed a similar trend, decreasing to 0.10mg/l in March 2014.

Figure 4.6 Nitrogen concentrations measured in Pasture Wharf



Salinity

Salinity at Pasture Wharf was 1.09‰ prior to the storm surge, increasing to 1.25‰ in December 2013. However, since the lake was not impacted by the storm surge this slight increase cannot be attributed to the surge. Post-storm surge, salinity levels in the lake have increased steadily up to 2.14‰, much higher than recorded before December 2013. It is possible that this may be related to the ingress of brackish estuarine water via groundwater flow or may be due to input of more saline water from adjacent lakes.

4.1.4 Other Lakes

Salinity levels reported in the 2012 nutrient study reported that Hotel Pit was brackish (2.1‰ average) and Hoe Hill Pit freshwater (0.6‰) according to JNCC classification. Salinity measured post surge show Barton Reedbeds to have the highest salinity through the post surge period, dropping from 11.5 to 8.4‰. Lowest salinities, post surge, were at Blow Wells Pits 3 and 5, around 0.6‰. The majority of other lakes (including Hotel Pit) had post-surge salinity ranges of 4.5 to 3.5‰ during this period.

4.2 WATER QUALITY ASSESSMENT DISCUSSION

This section discusses the results of the water quality monitoring in terms of pre storm surge, pre-post storm surge and post storm surge recovery.

4.2.1 Pre surge Storm Surge Discussion

In both Ness Pit and Pasture Wharf phosphate and nitrogen forms were found to increase to a maximum in late summer then decline prior to the storm surge in December 2013. Pursuit Pit is the exception in that phosphate values started high in August and declined prior to the surge, while total nitrogen increased to a maximum, declined slightly then increased prior to the storm surge.

Generally, peaks in phosphate did not correlate with peaks in nitrogen; with nitrogen peaks tending to be offset until later in the year when compared to phosphate. Based on limited data, it does appear that a standard lake nutrient pattern can be observed, where N is lower in summer (when it is being taken up by plant/algal growth in the lake) compared to winter (when N is not taken up by plant/algal growth). The highest P levels are towards the end of summer, when anoxia may be developing, leading to P release from the sediment. This is most clear for Ness Pit.

For phosphate it is apparent that the highest concentrations are in Pursuit Pit (around and above 0.2mg/l), closely followed by Ness Pit and Pasture Wharf (both around 0.1mg/l). For total nitrogen, a similar pattern is present. Pursuit Pit has significantly higher total nitrogen concentrations (around 2.5mg/l - 3.0mg/l) while Ness Pit and Pasture Wharf have much lower concentrations (around 1.5mg/l). This data suggests that prior to the storm surge water quality was lower in Pursuit Pit than Ness Pit or Pasture Wharf.

Salinity pre-surge indicated brackish water, although all values were close to the freshwater-brackish water threshold of 0.5‰. Pursuit Pit had the highest salinity (1.44‰) followed by

Pasture Wharf (1.09‰) and then Ness Pit (0.89‰). Immediately after the storm surge, salinity levels increased dramatically (4.00‰ at Ness Pit and 9.02‰ at Pursuit Pit) as a result of the inundation of the pits with brackish waters from the Humber Estuary.

It must be noted that the temporal coverage of the data collected before the storm surge limited a full understanding of the processes controlling nutrients in each of the lakes. A much higher temporal resolution covering as many seasons as possible would be required for this understanding. The fact that many of the peaks in determinands measured in the 2012-2013 study were not captured by the current study suggests that these peaks may point to controlling factors on water quality, such as seasonality (noting that this study did not include summer monitoring).

4.2.2 Pre and post Storm Surge Comparison

This section discusses the salinity and the general trends in phosphate and nitrogen changes, immediately prior to and immediately after the storm surge.

A comparison between key water quality determinands measured before and after the December 2013 storm surge was undertaken for Ness Pit, Pursuit Pit and Pasture Wharf, to ascertain any key changes in water quality which could be attributed to the surge (Tables 4.1, 4.2 and 4.3).

Ness Pit

Table 4.1 shows the changes between water quality determinands in Ness Pit measured prior to the storm surge in November 2013 and after the storm surge in December 2013.

Table 4.1 Pre and Post storm surge water quality comparisons for Ness Pit

	Pre surge (20 Nov 2013)	**Post surge (18 Dec 2013)**	**% change between Post and Pre surge**
Salinity (‰)	0.89	4.84	450
Turbidity (NTU)	0	17.1	-
Total phosphate (mg/l)	0.103	0.133	29
Nitrate (mg/l)	0.325	2.36	626
Suspended solids (mg/l)	1.5	9.6	540

Key determinands in Ness Pit showed significant increases, with nitrate increasing by 626% and suspended solids by 540% compared to pre-storm surge concentrations. As expected from inundation by brackish estuarine water, salinity also increases markedly by 450%. Total phosphate showed a limited increase only. This is likely due to the lower levels of phosphate in the incoming estuarine water, however it is possible that disturbance of the lake bed sediments (and phosphate stored therein) may account for the increase.

Turbidity also displayed a small increase, however it is likely that values of turbidity and suspended solids would have been much higher in the days immediately following the storm surge (5th December 2013), as between the surge and 18 December 2013, sediment will have had time to settle.

Pursuit Pit

Table 4.2 shows the changes between water quality determinands in Pursuit Pit measured prior to the storm surge in November 2013 and after the storm surge in December 2013.

Table 4.2 Pre and Post storm surge water quality comparisons for Pursuit Pit

	Pre surge (20 Nov 2013)	Post surge (18 Dec 2013)	% change between Post and Pre surge
Salinity (‰)	1.44	9.02	5.26
Turbidity (NTU)	41	18.1	-56
Total phosphate (mg/l)	0.264	0.153	-42
Nitrate (mg/l)	0.1	2.32	2220
Suspended solids (mg/l)	49.5	26.1	-47

Pursuit Pit showed significant increases in nitrate and salinity associated with estuarine water from the storm surge, increasing by 2220% and 526% respectively.

Total phosphate, turbidity and suspended solids all show decreases of between -42% to -56%, despite Pursuit Pit being subjected to most of the flooding from the storm surge. It is anticipated that these reductions could be due to the significant dilution of the water in the lake, especially as the lakes were experiencing historically low water levels prior to the storm surge (Lionel Grooby, pers. comm., 2014). Additionally, the impact of sediment settling out of the water column between the end of the surge and the monitoring which occurred on 18 December 2013 could also explain the reduced turbidity and suspended sediment concentrations.

Pasture Wharf

Table 4.3 shows the changes in water quality determinands in Pasture Wharf measured prior to the storm surge in November 2013 and after the storm surge in December 2013.

Table 4.3 Pre and Post storm surge water quality comparisons for Pasture Wharf

	Pre surge (20 Nov 2013)	Post surge (18 Dec 2013)	% change between Post and Pre surge
Salinity (‰)	1.09	1.25	15
Turbidity (NTU)	0	7.9	
Total phosphate (mg/l)	0.107	0.096	-11
Nitrate (mg/l)	0.307	0.33	8
Suspended solids (mg/l)	1.5	1.5	0

Key determinands in Pasture Wharf showed very little change, which is to be expected as the lake was not impacted by the storm surge.

4.2.3 Post Storm Surge Recovery Discussion

This section outlines how nutrient levels changed up to the 20th March 2014, identifying those parameters that have decreased/ increased since the storm surge (on 5th December

2014) and those determinands where levels have stabilised. This is discussed in the context of salinity and nutrient levels relative to the pre-surge data in order to ascertain if the conditions at the site are recovering.

Salinity

Salinity in Ness Pit and Pursuit Pit has declined from the 18th December 2013 to 20th March 2014, since the storm surge (5th December 2013) but not to or below, pre- storm concentrations which were in the range of 0.89‰ to 1.44‰ (measured in November 2013). Figure 4.7 shows post storm surge salinity for all the lakes - the first post-storm surge monitoring was undertaken on the 18 December 2013. As the inundation of brackish waters subsided from mid-December 2013, the majority of the lakes have seen a reduction or stabilisation in salinity.

Figure 4.7 Post-storm surge salinity comparisons

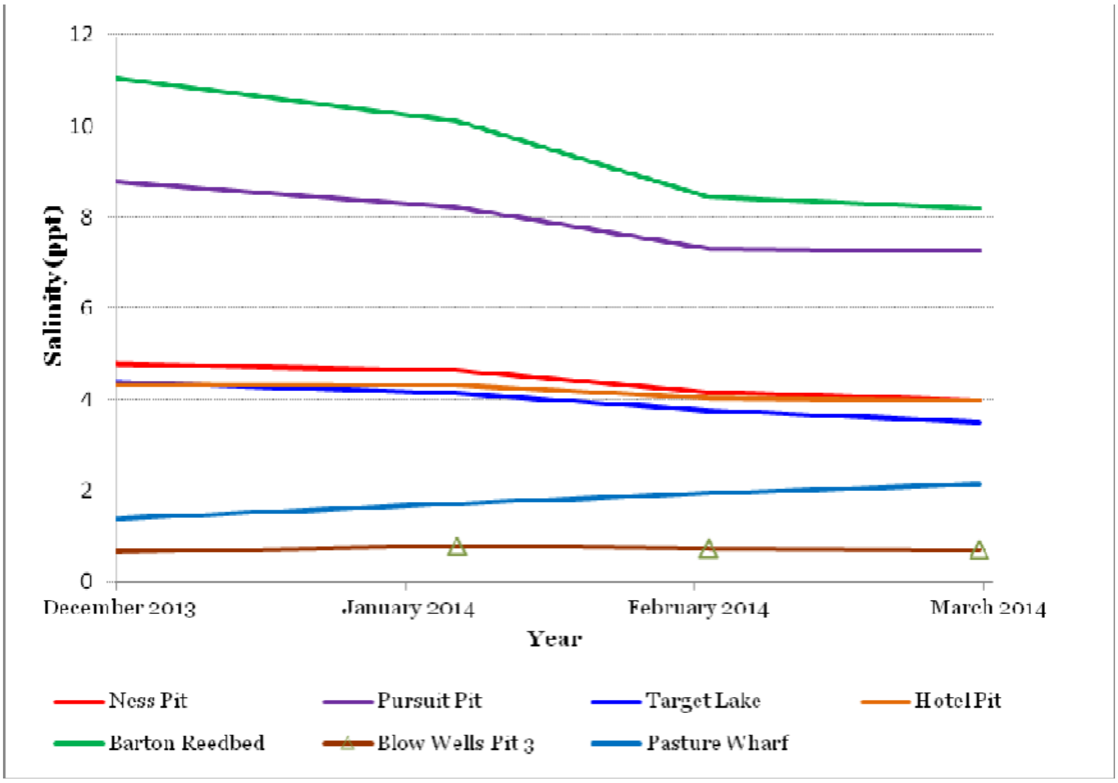


Figure 4.7 shows that both Pursuit Pit and Barton Reedbed had the highest salinity immediately after the storm surge, both of which were directly impacted by the intrusion of brackish water from the storm surge. Salinity dropped dramatically in January 2014 and February 2014 as the storm surge waters drained from the lakes and also from dilution of water in the lakes from other freshwater inputs (e.g. rain). However, salinity had stabilised in both lakes in March 2014, with concentrations between 7.28‰ (Pursuit Pit) and 8.21‰ (Barton Reedbed).

Ness Pit (along with the neighbouring lake of Hotel Pit and Target Lake) had salinity of between 4.35‰ and 4.78‰ immediately after the storm surge. Salinity declined slightly between January 2014 and March 2014, with concentrations ranging between 3.51‰ and

4.00‰.

Pasture Wharf had no direct inundation of brackish water from the storm surge and no changes would be expected as observed in the other lakes. However, since the storm surge there has been a slight increase in salinity from 1.09‰ pre surge, to 1.25‰ in mid-December 2013 (immediately after the storm surge) and 2.14‰ in March 2014. The increasing salinity could be explained by more saline water draining in from Hoe Hill Pit and/ or intrusion of groundwater into the lake from the Humber Estuary. Given the lack of long-term pre-surge data from which to determine the natural salinity regime, it is difficult to conclude whether the increased salinities are a one off event or part of a longer term response.

Nutrients

In Ness Pit, Pursuit Pit and Pasture Wharf phosphate concentrations all generally show declines to, or below, pre-storm concentrations after the storm surge. The exception to this were the final values measured in March 2014 in Ness Pit and Pursuit Pit which displayed sharp increases. This increase may be attributable to mobilisation of phosphate from the lake bed aided perhaps by wind mixing (there were high winds during monitoring). The fact that turbidity measurements in these lakes were elevated on this day and the presence of streaking on the lake surfaces suggests this circulation as a possible cause. Furthermore, elevated phosphate was not noted at Pasture Wharf, despite winds becoming stronger, noting this lake is heavily sheltered behind trees.

A similar response is also noted for nitrogen, with concentrations decreasing after the storm surge and returning to concentrations which are similar to or lower than those prior to the storm surge. Peaks in total nitrogen were also noted in March 2014. It is possible that wind may be a controlling factor with high re-suspension of bed material on the day.

For phosphate the highest concentrations post-storm surge were recorded in Pursuit Pit (around 0.15mg/l), followed by Ness Pit (around 0.1mg/l). Phosphate concentrations in Pasture Wharf were below 0.1mg/l for the period after the storm surge. The data suggested that, although phosphate quality in Pursuit Pit has improved since before the storm surge, this lake still had the lowest quality out of the three lakes.

For total nitrogen, a similar pattern was present. Pursuit Pit had higher total nitrogen concentrations (around 2.0mg/l) while Ness Pit and Pasture Wharf had lower concentrations (around 1.5mg/l). The data showed that phosphate and nitrogen quality in Pursuit Pit was poor prior to the storm surge but has significantly improved after the storm surge, nevertheless the lake still had the lowest quality out of the three lakes.

5. LAKE SEDIMENT ASSESSMENT

This section presents the results (Section 5.1) and discusses the analyses (Section 5.2) from lake sediment samples taken from Ness Pit, Pursuit Pit and Pasture Wharf, between February and March 2014.

5.1 LAKE SEDIMENT RESULTS

5.1.1 Ness Pit

The results of the analysis of lake bed sediment samples for Ness Pit are presented in Table 5.1. Figure 3.2 illustrates the location where each of these samples was taken.

Table 5.1 Ness Pit bed sediment sample analyses (25 March 2014)

Determinand	Unit	Sample location			
		1	2	3	4
Depth to lake bed	M	3.54	2.79	1.72	3.54
Ammoniacal Nitrogen	mg/kg	<8	<10	<10	<8
Nitrite	mg/kg	<0.4	<0.6	<0.6	<0.4
Total Oxidized Nitrogen	mg/kg	<10	<20	<20	<10
Orthophosphate	mg/kg	105	73.1	45	82.2
pH	pH units	7.98	8	8.03	8.02
Aluminium	mg/kg	33,100	27,000	20,400	30,300
Calcium	mg/kg	50,800	53,500	79,600	47,400
Iron	mg/kg	46,800	38,400	32,300	44,300
Total Phosphate	mg/kg	1,420	1,280	1,010	1,350
Dry Solids at 30°C	%	24.3	17.6	15.6	23.6

Samples taken from Ness Pit were found to be generally dark grey to black muddy homogeneous sediments with infrequent buff-coloured patches. Few organic fragments were present in the samples, however there was abundant fine linear leaved macrophytes extracted at each site (which were sieved out of the final sample). These macrophytes were alive, and using evidence of accumulation of the macrophytes on the Van Veen grab sampler, are predicted to thickly blanket the lake bed at all sites sampled.

5.1.2 Pursuit Pit

The results of the analysis of lake bed sediment samples for Pursuit Pit are presented in Table 5.2. Figure 3.2 illustrates the location where each of these samples was taken.

Table 5.2 Pursuit Pit bed sediment sample analyses (25 March 2014)

Determinand	Unit	Sample location			
		1	2	3	4
Depth to lake bed	M	3.04	1.95	1.45	2.24
Ammoniacal Nitrogen	mg/kg	<10	<10	<9	<10
Nitrite	mg/kg	<0.5	<0.6	<0.4	<0.5
Total Oxidized Nitrogen	mg/kg	<10	<20	<10	<20
Orthophosphate	mg/kg	89.1	54.6	63.5	93.2
pH	pH units	7.77	7.73	7.87	7.78
Aluminium	mg/kg	31,900	26,400	20,700	29,700
Calcium	mg/kg	28,600	31,100	41,800	24,100
Iron	mg/kg	49,100	43,000	38,500	45,600
Total Phosphate	mg/kg	1,660	1,340	1,190	1,640
Dry Solids at 30°C	%	20.9	15.5	23	18.2

Samples taken from Pursuit Pit were found to be generally dark grey to black silty homogeneous sediments with infrequent buff-coloured patches. The sample from Site 4 was generally a dark buff-colour. The particle sizes of the sample from Site 3 were slightly coarser than the samples from the other three sites and included some shelly fragments. There were abundant organic fragments, mostly reeds, with some fine linear leaved macrophytes sampled, particularly at Site 2.

5.1.3 Pasture Wharf

The results of the analysis of lake bed sediment samples for Pasture Wharf are presented in Table 5.3. Figure 3.2 illustrates the location where each of these samples was taken.

Table 5.3 Pasture Wharf bed sediment sample analyses (20 February 2014)

Determinand	Unit	Sample location		
		1	2	3
Depth to lake bed	M	2.68	1.68	1.98
Ammoniacal Nitrogen	mg/kg	14.6	24.7	15.1
Nitrite	mg/kg	<0.5	<0.6	<0.7
Total Oxidized Nitrogen	mg/kg	<10	<20	<20
Orthophosphate	mg/kg	12.7	11.3	14.6
pH	pH units	7.76	7.73	7.71
Aluminium	mg/kg	31,000	16,700	24,700
Calcium	mg/kg	35,300	134,000	62,100
Iron	mg/kg	45,100	28,600	35,900
Phosphate	mg/kg	1,000	963	1,160
Dry Solids at 30°C	%	20.7	15.8	13.6

Samples taken from Pasture Wharf were found to be generally dark grey to black muddy homogeneous sediments. Some coarse sediment particles were noted at Site 1 while abundant white shelly fragments were recorded at Site 2. Organic fragments and macrophytes were very infrequent.

5.2 LAKE SEDIMENT ASSESSMENT DISCUSSION

Table 5.4 provides a comparison between the phosphate concentrations measured in the bed sediments sampled in each of the three lakes. Natural England does not have standards for categorising lake sediment quality. As highlighted in Section 2.2.2, the Søndergaard et al., (2013) value of 1,000 mg/kg has been considered to indicate poor phosphate quality in a standing waterbody in this study.

Table 5.4 Comparison of measured bed sediment phosphate concentrations (mg/kg) between lakes

Ness Pit	Pursuit Pit	Pasture Wharf
Site 1: 1,420	Site 1: 1,660	Site 1: 1,000
Site 2: 1,280	Site 2: 1,340	Site 2: 963
Site 3: 1,010	Site 3: 1,190	Site 3: 1,160
Site 4: 1,350	Site 4: 1,640	

The data show that phosphate concentrations range between 963-1,660 mg/kg. The highest measured levels of phosphate are found in Pursuit Pit, while the lowest are found in Pasture Wharf. Median total phosphate concentrations at Ness Pit, Pursuit Pit and Pasture Wharf are 1,315 mg/kg, 1,490 mg/kg and 1,000 mg/kg respectively. All but one value is above the 1,000 mg/kg value considered by Søndergaard et al., (2013) to indicate poor phosphate quality in a standing waterbody. Median total phosphate results indicate that Pursuit Pit has the highest sediment TP concentrations (1,490 mg/kg) followed by Ness Pit (1,315 mg/kg). Although one of the individual values measured in Pasture Wharf exceeds 1,000 mg/kg the other two values are equal or slightly less. This is reflected in the median total phosphate of 1,000 mg/kg. This suggests that Pasture Wharf is, generally, at the threshold of having good phosphate quality but however they are not significantly lower than the other two lakes and any significant addition of phosphate could cause the threshold to be exceeded.

The phosphate concentrations within the lake sediments fall within the range reported by Søndergaard et al., (2013) as 740 mg/kg to 3,290 mg/kg. As highlighted in Section 2.2.2, Søndergaard et al., (2013) concluded that the external nutrient loading is determining the overall water quality of lakes, but the sediment plays a central role for the internal cycling of phosphorus.

It is possible that wind action causing circulation in the lakes e.g. as Langmuir circulation, has caused some disturbance of the bed and entrainment of phosphate rich bed sediments into the lake water column. This internal cycling of phosphate in the lakes could be likely as peaks in total phosphate are visible (from the water quality sampling) for 20 March 2014, when winds were noted to be at their strongest during any of the sampling periods. Phosphate in Pasture Wharf was not elevated in March 2014 and supports the assertion on the influence of the wind, given that Pasture Wharf is a smaller and more sheltered site.

6. PRELIMINARY GUANOTROPHY ASSESSMENT

Bird faeces (guano) are rich in nitrogen and phosphate and can be important sources of nutrients in standing waters, particularly where large flocks or colonies of birds gather. This section provides an overview on guanotrophy and the linkages it has to elucidating issues with regard to water quality. The derivation of bird populations for the lakes is described, and the development on how estimations of phosphate and nitrogen contributions from birds where calculated, followed by the results of the preliminary assessment and a summary of the findings.

6.1 OVERVIEW ON GUANOTROPHY AND WATER QUALITY

Birds are important components of conservation and are important natural contributors of nutrients to lakes (Manny et al, 1994[15]) however these inputs are sometimes highly damaging to the sites where they are conserved (Chaichana et al, 2010[16]). Bird faeces (guano) are rich in nitrogen and phosphate and can be important sources of nutrients in standing waters, particularly where large flocks or colonies of birds gather. Potentially of great significance are the problems of switching of shallow lakes from macrophyte-dominated communities to phytoplankton-dominated communities by bird flocks which are held well above the natural carrying capacity of a lake (Moss et al, 1996[17]). Guano inputs can create a conflict in terms of conservation management. On the positive side birds are important in they provide important contributions to the nutrient recycling within lakes. However these inputs can have a negative impact as they can lead to elevated concentrations of nitrogen and phosphate, as a result of management actions that either conserving a particular species of bird or change the habitat leading to a shift in populations. The key issue is to find a balance that is aligned to the aspirations for conservation management at the designated site.

The study area lakes are utilised extensively by birds and the nutrient load from bird guano was estimated for consideration in comparison to other nutrient sources. Such load estimates are difficult to calculate because they depend on a number of factors; for example, diurnal and seasonal variation in the bird population, variation in bird diet, and variation in volumes of guano produced by different bird species and estimations of guano nutrient load. To date no lake management plans are in place and as a result of the storm surge, these will require future consideration of guanotrophy as a contributory source of phosphate given that the Blow Wells and lake bed sediment (screened in to the scope of the study) do not appear to be the sole contributors. A more systematic investigation of sources and pathways may be required. The study outlines an approach and preliminary assessment of guanotrophy inputs into the lakes at Far Ings NNR, which could be expanded in order to compliment an evidence-based management approach.

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[15] Manny, B.A., W.C. Johnson and R.G. Wetzel. 1994. Nutrient Additions by Waterfowl to Lakes and Reservoirs: Predicting Their Effects on Productivity and Water Quality. Hydrobiologia 279/280:121-132.

[16] Chaichana, R., Leah, R., Moss, B.2010. Birds as eutrophicating agents: a nutrient budget for a small lake in a protected area. Hydrobiologia 646:111-121-132.

[17] Moss, B., J. Madgwick & G. Phillips, 1996. A guide to the restoration of nutrient- enriched shallow lakes. Environment Agency & Broads Authority, Norwich.

6.2 DERIVING THE KEY BIRD POPULATIONS

Many bird species have been identified by LWT as using the lakes at Far Ings NNR. Table 6.1 lists the species recorded and categorizes them according to comparative size.

Table 6.1 Bird species resident or wintering at Far Ings NNR

Small birds	Medium birds		Large birds
Bearded Tit	Bittern	Mallard	Great Black-backed Gull
Greenshank	Common Tern	Moorhen	Canada Geese
Pied Wagtail	Coot	Pochard	Cormorant
Reed Warbler	Fieldfare	Redshank	Herring Gull
Sand Martin	Gadwall	Shoveler	Mute Swan
Sedge Warbler	Goldeneye	Snipe	Blacked Headed Gull
Starling	Golden Plover	Teal	Common Gull
Swift	Grebe	Tufted Duck	Curlew
	Lapwing	Water Rail	Grey Heron
			Greylag Goose
			Lesser Black Backed Gull
			Marsh Harrier

Using LWT bird count data that spans 2001 to 2012 (LWT bird count data prior to 2007 were not available), it was possible to ascertain, for each species, the maximum count of birds per month for each year. From consideration of the potentially most significant species based on number, residence time, habit and defecation rate, seven species of bird have been selected for the preliminary guanotropy assessment. These species were chosen as the most frequent users of Ness Pit and Pursuit Pit for nesting and breeding. The bird count data was collated to calculate the summary statistics for each of the following bird species:

- Greylag Goose
- Canada Goose
- Mallard
- Coot
- Tufted Duck
- Teal
- Pochard

In terms of their influence on nutrient loadings, birds can be sub-divided into those that are responsible through their feeding habits for nutrient imports; external foragers, and those that recycle nutrients within the system; internal foragers. It is only the former that are of interest to this study. Carnivorous external foragers mainly comprise gulls. Cormorants, terns, herons, grebes and egrets are primarily internal foragers (Hahn et al, 2007[18], Chaichanna et al, 2010). Herbivorous birds tend to forage externally to varying extents.

[18] Hahn S, Bauer S and Klaassen M (2007). Estimating the contribution of carnivorous waterbirds to nutrient loading in freshwater habitats. Freshwater Biology, Vol. 52. 2421-2433.

6.3 ESTIMATING BIRD NUTRIENT INPUTS

Table 6.2 lists the birds (identified in Section 6.2) with their respective estimated population sizes[19]. These birds are considered significant contributors due to their number and behaviour.

The LWT bird count data were used to estimate overall contributions of phosphate from birds, using loading rates established by Manny et al, (1994), Weber et al (2006[20]), Hahn et al (2007 and 2008[21]) and Chaichanna et al, (2010). Bird data were converted to mean numbers of bird residence days per year (BRD/yr) in order to calculate annual, summer and winter phosphate loadings (kg P/day). Winter birds were assumed to be resident from November to February (120 days) and Summer birds were assumed to be resident from May to August (123 days).

Table 6.2 Maximum number of birds counted (in any given month) per year (excluding 2007, data not available)

Overall	2001	2002	2003	2004	2005	2006	2008	2009	2010	2011	2012
Canada Goose	2,240	4,942	3,512	1,391	939	361	175	156	494	603	182
Coot	254	857	1,227	824	580	860	1,390	1,436	1,675	1,333	1,883
Greylag Goose	356	2,031	2,727	1,803	952	684	780	1,775	1,333	1,931	1,131
Mallard	888	62	65	73	35	64	41	46	93	83	32
Pochard	452	613	854	514	343	439	230	307	660	298	381
Teal	394	916	3,138	1,329	339	378	452	254	314	224	556
Tufted duck	311	726	1,177	608	301	359	219	172	468	307	459

6.4 PHOSPHATE LOADING ASSESSMENT

Bird diet, bird size, population size, and lake usage pattern affect whether they are significant contributors of guano. For the period 2001 to 2012, Greylag Goose, Canada Goose, Mallard, Coot, Tufted Duck, Teal and Pochard collectively contributed on average 1,020 kg P/year (11,230 kg P in total across the eleven years). The greatest annual phosphate loading occurred in 2003 (2,271 kg P), with the lowest annual phosphate loading (588kg P) in 2005. Greylag Geese, Canada Geese and Coot (over 2,000kg P/yr) were the greatest contributors of phosphate, with dabbling ducks collectively providing contributions between 265 kg P/yr and 1,483 kg P/yr.

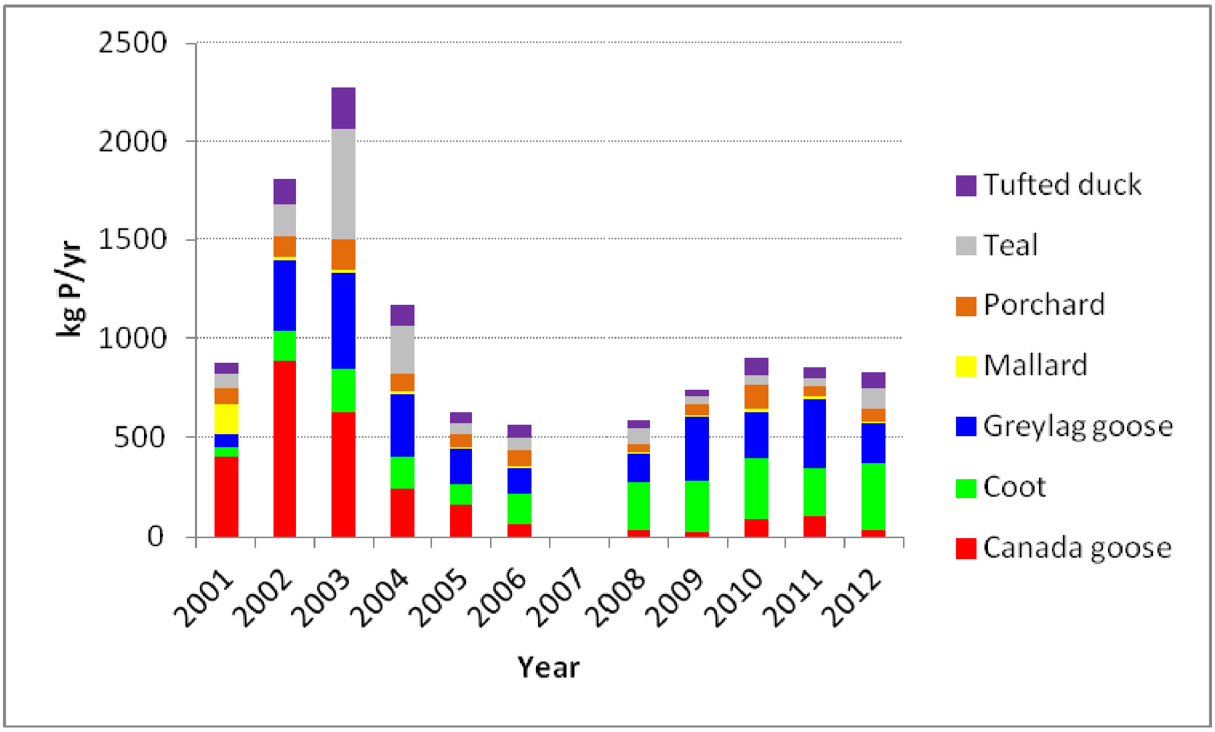
Figure 6.1 shows the phosphate contributions from birds between 2001 and 2012. The data suggest that the phosphate nutrient load was driven by an influx of Canada Geese in 2002 and 2003, with additional contributions from Coot and Greylag Geese in 2003. After 2004, the phosphate nutrient load from all bird species does not exceed 350 kg P/yr. This is considered as a significant input compared to other guanotrophy investigations undertaken

[19] Collated from the LWT dataset covering the entire spatial extent of the Far Ings NNR, however it is noted that most observations mostly came from Ness and Pursuit Pit.
[20] Weber, D., Drizo, A., Twohig, E., Bird, S. and Ross, D. 2006. Upgrading Constructed Wetlands Phosphorus Reduction from a Dairy Effluent using EAF Steel Slag Filters. Water Science and Technology.
[21] Hahn S, Bauer S and Klaassen M (2008). Quantification of allochthonous nutrient input into freshwater bodies by herbivorous waterbirds. Freshwater Biology, Vol. 53, 181-193

in the UK (discussed further in Section 6.6).

The current trend suggests that the phosphate nutrient load is driven by Coot and Greylag Geese. In comparison, dabbling ducks (including Mallard, Pochard, Teal and Tufted Duck) have never contributed more than 561 kg P/yr. Contributions from Mallard are the lowest, having never exceeded 159 kgP/yr.

Figure 6.1 Phosphate nutrient load (kg P/yr) between 2001 and 2012

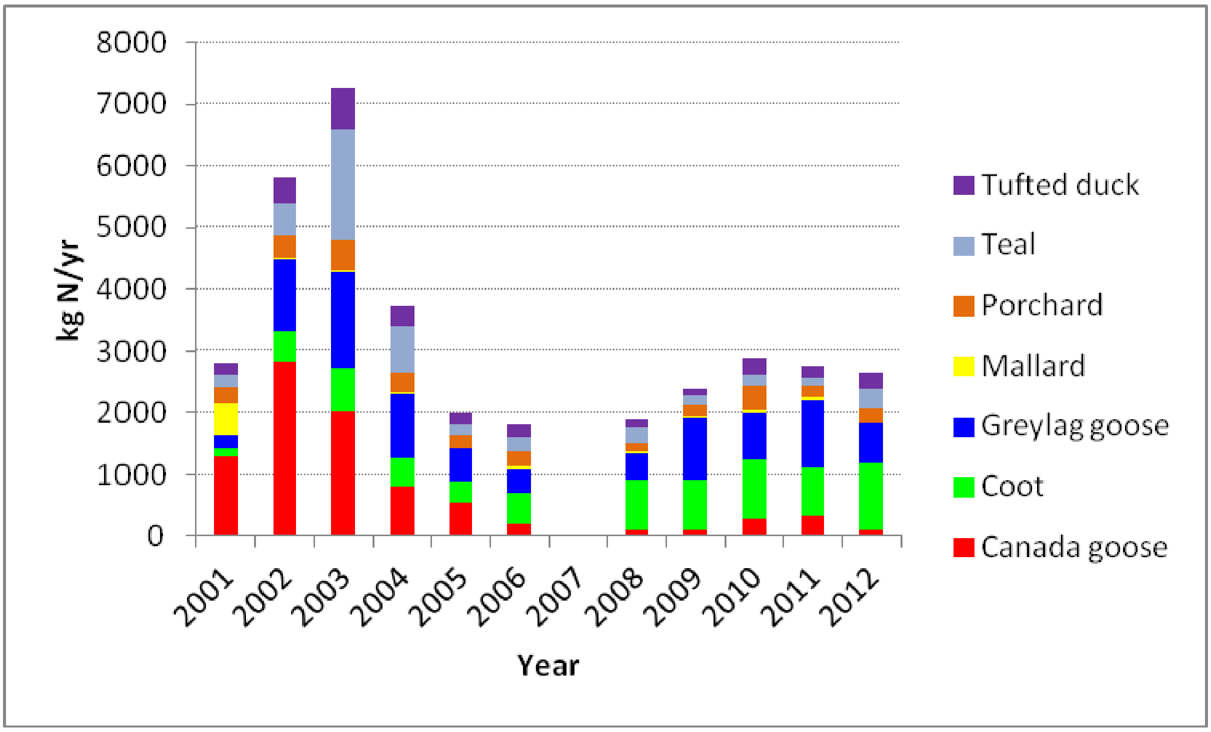


6.5 NITROGEN LOADING ASSESSMENT

For the period 2001 to 2012, Greylag Goose, Canada Goose, Mallard, Coot, Tufted Duck, Teal and Pochard collectively contributed on average 3,271 kgN/yr (35,982 kgN/yr in total across the eleven years). The greatest nitrogen loading occurred in 2003 (7,278 kgN/yr), with the lowest nitrogen loading (18,2 kgN/yr) in 2006. The Greylag Goose and Canada Goose (over 8,500 kgN/yr) were the greatest contributors of nitrogen, with dabbling ducks providing contributions between 849 kgN/yr and 4,753 kgN/yr).

Figure 6.2 shows the nitrogen contributions from birds between 2001 and 2012. The data suggest that the nitrogen nutrient load was driven in an identical manner as that for the phosphate nutrient load. Canada Geese were the main contributors in 2002 and 2003, with additional contributions from Greylag Geese in 2003. Compared to the phosphate nutrient loading, Coot did not contribute to nitrogen loading as much in 2003, although there is a greater contribution from Teal. After 2004, the nitrogen nutrient load from all bird species does not exceed 1,100 kgN/yr.

Figure 6.2 Nitrogen nutrient load (kg N/yr) between 2001 and 2012



The current trend suggests that the nitrogen nutrient load is driven by Coot and Greylag Geese. As for phosphate, dabbling ducks have never contributed more than 1,800 kgN/yr. Contributions from Mallard are the lowest, having never exceeded 509 kgN/yr.

6.6 GUANOTROPHY ASSESSMENT DISCUSSION

Based on the findings from the preliminary guanotrophy assessment, key bird species at the Far Ings NNR are contributing on average 1,020 kg phosphate per year and 3,271 kg nitrogen per year. This equates to 30 kg phosphorus per hectare per year, a very high load for phosphorus, and is probably the dominating source at the lakes.

The phosphate and nitrogen nutrient loadings have previously been driven by, in particular, Canada Geese between 2002 and 2003. However since 2012, the largest guanotrophic inputs have been from Greylag Geese and Coot. The preliminary guanotrophy assessment confirmed, as expected, that the guanotrophic inputs from dabbling ducks is limited (with the exception of Mallard in 2001 and Teal in 2003 and 2004).

Export coefficients from the literature have been used in this section to characterise loads from guanotrophy based on available bird count records to estimate contributions from avian sources. The current data set lacks the spatial detail needed in order to compare the findings directly to the phosphate contained within water samples taken from the lakes (Section 4) and the sediments (Section 5).Further monthly data on the numbers of birds at each lake would provide a more robust assessment of phosphate and nitrogen loadings given that the data suggests they are a large contributor of phosphate. The Wetlands Bird Survey does hold higher temporal resolution bird count data (see Table 6.3) from which a detailed guanotrophy assessment could be completed in the future.

Table 6.3 Wetland Bird Survey Data records

Name of Pit	Data Set Name (reference code)	Temporal Resolution
Target Lake	Barton Cliff - Sector E2 (ref: 38409)	1992-1993 to 2013-2014
Ness Pursuit Hotel Bridge	Barton to Chowder Ness - Sector F1 (ref: 38415)	1975-1976 to 2013-2014
Hoe Hill Pasture Wharf	Barrow to Barton (including Pits) - Sector F2 (ref: 38414)	1974-1975 to 2013-2014

This guanotrophy assessment has highlighted potential evidence gaps in current knowledge of birds around the Far Ings NNR in terms of contributions to the phosphate and nitrogen loading. These gaps are discussed in Sections 7 and inform the proposed monitoring plan, which is tailored to collect the additional data required. LWT bird count data does not cover Pasture Wharf therefore no preliminary guanotrophy assessment could be undertaken. There are a fewer number of birds at Pasture Wharf (based on ancillary information collated – see Pasture Wharf notes within Table B1 in Annex B) as they favour habitats at the other lakes. Therefore, it is anticipated that guanotrophic inputs would not be as great compared to those pits within Far Ings NNR.

7. HUMBER ESTUARY CLAY PITS: FOCUS TO RECOVERY

This section draws upon the analyses carried out on water quality (Section 4), lake sediments (Section 5) and guanotrophy (Section 6) in order to clarify current understanding on the impact of the storm surge on the Far Ings NNR and the key issues determining its recovery. It also includes a review of current compliance with water quality targets in the study area.

7.1 IMMEDIATE IMPACT OF THE STORM SURGE

The flow of water into the pits caused by the storm surge had a direct impact primarily on the pits adjacent to the Humber Estuary (primarily Ness Pit, Hotel Pit Target Pit and Pursuit Pit) in terms of saline water inundation. The other pits (those set inland) were indirectly affected with brackish water flowing into them from the lakes adjacent to the Humber Estuary. Pasture Wharf was not flooded but may have been indirectly impacted through surface water transfer. Based on the water quality and lake sediment analyses, it is clear that that the storm surge had a great impact on the lakes at Far Ings NNR.

7.1.1 Water Quality

The discussion in Section 4.2.2 identified two key impacts of the storm surge on water quality.

Salinity soared after the storm surge and this is considered to now be the driving factor in terms of the lakes, as a whole, recovering to a favourable condition; specifically Pursuit Pit, Hotel Pit, Ness Pit and Target Lake.

The phosphorus concentrations are lower post storm surge at both Ness Pit and Pursuit Pit, compared to the concentrations measured between August 2012 and November 2013. These phosphorus concentrations still exceed both the 0.1 mg/l and 0.05 mg/l CSM favourable conditional targets (except Ness Pit where it fails the 0.05 mg/l CSM favourable conditional targets from February 2014 onwards). Total phosphorus concentrations have dropped in Pursuit Pit from being just under 1.0 mg/l to just under 0.2 mg/l and in Ness Pit from 0.4mg/l to 0.2 mg/l. Nitrate and total nitrogen concentration currently remain comparable to those measured prior to the surge. There is no significant or clearly observable long term effect of the storm surge at Pursuit Pit however water quality analyses suggest that prior to the storm surge, water quality was lower in Pursuit Pit than Ness Pit or Pasture Wharf. Phosphorus concentrations at Pasture Wharf remain under the 0.1 mg/l and 0.05 mg/l CSM favourable condition targets for phosphorus (with the exception of December 2013 to February 2014 for the 0.05 mg/l CSM favourable condition target), while nitrogen concentrations have generally declined (with the exception of a peak of 1.72mg/l in January 2014). It is noted that assertions for Pasture Wharf are based on confines of fewer pre-storm surge data and concentrations should be considered borderline in terms of favourable condition targets for both phosphorus and nitrogen.

7.1.2 Lake Sediments

Sediment sampling was only undertaken post storm surge. Therefore, the impact of the surge on phosphate in the bed sediment cannot be ascertained. However, given the relative depths of the lakes and that all surface water connections (see Figure 2.1) are buried, it is unlikely the inflowing water caused significant disturbance of the lake bed sediments as total phosphate measured in the lake water did not vary significantly immediately after the storm surge. This suggests that the lake bed sediment total phosphate measurements are representative of concentrations prior to the storm surge.

7.2 POST STORM SURGE RECOVERY

7.2.1 Salinity

Data from monitoring in March 2014 shows that the water remains brackish in all lakes affected by the surge and would need to reduce in salinity before any progress could be viably made with respect to tackling other water quality issues. High salinity is the biggest short term issue facing the lakes in terms of recovery to favourable condition. Of those pits in the SPA, the following are considered brackish as on March 2014, using the JNCC standing water classification of brackish as greater than 1.3‰:

- Pursuit Pit: 7.3‰ salinity
- Hotel Pit: 4.0‰ salinity
- Ness Pit: 4.2‰ salinity
- Target Lake: 3.8‰ salinity.

It is clear from the water quality assessment that salinity levels are dropping post- storm surge however these lakes are still in excess of this threshold, with current levels (March 2014) ranging from 3.8‰ to 7.3‰.

Salinity in Ness Pit and Pursuit Pit has generally declined but not to or below, pre- storm concentrations. As the inundation of saline waters receded from mid December 2013, the majority of the other lakes have seen a reduction or stabilisation in saline concentrations.

Salinity for Pursuit Pit and Barton Reedbeds dropped dramatically in January 2014 and February 2014 as the storm surge waters receded but have stabilised in March 2014 at 7.3‰. Salinity at Ness Pit (along with the neighbouring lakes of Hotel Pit and Target Lake) declined slightly between January 2014 and March 2014 to 4.0‰.

Although not directly impacted, Pasture Wharf salinity increase slightly to 2.1‰. The increase could be explained by more saline water draining in from Hoe Hill Pit and/ or an intrusion of groundwater into the lake from the Humber Estuary.

7.2.2 Phosphate

The water column phosphate concentrations post surge are declining. Phosphate concentrations in March 2014 were above the CSM target of 0.1 mg/l for Ness Pit (0.19 mg/l) and Pursuit Pit (0.17 mg/l). Although Pasture Wharfe had a concentration of total phosphorus of 0.04 mg/l, the pit is considered borderline given previous fluctuations and likely inputs from Hoe Hill Pit. The current data set do not provide the temporal coverage to provide a robust assessment of the key drivers leading to poor water quality.

In Ness Pit, Pursuit Pit and Pasture Wharf water column phosphate concentrations all generally show declines to, or below, pre-storm concentrations after the storm surge. However, on any given day, values can be elevated, as seen in the March sampling. The data show suggest that water column phosphate quality in Pursuit Pit significantly improved post storm surge; however, the lake still has the poorest quality out of the three lakes. It is acknowledged that this change in water column phosphate quality could be accounted for by seasonal variations, however a more robust evidence base would be required to capture changes in phosphate concentrates in order to corroborate this assertion.

Based on maximum bird count data (for the Far Ings NNR as a whole), it is estimated that birds could be contributing on average 1,020 kg total phosphate each year. Although this is considered a high estimate, the preliminary guanotrophic assessment suggests with confidence that birds are the most significant source of nutrients to the lakes. Phosphate and nitrogen nutrient loadings are considered to be mainly driven by populations of Canada Goose, Greylag Goose and Coot.

Lake bed sediment samples, taken from all three lakes, indicate high phosphorus concentrations. Pursuit Pit has the most (1,490mg/kg) followed by Ness Pit (1,315mg/kg). Although one of the individual values measured in Pasture Wharf exceeds 1,000mg/kg the other two values are equal or slightly less. These results indicate that lake bed sediments are an important secondary source of nutrients to the water column, through remobilisation pathways.

7.3 LEARNING POINTS FROM THE STUDY

Current understanding in terms of determining the main contributory sources and key pathways has been advanced through the monitoring undertaken in this study. A series of learning points have been identified and these help to frame the suite of management options considered in Section 8.

Water Quality Assessment – It must be noted that the temporal coverage of the data collected before the storm surge limits a full understanding of the processes controlling nutrients in each of the lakes. A much higher temporal resolution covering as many seasons as possible would be required for this understanding. The fact that many of the peaks in determinands measured in the 2012-2013 study were not captured by the current study suggests that these peaks may point to controlling factors on water quality such as seasonality.

Lake Sediment Assessment – To make a reliable assessment on the effects of phosphate within lake sediments, knowledge of both external and internal phosphate sources is required. No lake sediment assessments have been carried out prior to this study, therefore a much higher spatial resolution of surface sediment sampling within each lake, including any key inflows and surface water connections could lead to a more robust and detailed level of understanding. Several of the water connections were dried up during the duration of this study and therefore no assessment could be made in terms of their influence on the nutrient budget. It is also important to note that there are a number of different mechanisms might induce internal phosphate release in the lakes depending on a variety of physical–chemical as well as biological factors.

Guanotrophy – The preliminary assessment provides headline estimates. Additional data, such as WeBS counts, would be required to accurately reflect the numbers of each bird species per season to allow more robust calculations to be made and reduce uncertainty in the nutrient loading from birds, with particular focus on the larger birds since these are the largest guano contributors. This type of assessment would only be reliable if it can be cross referenced to specific lakes.

8. RECOMMENDATIONS: FUTURE MANAGEMENT AND MONITORING

Based on the findings of the assessment presented above, this section makes a series of recommendations in terms of:

- Identifying a suite of future management actions to support the recovery of the water quality within the study area(Section 8.1).
- Developing a robust monitoring programme for the year ahead (2014 to 2015) that supports the delivery of any ongoing, amended or additional water quality management actions (Section 8.2).

8.1 FUTURE MANAGEMENT OF HUMBER ESTUARY CLAY PITS WATER QUALITY

Based on water quality sampling undertaken as part of this study, the levels of salinity across the lakes is now the key water quality driver affecting favourable condition of the SSSI units and SPA. Prior to the storm surge, phosphate was the driving parameter. The findings from this study acknowledge that levels of phosphate in the lakes remain high as previously and in terms of compliance with CSM water quality targets, it remains a long term issue. However, any future management actions need to focus on reducing the levels of salinity at the lakes before any progress can be made in managing phosphate.

8.1.1 Review of Potential Management Options

This section provides an initial steer on future recovery and management of the lakes within the study area. A preliminary options appraisal, reviewing a range of potential management options, was discussed with Natural England and LWT in March 2014. This section presents a high level options cost-effectiveness appraisal and makes recommendations for the next steps in terms of the potential future management actions for the study area. This option appraisal forms the basis for the proposed monitoring programme for 2014 to 2015 in Section 8.2. This approach is looking to implement solutions to:

- Reduce salinity levels currently in the brackish lakes affected by the surge (Pursuit Pit, Ness Pit, Hotel Pit and Target Lake) in the short term
- Reduce nutrient (phosphate) inputs to the high nutrient lakes (Ness Pit and Pursuit Pit) in the long term.

The initial options appraisal takes a strategic approach considering catchment management options that provide benefits to the wider environment in tandem with addressing issues at the lakes. Examples of options considered included:

- Catchment management to reduce nutrient/ sediment inputs
- Bird management to reduce nutrient inputs
- Removal of legacy nutrient load, for example by sediment removal
- Locking of legacy phosphate load through use of Phoslock™
- Biomanipulation, for example through fish removal.

8.1.2 Preliminary Options Appraisal

A preliminary options appraisal has been carried out (Table 8.1) which outlines a suite of potential management options that could be considered going forward in terms of future management. The options appraisal reviews for each option:

- Description of the option
- What problem/ issue the option aims to resolve
- Work required
- Identification of possible inputs from other stakeholders
- Advantages and disadvantages of the option.

Table 8.2 takes the management options identified in the previous section and outlines the reasoning to support whether they should be considered.

Table 8.1 Preliminary options appraisal

Options		Aims to Resolve	Work Required	Stakeholder Input				Advantage of Option	Disadvantage of Option
No.	Description			LWT	EA	RSPB	OTHER		
1	Do Nothing – Allow lakes to recover naturally	Allow system to recover naturally (with no intervention)	None					No additional cost. Lakes can recover naturally from elevated salinity (eventually).	Medium term salinity issues could have long term and adverse effects on the ecological functioning of the lakes and supported birds. Lakes may not recover naturally from high phosphorus concentrations.
2	Watching brief – Monitoring of lakes' natural recovery	Allow system to recover naturally as above but monitor water quality levels in lakes as a trigger to implement further actions to avert further deterioration	None	✓				Minor cost requiring continuation of target monitoring. Lakes can recover naturally from elevated salinity (eventually).	Medium term salinity issues could have long term and adverse effects on the ecological functioning of the lakes and supported birds. Lakes may not recover naturally from high phosphorus concentrations.
3	Monitoring.Maintenance of site including surrounding reedbeds and use of vegetation to act as wind breaks	Control inputs of phosphorus from reedbed detritus and enable the operation of surface water connections	Increased maintenance of lakes	✓				Encourage shading by reedbeds at the edge of the lake. This is a cost-moderate method that only can give an acceptable result for small size lakes due to the low area/ circumference ratio. Reduce impacts of wind on stirring up	No benefit to salinity.

Options		Aims to Resolve	Work Required	Stakeholder Input				Advantage of Option	Disadvantage of Option
No.	Description			LWT	EA	RSPB	OTHER		
								phosphorus contained with lake sediments.	
4	After flow between connections	Reduce phosphorus and salinity by flushing and dilution	Increased maintenance of lakes	✓	✓			Improved flow through the lakes will stop phosphorus settling.	Reliant on connections being maintained and kept open. Better understanding of the flow regime associated with each connection is required. Requires low nutrient source of water.
5	Catchment managaement	Reduce nutrient and sediment inputs	Construct wetlands to reduce nutrient inputs	✓	✓			Protect lakes from contamination originating from activities (e.g. nutrient inputs from the use of pesticides on agricultural land) on margins of the lakes.	No benefit to salinity. Minimal effectiveness for nutrients given low significance of surface runoff pathway.
6	Bird management to reduce nutrient inputs	Reduce phosphate inputs	Will require liaison between LWT and RSPB to focus on priority bird species	✓		✓		High contributors of phosphate and nitrogen can be managed to improve the water quality of the lakes.	No benefit to salinity. Study area (Ness Pit and Pursuit Pit) dependent on its current rich range of bird species and any change may result in a change to its designation. Highly contentious with recreational users of the study area.

Options		Aims to Resolve	Work Required	Stakeholder Input				Advantage of Option	Disadvantage of Option
No.	Description			LWT	EA	RSPB	OTHER		
7	Removal of legacy nutrient load, for example by sediment removal	Reduce stored phosphate	Dredging	✓	✓		✓	Removal of bed sediment by dredging resulting in short to medium term improvement of water quality.	No benefit to salinity. Very expensive. Does not address primary sources and therefore not a long term solution. Impacts on recreational uses of the lakes.
8	Locking of legacy phosphate load through use of Phoslock™	Prevent remobilisation of phosphate from the lakes beds	One-off dosing of treatment chemical	✓			✓	Potential to seal phosphate effectively to prevent most of the release processes. Method is considerably more cost-moderate than dredging.	No benefit to salinity. Not been applied extensively in the UK. Does not address primary sources and therefore not a long term solution. Product may be washed out in future storm surges.
9	Biomanipulation for example through fish removal	Overcomes algal dominance in favour of macrophyte dominance when there are two possible ecological structures at the phosphate range of approximately 50 to 150 µg/l	Removal of planktivorous fish and release of carnivorous fish	✓	✓			Cost-moderate. Possible to maintain a relatively high biodiversity, which does not change the stability of the system. A higher biodiversity gives the ecosystem a higher probability to meet future unforeseen changes without changes in the ecosystem function.	No benefit to salinity. No evidence that the fish community is currently driving in-lake processes.

Options		Aims to Resolve	Work Required	Stakeholder Input				Advantage of Option	Disadvantage of Option
No.	Description			LWT	EA	RSPB	OTHER		
10	Dig new lakes to provide freshwater lake habitat	Provision of more resilient freshwater habitat	Creation of new lakes, requiring excavation and maintenance	✓				Long term solution in terms of provision of a freshwater habitats.	Expensive in terms of source of funding. May not meet conservation management objectives.
11	Partially empty the lakes (to normal low levels) and refill	Reduce phosphorus and salinity by flushing and dilution	Pumping of water out of pits Allows the pits to fill up again with rainwater/blow wells water	✓	✓	✓		Low cost and high chance of effectiveness.	Although could be undertaken at non- bird sensitive times, will likely have an impact on bird populations. If water was pumped in the summer when phosphorus is most soluble, then it could feasibly remove phosphorus, however it would cause the lakes to dry out that year (until the blow wells and rain fall provides enough water to fill the lake), which has major implications on the bird populations. Does not address phosphorus within sediment.

Table 8.2 Selection of Management Options

Options		Consider Further	Reasoning	Issues to be aware of	Lakes applicable to
No.	**Description**				
1	Do Nothing – Allow lakes to recover naturally	No	No – Although the lakes are complex and current understanding of sources and pathways are not fully understood (and complicated by the storm surge), the lakes are designated and inaction is not appropriate.	-	-
2	Watching brief – Monitoring of lakes' natural recovery	Yes (short term)	As 1 above however permits salinity levels to be monitored and potential intervention should water quality issues not improve (or there is evidence to support intervention).	Continued monitoring is required to deliver.	Ness Pit, Pursuit Pit, Hotel Pit, Target Lake & Bridge Pit
3	Maintenance of site including surrounding reedbeds and use of vegetation to act as wind breaks	Yes (short term)	A review of ongoing reedbed maintenance could be trialled to determine if it leads to an improvement in water quality.	Maintaining records of any changes to operation will aid the impact of changing flows to be determined and reduced potential impacts of wind on stirring up phosphorus contained within sediment.	Ness Pit, Pursuit Pit, Hotel Pit, Target Lake & Bridge Pit
4	Alter flow between connections	Yes (short term)	Should water levels in the lakes increase, the surface water connections may change the hydrological regime with implications for salinity and phosphate. Maintaining the surface water connections from encroachment by reeds is important to ensure they are operational.	Maintaining records of any changes to operation will aid the impact of changing flows to be determined.	All lakes within NNR
5	Catchment management	Yes (long term)	Potential partnership working e.g. through agri-environmental funded schemes and awareness of regional strategies and initiatives may lead to potential benefits to the lakes.	Maintain liaison with Environment Agency on flood defence funding.	All lakes within NNR
6	Bird management to reduce nutrient inputs	No	The study area (in particular Ness Pit and Pursuit Pit) has a wide variety of birds. Any alteration in the number or location of resident/ migrant birds would be jeopardise the integrity of designated pits with the study area and would be very difficult to implement.	-	-

7	Removal of legacy nutrient load, for example by sediment removal	No	Any action to remove sediment would be unsustainable and not address salinity effects.	-	-
8	Locking of legacy phosphate load through use of Phoslock^{TM}	No	As a precautionary approach, this option could merit future consideration once salinity levels have dropped sufficiently and the phosphate becomes the key driver. Does not address inputs and only a long term solution if repeated in future.	Maintain liaison with Environment Agency on flood defence funding.	Ness Pit, Pursuit Pit
9	Biomanipulation for example through fish removal	Yes (long term)	Any action to remove fish would be unsustainable and not address salinity effects. Fish numbers in the lakes are currently thought to be low.	-	Ness Pit, Pursuit Pit
10	Dig new lakes to provide freshwater lake habitat	No	Long term solution to providing freshwater habitat at new sites inland however in short term does not address salinity and water quality effects.	Seek partnership funding opportunities and scope potential sites inland.	
11	Partially empty the lakes (to normal low levels) and refill	Yes	Addresses the effects of both salinity and phosphate.	Potential impact on bird populations (in the short and long term) and the conservation of the reedbeds, due to changing water levels.	Pursuit Pit first then Ness Pit (given birds favour Ness Pit)

After reviewing a range of options, there are three tiers of action

1. **Watching brief –** to oversee and monitor the speed of natural recovery to pre- surge salinity levels (This is particularly relevant to Ness Pit, Pursuit Pit, Target Lake, Hotel Pit and Bridge Pit given they are designated however a precautionary approach would include the non-designated pits to the south of Far Ings NNR as well as Pasture Wharfe and Hoe Hill Pits which are also within the SPA.
2. **Actively manage a reduction in salinity –** recommended to be achieved through urgent practical, low cost-effective and realistic means available. This is recommended to be initially set out as enhanced management of the use of water from the blow wells to flush brackish water from the affected lakes through existing surface water connections or additional connections. An extended period of high salinity may adversely affect the ecological condition of the lakes and also protract the ecological recovery once freshwater has been returned to pre-surge salinity levels. This is particularly relevant to Ness Pit, Pursuit Pit and Target Lake given their proximity to the blow wells.
3. **Actively manage a reduction in phosphorus concentrations –** following further understanding of the key sources and pathways of phosphate into the water column of the relevant lakes identified in this study. We recommend consideration of resolving elevated phosphorus concentrations through a combined strategy of immobilising phosphorus currently in the sediment (e.g. the use of Phoslock™) and then maintaining a low concentration by routine active management using blow wells water, biomanipulation through fish removal, or repeat dosing of Phoslock™ when concentrations have risen again towards high levels. We consider this approach to be the least intrusive for the NNR and its users. This is particularly relevant to Ness Pit and Pursuit Pit given their designation within the SPA and high concentrations of phosphorus but could also include Target Lake, Hotel Pit and Bridge Pit given they fail the phosphorus CSM threshold for favourable status and are designated too.

Phoslock™ is a modified clay product that was developed by the Commonwealth Scientific and Industrial Research Organisation to remove phosphorus from water bodies and eliminate the incidence of blue-green algal blooms. The use of Phoslock™ with its active ingredient lanthanum is a new but fast emerging effective phosphate inactivation and blue-green algae management tool (Davies, 2011[22]). Although there is very little evidence to demonstrate the successful application of Phoslock™ in the UK, it is one of very few active intervention options (other viable alternatives include sediment removal) available for tackling the elevated levels of phosphorus. Phoslock™ also provides the opportunity to help manage phosphorus levels in the long run, through repeat dosing, but only if phosphorus in the water column phosphorus is reduced and the bed phosphorus was previously locked. Chemicals for a one-off dosing would cost in the region of £6,000 for Pursuit Pit and £3,000 for Ness Pit based on estimation of the current total phosphate load within the water column of each lake.

To assess and manage any possible adverse environmental side effects of a new product, it is crucial to understand the hazards and risks associated with its use, in this case to the

[22] Davies, S. 2011. Phoslock Risk Assessment: An overview of risks to the aquatic environment associated with the use of Phoslock. CSIRO.

aquatic ecosystem. In the case of Phoslock™, Davies (2011) states that the main hazard associated with Phoslock™ is from lanthanum which has been shown to cause toxic effects to some aquatic organisms, although it is used in much higher concentrations as a human medicine. However, the risks from Lanthanum through the use of Phoslock™ are strongly mitigated, reduced to a minimum by the chemical composition of Phoslock™ and its conditions of use. Progressing with this option will largely depend on further investigation on the likelihood Phoslock™ would work at Far Ings NNR and provide a sustainable long term solution, and hence value for money. In the long term, there are risks associated with the lack of future maintenance of the flood defences on the Humber Estuary. This potentially heightens the risk and frequency of inundation of brackish water from storm surge waters from the Humber Estuary in the future. This potentially compromises any management actions implemented that are tailored to address water quality issues in the short term.

It is recommended that the following management options do not receive future consideration as they are unsustainable (impractical, no evidence of successful application in the UK and/or are too expensive) and do not address the key issues in the short term:

1. **Do Nothing – allow lakes to recover naturally** (reason not to consider option further: impractical) - the lakes are designated and inaction is not appropriate.
2. **Bird management to reduce nutrient inputs** (reason not to consider option further: impractical) - any alteration in the number or location of resident/ migrant birds would be impractical and very difficult to implement.
3. **Removal of legacy nutrient load, for example by sediment removal** (reason not to consider option further: impractical) – removing sediment would be unsustainable and not address salinity effects.
4. **Dig new pits** (reason not to consider option further: too expensive and doesn't protect currently designated habitat) - this option could merit future consideration in the long term (once potential sites are identified and funding secured) providing freshwater habitat at new sites inland. However, in short term does not address salinity and water quality effects at the lakes not in favourable condition.

8.2 FUTURE MONITORING OF HUMBER ESTUARY CLAY PITS WATER QUALITY

Based on the outcomes of this study, further investigative monitoring is recommended to support the future management of the lakes, acknowledging that the key driver is returning salinity to pre-storm surge levels. This section outlines a potential monitoring programme for 2014/2015 that takes into consideration the management option proposed in Section 8.2.

The monitoring proposed will provide Natural England the opportunity to:

- Improve baseline monitoring based on gaps identified in water quality and lake sediment assessments
- Support potential management actions to take forward from the preliminary options appraisal.

Additional monitoring is recommended to improve current understanding on issues relating to the impact of the storm surge and to aid the recovery of the lakes towards favourable condition. The monitoring is therefore focussed for each lake (see Table 8.3) and prioritised on filling evidence gaps identified in Sections 4, 5 and 6:

Water quality – continue to monitor levels of salinity and phosphate in order to identify if and when levels reduce and provide an opportunity for (seasonal) trends to be picked up in the future. This monitoring is recommended in the short-term for salinity to determine the condition of the lakes with respect to recovering to freshwater. In the long term, monitoring is recommended as the variability in phosphate concentration over time, between seasons and between lakes is not well understood.

Aquatic macrophytes – a survey is required at the lakes to assess the current diversity and abundance of aquatic macrophytes. This monitoring is recommended in the short term for salinity in order to establish the impact of the storm surge. The monitoring results can be compared to previous surveys to understand any changes in aquatic macrophyte assemblages, particularly in relation to brackish water intolerant species. Recording the timing, frequency, location and description of any management activities (undertaken by LWT) associated with the conservation of the reedbeds would also be beneficial.

Bird survey – quantified bird monitoring of key species known to be large contributors of phosphate at each of the study lakes pits is required for a robust guanotrophy assessment to be completed. This monitoring is recommended in the short term as there are plenty of volunteers at LWT already collecting these data. The information collated would be very useful if tailored and collected in terms of representative monthly counts of Canada Goose, Greylag Goose and Coot.

Surface water connection – to improve understanding on the flows passing through these connections and provide a better evidence base from which salinity and phosphate management by flushing and dilution could be utilised. The continuation of the monitoring of water levels and any changes in the operation and maintenance of the surface water connections by LWT is recommended in the short term however assistance in recording the information in a format that is easily transferable is required so up to date reading can be compared to other monitoring assessments.

Table 8.3 Proposed monitoring programme for the study area (2014/2015)

Type of Monitoring	Aim of Monitoring	Approach	Freq.	Lake														
				Ness Pit	East Ness	West Ness	Target Lake	New Scrape	Hotel Pit	Blow Wells 1	Blow Wells 2	Blow Wells 3	Blow Wells 4	Blow Wells 5	Pursuit Pit	Bridge Pit	Barton	Pasture Wharf
Water quality	Measurements of nutrients to assess if CSM compliant	Bottle sample with laboratory analysis	Monthly	✓											✓			✓
	Rapid testing of salinity at all lakes	Sonde/ hand-held monitor	Monthly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Flow[†]	Assess connectivity of lakes and potential transfer of P and N	Visual survey (with flow meter)	Monthly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	Record any routine maintenance to the weirs and connections	LWT record	Monthly	✓	✓	✓	✓	✓	✓						✓	✓		
Reedbed management[†]	Record any routine maintenance for the reedbeds	LWT record	As occurs	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓	
Bird (guanotrophy inputs)	Calculation of annual phosphate and nitrogen contributions to nutrient loading	Survey	Monthly	✓											✓			

Type of Monitoring	Aim of Monitoring	Approach	Freq.	Lake														
				Ness Pit	East Ness	West Ness	Target Lake	New Scrape	Hotel Pit	Blow Wells 1	Blow Wells 2	Blow Wells 3	Blow Wells 4	Blow Wells 5	Pursuit Pit	Bridge Pit	Barton	Pasture Wharf
Aquatic macrophytes	Determine changes to aquatic macrophytes	Survey	One off	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓		
Water level [†] (including accompanying rainfall data)	Continuation of lake water level survey	LWT survey	As occurs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

[†] Denotes monitoring already undertaken by LWT as part of their routine management of Far Ings NNR

APPENDICES

APPENDIX A: MONITORING DATA RE-PRESENTED FROM THE 2012 TO 2013 NUTRIENT STUDY

Pit Name	Date	pH	Temp (Deg. C)	Conductivity (µS/m)	Conductivity (ppt)	Total nitrogen (mg/l)	Total phosphorus (mg/l)	Suspended solids (mg/l)	DO (%sat)	DO (mg/l)
Barrow Tileries 1	16/08/2012	7.9	21.1	1650.0	1.0	0.8	0.1	35.9	126.0	11.2
	17/10/2012	7.9	8.9	1861.0	0.7	1.6	0.1	21.3	62.6	7.1
	08/01/2012	8.5	6.6	1597.0	0.6	1.3	0.0	20.1	70.5	9.3
	21/02/2013	8.3	3.2	1590.0	0.6	0.8	0.0	8.7	107.0	14.1
	10/04/2013	8.4	7.1	980.0	0.8	0.8	0.0	15.5	123.3	14.9
Barrow Tileries 2	16/08/2012	8.1	20.9	2074.3	1.2	0.8	0.1	7.0	108.3	9.9
	17/10/2012	9.9	8.9	2306.7	1.0	1.5	0.1	6.1	79.3	8.7
	08/01/2012	8.4	6.8	2053.3	0.9	1.4	0.0	5.0	72.0	8.8
	21/02/2013	8.3	3.1	2062.8	0.9	1.3	0.0	5.7	92.0	12.6
	10/04/2013	8.6	6.4	1272.7	1.0	1.2	0.0	8.4	119.4	14.6
Barrow Tileries 2	16/08/2012	8.4	20.9	1886.3	1.0	1.0	0.1	5.2	130.8	12.2
	17/10/2012	9.6	8.8	2060.0	0.9	1.6	0.0	6.3	74.3	8.2
	08/01/2012	8.3	6.9	1809.7	0.9	1.9	0.1	13.4	71.0	9.2
	21/02/2013	8.9	3.1	1816.7	0.7	1.8	0.2	17.0	105.3	14.6
	10/04/2013	8.4	6.9	1157.8	0.9	1.5	0.1	8.4	118.1	14.3
Barrow Tileries 4	16/08/2012	8.0	20.5	990.0	0.3	0.7	0.2	71.5	28.5	2.2
	17/10/2012	8.6	9.3	1023.0	0.3	0.9	0.1	7.6	47.0	5.3
	08/01/2012	8.6	7.1	986.0	0.7	1.5	0.2	4.7	50.0	6.3
	21/02/2013	8.2	3.0	1155.0	0.5	1.5	0.2	40.0	122.3	16.7
	10/04/2013	8.3	7.4	881.0	0.7	1.9	0.3	14.7	11.0	13.2
Hoe Hill	16/08/2012	8.1	20.5	1647.9	1.0	0.8	0.1	17.1	107.8	9.7
	17/10/2012	9.9	9.8	1877.6	0.8	1.4	0.0	9.0	64.9	7.2
	08/01/2012	7.9	6.5	1606.6	0.6	1.2	0.0	12.3	50.7	6.6
	20/02/2013	7.1	3.6	1588.4	0.6	1.1	0.0	8.8	112.4	14.9
	10/04/2013	8.5	6.1	957.8	0.8	1.1	0.0	14.2	117.3	14.5

Pit Name	Date	pH	Temp (Deg. C)	Conductivity (µS/m)	Conductivity (ppt)	Total nitrogen (mg/l)	Total phosphorus (mg/l)	Suspended solids (mg/l)	DO (%sat)	DO (mg/l)
Hotel	16/08/2012	8.0	19.3	4025.0	2.4	0.5	0.0	10.2	82.0	7.0
	16/10/2012	7.5	9.7	4413.3	2.3	0.9	0.0	10.4	96.0	10.8
	16/12/2012	9.6	3.3	3606.7	1.7	0.9	0.0	4.9	99.7	13.5
	19/02/2013	8.3	3.8	4210.0	2.0	0.8	0.0	9.9	186.3	17.0
	09/04/2013	8.4	4.9	2522.3	2.2	0.8	0.0	14.2	119.5	15.1
Ness	15/08/2012	8.9	20.9	1790.8	0.9	0.7	0.4	9.1	128.6	11.3
	18/10/2012	8.4	9.5	2040.0	0.9	1.1	0.4	4.8	58.1	6.4
	17/12/2012	8.9	2.8	1680.8	0.7	1.7	0.4	4.5	132.1	17.7
	19/02/2013	8.1	3.0	1784.8	0.7	2.5	0.3	13.2	116.2	15.9
	09/04/2013	8.8	4.9	1017.2	0.8	1.5	0.1	8.2	123.1	15.7
Non SSSI 1	15/08/2012	8.4	20.4	498.7	0.3	0.7	0.0	3.5	37.3	3.5
	16/10/2012	9.2	9.1	452.7	0.0	0.8	0.0	4.4	85.0	9.7
	16/12/2012	7.9	2.7	628.7	0.0	0.7	0.0	3.5	38.0	5.2
	20/02/2013	7.1	3.7	475.3	0.1	1.1	0.0	6.5	97.3	13.1
	09/04/2013	8.5	6.2	428.0	0.3	0.7	0.0	4.9	113.5	14.1
Non SSSI 2	15/08/2012	7.8	20.5	419.0	0.2	0.6	0.0	5.0	83.0	7.5
	16/10/2012	8.7	9.0	545.7	0.0	0.7	0.0	3.1	85.5	9.5
	16/12/2012	8.7	2.5	582.7	0.0	0.9	0.0	3.0	39.7	5.4
	20/02/2013	7.7	3.8	644.0	0.0	1.0	0.0	5.1	71.3	14.0
	09/04/2013	8.4	6.1	402.3	0.3	0.7	0.0	4.4	125.4	15.6
Non SSSI 3	15/08/2012	7.8	20.9	375.4	0.2	0.5	0.0	3.7	204.0	17.7
	16/10/2012	7.7	9.8	451.3	0.0	0.8	0.0	43.1	106.0	11.6
	16/12/2012	9.2	2.6	480.0	0.0	1.0	0.0	3.0	38.7	5.1
	20/02/2013	7.9	3.4	538.7	0.0	1.6	0.0	3.0	121.3	16.1
	09/04/2013	8.4	5.7	327.0	0.3	1.5	0.0	3.0	118.7	14.9
Non SSSI 4	15/08/2012	9.2	21.2	327.8	0.2	0.6	0.0	3.3	145.3	12.7
	16/10/2012	8.4	9.3	396.4	0.0	1.1	0.1	156.2	87.0	9.9
	16/12/2012	9.9	2.8	440.3	0.0	0.7	0.0	3.0	50.0	6.9
	20/02/2013	7.8	3.6	536.3	0.0	1.5	0.0	4.1	119.0	16.0
	09/04/2013	8.3	6.6	334.7	0.3	1.2	0.0	3.7	126.3	15.5

Pit Name	Date	pH	Temp (Deg. C)	Conductivity (µS/m)	Conductivity (ppt)	Total nitrogen (mg/l)	Total phosphorus (mg/l)	Suspended solids (mg/l)	DO (%sat)	DO (mg/l)
Non SSSI 5	15/08/2012	8.9	21.1	594.6	0.1	0.5	0.1	44.2	103.3	9.2
	16/10/2012	9.4	9.8	614.7	0.0	0.7	0.0	4.4	98.3	10.9
	16/12/2012	10.1	3.0	637.7	0.0	1.3	0.0	3.0	84.0	11.5
	20/02/2013	8.0	3.7	848.0	0.2	10.3	0.0	3.2	109.0	14.6
	09/04/2013	8.4	5.9	469.0	0.4	7.3	0.0	4.0	128.3	16.0
Pasture Wharf	16/08/2012	7.7	20.7	2228.0	1.3	1.1	0.1	12.8	130.2	11.2
	17/10/2012	8.2	10.4	2506.0	1.1	3.4	0.3	10.9	69.3	8.0
	08/01/2012	9.8	6.3	2074.0	1.1	2.0	0.2	5.2	57.2	7.1
	20/02/2013	6.9	3.7	2005.8	0.8	1.8	0.1	10.8	141.8	19.2
	10/04/2013	8.6	6.0	1184.2	0.9	1.6	0.1	13.7	128.5	15.9
Pursuit	16/08/2012	7.5	19.2	2543.3	1.5	1.4	1.0	86.5	104.2	9.4
	17/10/2012	8.3	9.8	2945.6	1.4	3.1	0.3	38.3	71.4	8.8
	11/12/2012	7.8	1.9	2310.0	1.4	2.8	0.2	28.3	32.5	4.6
	19/02/2013	7.7	3.0	2172.7	1.1	2.2	0.2	28.1	90.1	12.2
	10/04/2013	8.3	5.6	1428.4	1.2	2.4	0.2	38.3	112.7	14.0

APPENDIX B: EVENTS, ACTIONS AND DECISIONS TAKEN DURING STUDY LEADING TO THE CONSOLIDATION OF THE REVISED SCOPE

Date	Event	Decision Making	Action
15 October 2013	Inception Meeting	Surface water connection found to be buried –flow monitoring removed from scope.	Scope potential sediment analyses to replace.
20 November 2013	Water quality monitoring trip 1	Water quality surface samples taken from centre of lake.	Water quality monitoring (water bottle sampling from centre of lake) undertaken at the three lakes.
5 December 2013	Storm Surge at Far Ings NNR	Revise scope depending on extent of damage to lakes.	Organise reconnaissance field trip to assess access to lakes, key impacts and take water quality samples at accessible location via sonde.
18 December 2013	Post storm surge reconnaissance and water quality monitoring trip 2	Determine key impacts of storm surge and access to each lake and get initial understanding of water quality changes at lakes through Far Ings NNR.	Hold water quality sampling from centre of lakes due to scope revision. Water quality monitoring (water bottle sampling from edge of each lake). Undertaken at Ness Pit, Pursuit Pit and Pasture Wharf. Samples also taken from accessible sites at Hotel Pit, Blow Wells Pit 3 and Barton Reedbed. Sonde measurements taken at 12 lakes: Ness Pit, East Ness Pit, West Ness Pit, Target Lake, New Scrape, Hotel Pit, Blow Wells Pit 3, Blow Wells Pit 5, Blow Wells Pit 4, Barton Reedbed, Pursuit Pit and Pasture Wharf.
23 January 2014	Water quality monitoring trip 3	Understanding of water quality changes remains unknown at lakes throughout Far Ings NNR so monitoring programme in December 2013 repeated.	Continue water quality sampling as in December2013 due to inconclusive results. Sediment thought to be a likely source of phosphate therefore scope for monitoring tailored to be added to February 2014 monitoring.
19 February 2014	Water quality monitoring trip 4	Continue with current water quality monitoring programme for direct comparison.	None

Date	Event	Decision Making	Action
20 February 2014	Lake sediment sampling trip 1	Results from monitoring at Ness Pit and Pasture Wharf yield extremely high values for phosphate and nitrogen. Pursuit Pit not sampled due to adverse weather conditions.	Lake Sediment monitoring undertaken to be repeated due to high results in Ness Pit and Pasture Wharf and ascertain levels of P and N in Pursuit Pit.
20 March 2014	Water quality monitoring trip 5	Continue with current water quality monitoring programme for direct comparison.	None
25 March 2014	Lake sediment sampling trip 2	Lake sediment sampling for Ness Pit and Pursuit Pit undertaken. Given high P and N findings from lake sediment sampling trip 1, lake sediment sampling focussed on taking a greater number of samples at Ness Pit and Pursuit Pit, given previous Pasture Wharf samples.	None

APPENDIX C: ANCILLIARY INFORMATION ON THE MANAGEMENT OF THE CLAY PITS

OVERVIEW

This section provides a comprehensive overview of the study area, in particular those pits within the SPA designation, reporting on the management of the Far Ings NNR (in particular Ness Pit and Pursuit Pit, which are included in the study area), designations, land use and landscape, flora and fauna, hydrology, water quality (in terms of compliance with targets), WFD status and finally a review of the key sources and pathways.

MANAGEMENT HISTORY OF FAR INGS NNR

The Far Ings NNR used to be a cement works, operational from 1850 to 1925. The blow well was tapped to provide water by pipe to the cement works. The Clay Pits were dug as balancing ponds, with the deepest being the ones closest to the cement works. After the cement works stopped, the land was grazed with cattle. The blow well which was originally piped into Hotel Pit, was breached so that it provided freshwater into the reserve.

Pursuit Pit used to be run by council as outdoor pursuits area. LWT bought it in c. 2005. Hotel Pit used to be run as a fishery and had a reputation as being the best carp fishery locally. It was heavily stocked and still has a lot of carp today. When the LWT bought the lake in 1996, it was no longer managed as a fishery. The Non SSSI lakes are the newest lakes and are located to the south of the Far Ings NNR. These lakes were dug over winters 2001 to 2003 to provide clay to cap the toxic landfill sites at Waters Edge and were initially fed by blow well (now rainwater fed). Additional information on each lake is collated in Appendix B. The lakes under review are Ness Pit, Pursuit Pit and Pasture Wharf. As part of the revised scope (see Section 1.4), additional lakes were added to the study (see Section 3) in order to monitor their recovery after the storm surge in December 2013.

LWT manages the reserve and it is regarded as one of the foremost areas in the country for the conservation of reedbeds and a stronghold for one of Britain’s rarest birds, the Bittern. The site has a wide variety of habitats from open water, reedbeds and meadows on the reserve. Its location on the Humber, one of Europe’s top destinations for migratory wildfowl, provides essential feeding sites for thousands of birds on the way to their winter-feeding grounds.

DESIGNATIONS

The study area includes a series of former Clay Pits that have been flooded to create reed beds. As well as reedbeds the reserve contains a mosaic of rough grassland and scrub, open water and wetland habitats. The nature reserve was created in 1973 and was designated as an NNR in 2005.

The Clay Pits monitored all fall within the Humber Estuary SSSI[23], SPA and Ramsar site. The nationally important habitats consist of the estuary itself with its component habitats of intertidal mudflats and sandflats and coastal saltmarsh as well as saline lagoons, sand dunes and standing waters. The SSSI site is also of national importance for the geological interest at South Ferriby Cliff (Late Pleistocene sediments) and for the coastal geomorphology of Spurn Point. Table C.1 documents the characteristics of each lake outlining ancillary information on SSSI Interest Units (SSSI ID Unit reference), corresponding Site Unit Condition, and the reason for assigning it as in adverse condition. All the lakes are in unfavourable declining condition except Blow Wells Pit 3 (as of the last assessment in January 2011). The Clay Pits provide supporting habitat for breeding, wintering and passage birds which are SPA and Ramsar features. Macrophytes are an important food source for species such as pochard, tufted duck, wigeon and teal. The Clay Pits are also SSSI features, with the interest being the complex of lakes with variation of salinities from freshwater to brackish.

Table C.1 SSSI Unit Information relating to Humber Clay Pits

Lake Name	Area* (ha)	Primary Scope	SSSI ID Unit	Site Unit Condition	Further comments on condition assessment
Blow Wells Pit 1	1.7		Not applicable		
Blow Wells Pit 2	1.3				
Blow Wells Pit 3	2.1		144	Favourable	The extent of the drain leading to the blow wells has not changed. A population of Lophopus crystallinus are still present at the blow wells, attached to submerged sticks and branches.
Blow Wells Pit 4	1.1		Not applicable		
Blow Wells Pit 5	1.3				
Hoe Hill	4.1		130	Unfavourable Declining	This unit was included in WFD funded project 2012/13. Water quality sampling undertaken at intervals from Aug 2012 to April 2013, and analysed against WFD and CSM targets. Annual average total phosphorus very high (154ug/l) and fails target of 50ug/l. Elevated levels of total N.
Pasture Wharf	1.3		132		
Bridge Pit	2.8		143	Unfavourable Declining	Habitat assessment undertaken in October 2008. Bird features assessed separately in December 2010.

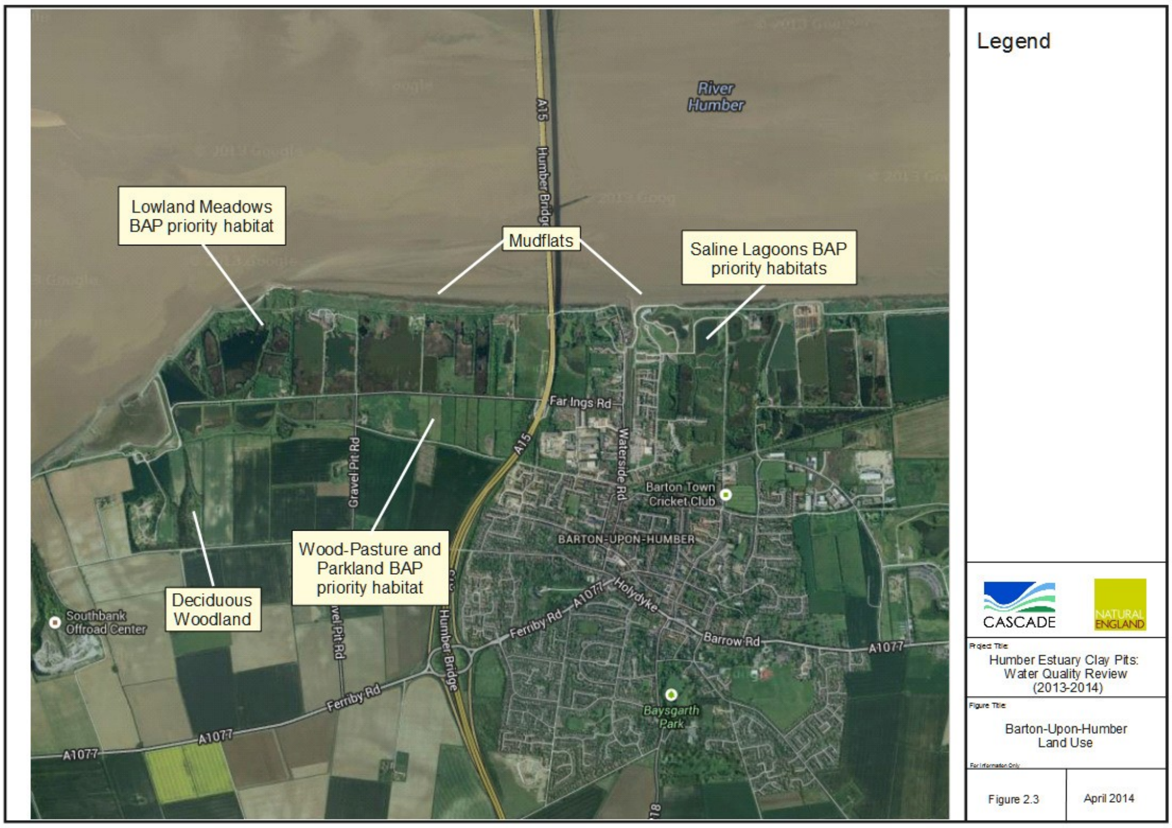
[23] http://www.sssi.naturalengland.org.uk/citation/citation_photo/2000480.pdf

Lake Name	Area* (ha)	Primary Scope	SSSI ID Unit	Site Unit Condition	Further comments on condition assessment
Pursuit Pit	8.1		142	Unfavourable Declining	Unit included in WFD funded project 2012/13. Water quality sampling from Aug 2012 to April 2013 and interpretation against WFD and CSM targets. This unit had very high annual average phosphate (377ug/l) which failed target of 50ug/l. Total N also elevated. Habitat assessment undertaken in September 2008. Bird features assessed separately in December 2010.
Ness Pit	3.9		145	Unfavourable Declining	Ness Pit included in WFD funded project 2012/13. Water quality sampling from Aug 2012 to April 2013 and interpretation against WFD and CSM targets. Ness Pit had very high annual average phosphate (309ug/l) which failed target of 50ug/l. Total N also elevated. Habitat assessment undertaken in October 2008. Bird features assessed separately in December 2010.
West Ness Pit Scrape	1.3				
New Scrape	0.7				
East Ness Pit Scrape	1.4				
Barton Reedbed	1.2		141	Unfavourable Declining	Habitat assessment undertaken in October 2008. Bird features assessed separately in December 2010.
Hotel Pit	4.6		143	Unfavourable Declining	
Target Lake	2.5		146	Unfavourable Declining	

LAND USE AND LANDSCAPE

The Humber Estuary Clay Pits support some of the most extensive complex mosaic of semi-natural habitats along the Humber Estuary, comprising predominantly of saline lagoon and reedbed Biodiversity Action Plan (BAP) Priority Habitat (see Figure C.1). The surrounding landscape (Figure 2.1) is largely dominated by the Humber Estuary which forms the northern edge of the Clay Pits, with extensive arable farmland to the south and the urbanised area of Barton-upon-Humber lying between the Clay Pits themselves. There are also ecologically significant priority habitats surround the Clay Pits, these include lowland meadows, and mudflats.

Figure C.1 Far Ings Clay Pits SSSI Site Unit Information



Vegetation surveys were undertaken in 2007 and 2008 on lakes of the Clay Pits and compared with the baseline in 1987, significant declines in macrophyte diversity and abundance occurred. Little is known as to the likely causes of this, which is contributing to failure to meet appropriate target condition, although poor water quality has been suggested as a contributing factor.

FAUNA

The Humber Estuary supports an internationally important assemblage of bird species throughout the year, for breeding, over-wintering and passage[24]. The Humber Estuary regularly supports 154,000 waterfowl during the non-breeding season. Of this assemblage many are present at Far Ings NNR and include: Bittern *Botarus stellaris*, Marsh Harrier *Circus aeruginosus*, European Golden Plover *Pluvialis apricaria*, Dunlin *Calidris alpina alpina*, Common Shelduck *Tadorna tadorna* and Common Redshank *Tringa totanus*.

The Humber Estuary SSSI designation recognises the presence of nationally important numbers of wintering and passerine wildfowl, many of which are present at Far Ings NNR. These include the following (in addition to those mentioned above): Teal *Anas crecca*, Wigeon *Anas penelope*, Pochard *Aythya farina*, Goldeneye *Bucephala clangula*, Ringed Plover *Charadrius hiaticula*, Oystercatcher *Haematopus ostralegus*, Greenshank *Tringa nebularia* and Lapwing *Vanellus vanellus*. The breeding bird assemblages present at the reserve and cited in the SSSI include: Bittern, Marsh Harrier, Bearded Tit *Pamarus*

[24] http://www.sssi.naturalengland.org.uk/citation/citation_photo/2000480.pdf

biamicus, Little Grebe *Tachybaptus ruficollis*, Great Crested Grebe *Podiceps cristatus*, Mute Swan *Cygnus olor*, Gadwall *Anas strepera*, Shoveler *Anas clypeata*, Tufted duck *Aythya fuligula*, Water Rail *Rallus aquaticus*, Snipe *Gallinago gallinago*, Common Tern *Sterna hirundo*, Cuckoo *Cuculus canorus*, Kingfisher *Alcedo atthis*, Yellow Wagtail *Motacilla flava*, Grasshopper Warbler *Locustella naevia*, Sedge Warbler *Acrocephalus schoenobaenus*, Reed Warbler *Acrocephalus scirpaceus* and Reed Bunting *Emberiza schoeniclus*.

FLORA

The surrounding hawthorn scrub provides excellent nesting habitat for small birds. The Clay Pits are particularly noted for their extensive reedbeds, composed predominantly of the Common reed *Phragmites australis*. These grow in varying water depths and form dense stands which are of great importance to wildlife. Many invertebrates live on the reeds, proving a rich food source for a variety of reed-dwelling specialists such as Reed Warbler, Water Rail and the Uncommon Bearded Tit. At the reserve management work undertaken over the past 15 years has improved the reedbed habitat and created more open feeding areas with the aim of attracting Bitterns back as a nesting species. This proved successful and, after an absence of 21 years, Bitterns again began breeding at the site in 2000.

WATER QUALITY

From the Natural England study (2013[25]) , it was concluded that a number of the lakes sampled failed to meet defined environmental quality targets given in the Common Targets Monitoring Guidance for Standing Waters (JNCC, 2005) and by the UK Technical Advisory Group on the Water Framework Directive (UKTAG, 2003[26]).

With respect to the Clay Pits the data from the 2012-2013 study, which included Ness Pit and Pursuit Pit, suggested nutrient enrichment is occurring and that resulting competition from algal blooms and filamentous algae are likely to be limiting macrophyte abundance and diversity. Pasture Wharf displayed evidence of nutrient enrichment with elevated levels of orthophosphate, total phosphate (fails to achieve CSM and WFD targets), total nitrogen and chlorophyll-a.

The study also suggested that the proximity of the Humber Estuary has a large influence on the conductivity of the majority of the lakes sampled within the SSSI, with consistently elevated levels of conductivity (representative of brackish waters) being recorded in most lakes.

ANCILLARY INFORMATION ON CLAY PITS

When outlining and recommending a potential suite of actions for the future management of the site (discussed further in Section 8), in terms of addressing the poor water quality at the Clay Pits site, it should be noted that potential work could be tied into mitigation measures “not in place”.

[25] Natural England (2013) Clay Pits Nutrient Sampling, Final Report. Report prepared by JBA Consulting.
[26] UKTAG (2003) Guidance on the identification of small surface waterbodies. Final Guidance paper.

Table C.2 Ancillary information on Clay Pits ascertained from LWT study area visit

Location	Ancillary information ascertained from LWT site visit
History of Far Ings NNR	The site used to be a cement works, operational from c.1850 - 1925. The Blow Well was tapped to provide water by pipe to the cement works. Clay Pits were dug as balancing ponds, with the deepest being the ones closest to the cement works. Hotel Pit is ~6.7m deep near the hotel. After the cement works closed, the surrounding land was grazed by cattle. The Blow Well which was originally piped into Hotel Pit, was breached so that it provided freshwater into the reserve.
Non SSSI lakes (Blow Wells Pits)	The new lakes (Blow Wells Pits) to the south were dug over winters 2001, 2002 and 2003 to provide clay to cap the toxic landfill sites at Waters Edge, to the east of the NNR. The Blow Wells Pits were initially fed by the Blow Well however they are now rain fed. Aquatic plant surveys have found these sites to be rich in flora.
Hotel Pit	Used to be run as a fishery and had a reputation as being the best local carp fishery It was heavily stocked and still has a lot of resident carp today. When the LWT bought the lake in c.1996 it was no longer managed as a fishery. Hotel Pit is rain and groundwater fed. Geese do not tend to use this lake.
Pursuit Pit	Pursuit Pit used to be run by Lincolnshire Council as outdoor pursuits centre. LWT bought the lake in c.2005. The lake used to be very suitable for macrophytes until it begun to be used by geese . Canada Geese populated the lake initially, followed by Greylag Geese. Geese may have increased on the lake because there is less disturbance here and hence could provide a significant P input to the lake. Pursuit Pit is rain and groundwater fed, though may have originally been fed by the Blow Well. There is an outflow in the south leading to Far Ings Drain. There is possibly some seepage inflow from Barton Reedbed directly east of the lake, although this is unlikely as Pursuit Pit is slightly higher than Barton Reedbed. There is no connection to Bridge Pit, located to the west. There are no inflows that can be monitored.
Ness Pit	Ness Pit has never been suitable for macrophytes (check baseline survey) as it is deeper and suffers from wave wash (~10ft deep). (However our sediment sampling confirms extensive macrophytes across the lake bed, Section 5). The lake is fed by 2 x 15cm diameter pipes from East Pit, bringing water from Blow Wells (low P, high N). There is an outflow pipe to the west pits and scrapes. There are very few fish in the lake. There was previously carp while rudd and roach were introduced in 2001 for bittern (the former is particularly good for bitterns). According to LWT, there are eel present and these are encouraged into the reserve as part of the management activities. High abundance of zooplanktivorous fish reduce algal grazing, resulting in algal blooms and loss of water clarity and ultimately submerged aquatic plants. High P looks to be an in-lake problem. Geese favour this lake, although not as much as Pursuit Pit. There is a saline influence on the northern shore from the Humber Estuary.
West Pit	West Pit channels all dug in 1990s to benefit the bittern. Good for macrophytes.
Target Lake	Target Lake has two inflows from Far Ings Drain and a single outflow by sluice to Humber Estuary. This is the only outflow to the estuary for the entire reserve. This lake was not included in the monitoring programme in 2012/13 because new islands were being created with spoil from New Scrape which was being created (located immediately to the east of Target Lake).

Pasture Wharf	Pasture Wharf has an inflow from Hoe Hill, the lake immediately to the west. This inflow is blocked off because water is considered too saline. The main source of water to the lake is via precipitation. Outflow is into the large lake to the east which is a Sailing Club. Little bird use due to its small size. High P looks to be an in-lake problem. There is no saline influence in this lake. It has many fish including bream and carp. It is weedy (good macrophyte abundance).

APPENDIX D: LABORATORY RESULTS FOR WATER SAMPLES OF ALL LAKES SAMPLED (RESULTS FOR THE THREE KEY LAKES HIGHLIGHTED IN GREY)

Lake name	DO conc. (mg/l)	Total nitrogen (mg/l)	Total phosphate (mg/l)	Ammoniacal Nitrogen (mg/l)	Nitrite (mg/l)	Total Oxidized nitrogen (mg/l)	Orthophosphate (mg/l)	Suspended solids (mg/l)	Nitrate (mg/l)
Sampling Date: 20 Nov 2013									
Ness Pit	13.3	1.47	0.103	0.199	0.0352	0.36	0.077	<3	0.325
Pasture Wharf	9.07	1.70	0.107	0.283	0.0232	0.33	0.082	<3	0.307
Pursuit Pit	12.6	3.25	0.264	<0.03	<0.004	<0.2	<0.02	49.5	<0.2
Sampling Date: 18 Dec 2013									
Ness Pit	12	3.59	0.133	0.379	0.0391	2.4	0.105	9.6	2.36
Hotel Pit	16.5	2.26	0.0768	0.073	0.0082	1.31	0.034	10.6	1.3
Blow Wells Pit 3	15.1	0.84	0.0237	<0.0300	<0.00400	<0.200	<0.0200	4.67	<0.200
Barton Reedbed	12.8	3.89	0.0612	0.691	0.0355	2.27	0.022	6.1	2.23
Pasture Wharf	10.7	1.68	0.0957	0.132	0.0104	0.34	0.072	<3	0.33
Pursuit Pit	14.1	3.93	0.153	0.243	0.0146	2.33	0.025	26.1	2.32
Sampling Date: 23 January 2014									
Ness Pit	19	2.68	0.117	<0.0300	0.0241	1.21	<0.0200	16.2	1.19
Hotel Pit	19.2	1.7	0.0547	<0.0300	0.0043	0.55	<0.0200	7.5	0.546
Blow Wells Pit 3	16.5	0.89	0.0434	0.077	<0.00400	<0.200	<0.0200	17	<0.200
Barton Reedbed	15.6	2.5	0.0548	0.43	0.844	0.86	<0.0200	8.4	0.844
Pursuit Pit	15.3	2.33	0.13	0.094	0.0055	<0.200	<0.0200	27.5	<0.195
Pasture Wharf	16	1.72	0.0905	0.123	0.0064	0.27	0.058	<3	0.264
Sampling Date: 19 February 2014									
Ness Pit	18.9	1.47	0.0333	<0.0300	<0.00400	<0.200	<0.0200	8.7	<0.200
Hotel Pit	15.5	1.22	<0.0200	0.04	0.0061	0.35	<0.0200	7.2	0.344
Blow Wells Pit 3	16.6	0.74	<0.0200	0.04	0.0063	<0.200	<0.0200	3.2	<0.194
Barton Reedbed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Blow well outflow	14	17.1	<0.0200	<0.0300	<0.00400	17	<0.0200	<3	<17.0
Pursuit Pit	16.3	1.85	0.133	0.064	<0.00400	<0.200	<0.0200	22.4	<0.200
Pasture Wharf	15.1	1.62	0.0503	0.11	0.0049	0.24	0.03	<3	0.235

Lake name	DO conc. (mg/l)	Total nitrogen (mg/l)	Total phosphate (mg/l)	Ammoniacal Nitrogen (mg/l)	Nitrite (mg/l)	Total Oxidized nitrogen (mg/l)	Orthophosphate (mg/l)	Suspended solids (mg/l)	Nitrate (mg/l)
Sampling Date: 20 March 2014									
Ness Pit	18.9	1.47	0.192	<0.0300	<0.00400	<0.200	<0.0200	14.8	<0.200
Hotel Pit	15.5	1.22	0.0445	<0.0300	<0.00400	<0.200	<0.0200	15.2	<0.200
Blow Wells Pit 3	16.6	0.74	<0.0200	<0.0300	<0.00400	<0.200	<0.0200	7.52	<0.200
Barton Reedbed	N/A	N/A	0.0912	0.13	<0.00400	<0.200	<0.0200	15	<0.200
Pursuit Pit	16.3	1.85	0.171	0.033	<0.00400	<0.200	<0.0200	50.9	<0.200
Pasture Wharf	15.1	1.62	0.0406	0.114	<0.00400	<0.200	<0.0200	4.2	<0.200

APPENDIX E: SONDE DATA FOR WATER SAMPLES OF ALL LAKES SAMPLED (RESULTS FOR THE THREE KEY LAKES HIGHLIGHTED IN GREY)

Lake name	pH	Conductivity (µS/cm)	Salinity (‰)	Turbidity (NTU)	Temp (C)	Dissolved Oxygen Saturation (%)	Dissolved Oxygen concentration (mg/l)
Sampling Date: 20 November 2013							
Ness Pit	7.81	1742	0.88	0	4.72	96.8	12.37
Pasture	8.44	2143	1.09	0	5.32	68.3	8.42
Pursuit Pit	8.07	2788	1.44	41	4.28	96	12.36
Sampling Date: 18 December 2013							
Ness Pit	7.99	8711	4.84	17.1	6.08	97.5	11.72
East Ness	7.85	3673	1.92	2.3	5.63	35.6	4.3
West Ness	7.54	8377	4.65	3.2	5.67	45.6	5.48
Target Lake	7.68	8122	4.49	14.1	5.81	94.6	11.46
New Scrape	7.81	8627	4.78	9.4	5.24	107.5	12.8
Hotel Pit	8.16	7888	4.35	4.8	5.95	105.6	12.79
Blow Wells	8.61	1219	0.61	3.8	6.07	106.2	13.16
Blow Wells	8.43	1091	0.54	4.4	6.19	105.9	13.08
Blow Wells	8.06	4381	2.33	4.4	6.08	106.2	12.8
Barton	7.9	19443	11.48	12	6.33	97.7	11.16
Pursuit Pit	8.07	15548	9.02	18.1	6.36	102.5	12.8
Pasture	8.72	2423	1.25	7.9	5.66	84.6	10.52
Sampling Date: 23 January 2013							
Ness Pit	8.25	8419	4.64	6.3	4.35	123.4	5.6
East Ness	8.42	2687	1.38	13.6	4.17	56	7.23
West Ness	7.52	8012	4.42	19.1	5.41	40.3	4.94
Target Lake	7.84	7549	4.13	26.8	4.29	103.4	13.09
New Scrape	7.96	6790	3.69	20.8	4.28	105.7	13.41
Hotel Pit	8.62	7848	4.31	3.7	4.36	122.5	15.45
Blow Wells	8.57	1562	0.78	6.5	4.23	102.5	13.27
Blow Wells	8.55	1055	0.52	1.2	4.26	105.3	13.66
Blow Wells	8.17	3591	1.88	2.7	4.32	106	13.61
Barton	8.03	17381	10.11	4	4.26	102.5	12.47
Pursuit Pit	8.27	14358	8.22	25.1	4.24	110.6	13.64
Pasture	8.52	3279	1.71	0.1	4.31	90.3	11.63
Sampling Date: 19 February 2013							
Ness Pit	8.52	7582	4.17	6.3	5.36	111	13.7
East Ness	8.26	2329	1.2	0.8	5.94	77.5	9.54
West Ness	7.82	6305	3.43	6.7	6.31	81	9.77
Target Lake	8.23	6880	3.76	8	5.4	120.8	14.89
New Scrape	8.35	5534	2.99	11.4	6.43	100.4	12.13
Hotel Pit	8.36	7353	4.03	12.7	4.87	95.6	11.94
Blow Wells	8.77	1474	0.74	1.3	5.34	98.6	12.42
Blow Wells	8.54	985	0.49	1.9	5.59	98.2	12.31
Blow Wells	8.16	2976	1.55	7.9	6.01	98.4	12.13
Barton	7.89	14644	8.44	10.6	5.55	122.7	14.59
Pursuit Pit	8.21	12809	7.31	15.1	5.63	100.2	12
Pasture	8.25	3730	1.96	1.9	5.28	92.9	11.63
Blow well	7.87	921	0.46	0.4	10.19	87.6	9.8

Lake name	pH	Conductivity (µS/cm)	Salinity (‰)	Turbidity (NTU)	Temp (C)	Dissolved Oxygen Saturation (%)	Dissolved Oxygen concentration (mg/l)
Sampling Date: 20 March 2013							
Ness Pit	8.07	7100	3.91	9.9	9.26	105.1	11.77
East Ness	8.44	1341	0.67	1.4	9.02	106.8	12.28
West Ness	7.8	6123	3.34	9.7	8.63	91.2	10.39
Target Lake	8.09	6413	3.51	106.4	8.97	106.2	12.01
New Scrape	8.25	5751	3.12	10.4	8.48	100.4	11.52
Hotel Pit	8.3	7248	4	7.4	8.92	99.2	11.2
Blow Wells	8.67	1438	0.72	2.2	8.91	98.9	11.4
Blow Wells	8.5	986	0.49	3.8	9.33	99.2	11.35
Blow Wells	8.23	2728	1.42	9.1	8.82	98.9	11.38
Barton	7.96	14169	8.21	10.2	9.01	98	10.75
Pursuit Pit	8.16	12678	7.28	44.7	8.91	100.8	11.15
Pasture	8.36	4021	2.14	3	9.25	97.6	11.06