Centre for Environment Fisheries & Aquaculture Science

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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

The Wash

October 2013

Food Standards Agency

Cover photo: Shellfish boats on the Wash.

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Statement of use

This report provides a sanitary survey relevant to bivalve mollusc beds within The Wash, as required under EC Regulation 854/2004 which lays down specific rules for official controls on products of animal origin intended for human consumption. It provides an appropriate hygiene classification zoning and monitoring plan based on the best available information with detailed supporting evidence. The Centre for Environment, Fisheries & Aquaculture Science (Cefas) undertook this work on behalf of the Food Standards Agency (FSA).

Report prepared by

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Revision history

Version	Details	Approved by	Approval date
1	Draft for internal consultation	Fiona Vogt	21/10/13
2	Draft for client/consultee comment	Simon Kershaw	21/10/13
3	Final	Simon Kershaw	16/01/14

Consultation

Consultee	Date of consultation	Date of response
King's Lynn and West Norfolk Council	21/10/13	14/11/13
Fenland District Council	21/10/13	18/11/13
East Lindsey District Council	21/10/13	18/11/13
Boston Council	21/10/13	None
Eastern IFCA	21/10/13	25/11/13
Environment Agency	21/10/13	21/11/13
Anglian Water	21/10/13	12/11/13
SAGB	21/10/13	None

Dissemination

Food Standards Agency, King's Lynn and West Norfolk Council, Fenland Council, Boston Council, East Lindsey District Council. The report is available publicly via the Cefas website.

Recommended Bibliographic Reference

Cefas, 2013. Sanitary survey of The Wash. Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under EC regulation No. 854/2004.

Contents

1. Introduction

1.1. Legislative Requirement

Filter feeding, bivalve molluscan shellfish (e.g. mussels, clams, oysters) retain and accumulate a variety of microorganisms from their natural environments. Since filter feeding promotes retention and accumulation of these microorganisms, the microbiological safety of bivalves for human consumption depends heavily on the quality of the waters from which they are taken.

When consumed raw or lightly cooked, bivalves contaminated with pathogenic microorganisms may cause infectious diseases (e.g. Norovirus-associated gastroenteritis, Hepatitis A and Salmonellosis) in humans. Infectious disease outbreaks are more likely to occur in coastal areas where bivalve mollusc production areas (BMPAs) are impacted by sources of microbiological contamination of human and/or animal origin.

In England and Wales, fish and shellfish constitute the fourth most reported food item causing infectious disease outbreaks in humans after poultry, red meat and desserts (Hughes *et al.*, 2007).

The risk of contamination of bivalve molluscs with pathogens is assessed through the microbiological monitoring of bivalves. This assessment results in the classification of BMPAs, which determines the level of treatment (e.g. purification, relaying, cooking) required before human consumption of bivalves (Lee and Younger, 2002).

Under EC Regulation 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption, sanitary surveys of BMPAs and their associated hydrological catchments and coastal waters are required in order to establish the appropriate representative monitoring points (RMPs) for the monitoring programme.

The Centre for Environment, Fisheries & Aquaculture Science (Cefas) is performing sanitary surveys for new BMPAs in England and Wales, on behalf of the Food Standards Agency (FSA). The purposes of the sanitary surveys are to demonstrate compliance with the requirements stated in Annex II (Chapter II paragraph 6) of EC Regulation 854/2004, whereby 'if the competent authority decides in principle to classify a production or relay area it must:

a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;

b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human and animal populations in the catchment area, rainfall readings, waste-water treatment, etc.;

c) determine the characteristics of the circulation of pollutants by virtue of current patterns, bathymetry and the tidal cycle in the production area; and

d) establish a sampling programme of bivalve molluscs in the production area which is based on the examination of established data, and with a number of samples, a geographical distribution of the sampling points and a sampling frequency which must ensure that the results of the analysis are as representative as possible for the area considered.'

EC Regulation 854/2004 also specifies the use of *Escherichia coli* as an indicator of microbiological contamination in bivalves. This bacterium is present in animal and human faeces in large numbers and is therefore indicative of contamination of faecal origin.

In addition to better targeting the location of RMPs and frequency of sampling for microbiological monitoring, it is believed that the sanitary survey may serve to help to target future water quality improvements and improve analysis of their effects on shellfish hygiene. Improved monitoring should lead to improved detection of pollution events and identification of the likely sources of pollution. Remedial action may then be possible either through funding of improvements in point sources of contamination or as a result of changes in land management practices.

This report documents the information relevant to a sanitary survey undertaken for cockles (*Cerastoderma edule*) and mussels (*Mytilus* spp.) within The Wash. The area was prioritised for survey in 2013-14 by a shellfish hygiene risk ranking exercise of existing classified areas. The survey also considered Razors (*Ensis* spp) in The Wash although any dredge fishery for this species is banned on conservation grounds.

1.2. Area description

The Wash, England's largest tidal embayment (MMO, 2013), is situated on the east coast of England and is bordered by the counties of Lincolnshire and Norfolk (Figure 1.1). It has some estuarine characteristics having four canalised river estuaries feeding into it. A wide mouth (20 km) connects it to the North Sea. The Wash covers an area of approximately 667 km² of which 45% is intertidal (Futurecoast, 2002).

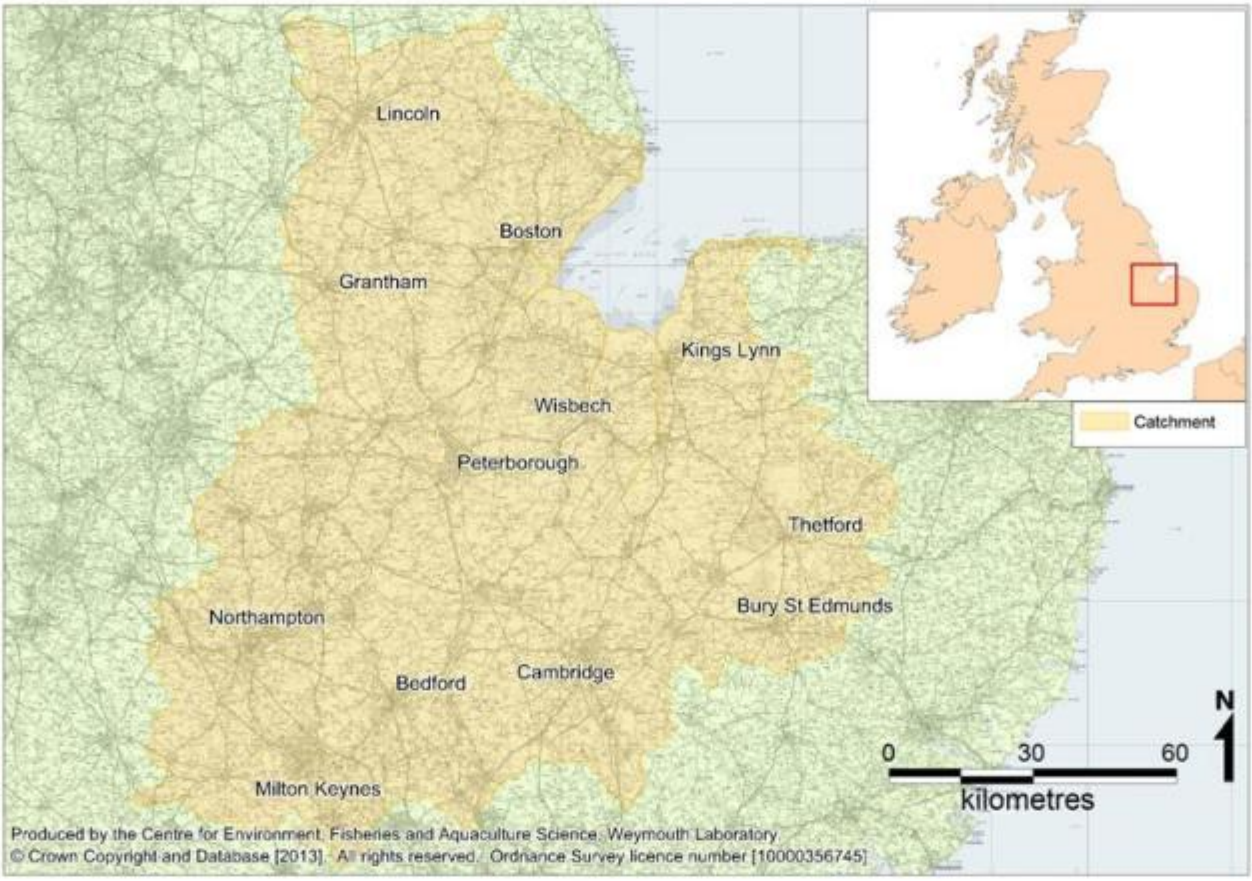

Figure 1.1 Location of The Wash

Four main rivers flow into The Wash; the Witham, Welland, Nene and Great Ouse. These are heavily engineered lowland rivers which have long, canalised estuaries that extend a significant distance inland. Most of the adjacent land has been reclaimed and is now high grade agricultural land. The majority of the coastline is flanked by earth banks fronted by extensive saltmarshes, mudflats and sandflats. Further offshore there are intertidal sandbanks lying between parallel subtidal channels. There are cliffs at Hunstanton, and sand dunes at Gibraltar Point. The Wash is protected by several conservation designations, mainly in recognition of the fact it hosts the largest aggregation of overwintering waterbirds in the UK as well as a large seal colony. The principal bivalve mollusc fisheries it supports are for cockles, mussels.

1.3. Catchment

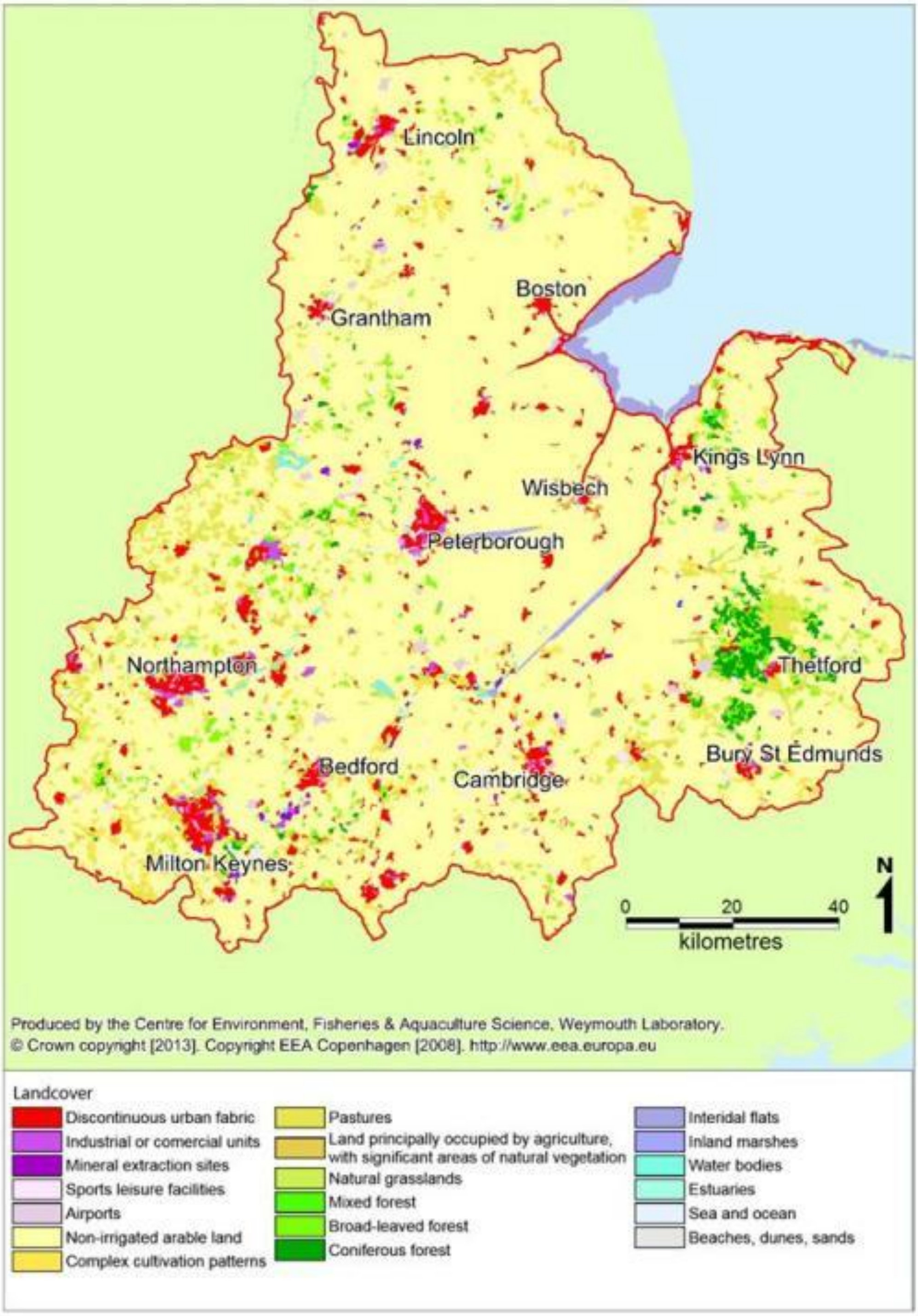

Figure 1.2 Landcover in The Wash catchment area

Figure 1.2 illustrates landcover within the hydrological catchment of The Wash, which covers an area of 15,920 km^2, about 12% of the total area of England. It is predominantly covered by arable farmland with some pockets of pasture and woodland. There are also some significant built up areas, the majority of which lie inland. The towns of King's Lynn and Boston are situated on the tidal Ouse and

Witham (The Haven), respectively. The total resident population within the catchment is about 3.6 million.

Different land cover types will generate differing levels of contamination in surface runoff. Highest faecal coliform contribution arises from developed areas, with intermediate contributions from the improved pastures and lower contributions from the other land types (Kay *et al*. 2008a). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, particularly for improved grassland which increase up to 100 fold.

The underlying geology of the catchment comprises of a mixture of bedrock, predominantly mudstone with bands of clay, limestone and sandstone. Land directly surrounding The Wash comprises of low permeability mudstones and clay bedrock (EA, 2009 a,b,c and EA, 2011).

2. Recommendations

The Wash is a vast area, but the main fluxes of contamination into it are via the four river outfalls. It is likely that there are other minor hotspots of contamination, for example within intertidal drainage channels which may carry freshwater inputs or contamination washed off salt marshes. The requirement not to increase monitoring effort significantly means that the zoning and monitoring arrangements will be principally based on the main inputs. It will not be practical to further subdivide the area into smaller zones and propose RMPs to specifically capture the more minor inputs.

Currently, The Wash consists of two production areas; Boston and King's Lynn. The redefined boundaries do not align exactly with these definitions, as the dividing line lies along a river channel. From a hygiene zoning perspective it is more appropriate to define a single zone around the river outfall rather than having two zones extending into the most contaminated area around the outfall. It is therefore proposed that The Wash should be redefined as a single production area. The locations of the individual RMPs will identify to which LEA they belong.

It is recognised that shifting stock distributions may result in changes to the exact location of some RMPs. Where needs be, RMP locations may be adjusted to reflect this. Any change in RMP location should follow the principles identified in these recommendations to ensure they are best protective of public health. New RMP locations should be recorded via GPS, on sample submission forms, and communicated to Cefas.

Where possible/appropriate zone boundaries are aligned along lines of latitude and longitude. This way a GPS reading should clearly identify which zone a vessel is in.

2.1. Mussels

<u>Heacham & Hunstanton.</u> The only mussel resources which fall within this zone are the stocks off Hunstanton. As this area is not subject to survey the current extent of these beds are uncertain. Sources of contamination to this zone include the residual effects of the Ouse and Nene river outfalls, the Heacham River, a cluster of unmonitored intermittent sewage discharges at Hunstanton, urban runoff principally from Hunstanton and possibly the River Ingol to the south. More diffuse sources such as dogs and wildlife may also contribute. It is therefore recommended that the RMP be located at the south eastern extremity of the mussel bed off Hunstanton. The existing RMP (Hunstanton Holmeside) appears suitable, although may require slight relocation to align with the south eastern tip of the beds.

Ouse Mouth

There are some mussel stocks on the Ouse training wall, although these are not a major resource, and Eastern IFCA note that in recent years much of the wall has become covered in sediment. The mussels lie within an area of significantly increased contamination around the river Ouse outfall, where class B compliance may be borderline. Eastern IFCA informed us that unlike the mussels on the Welland Wall, these mussels on this wall are not considered sufficient to warrant surveying and are not opened to the fishery. It is therefore recommended that this relatively small zone is excluded from classification. North of the mouth of the Ouse there are significant stocks over several mussel beds and lays on Breast Sand and the deltas extending from the mouth of the River Ouse. The River Ouse is likely to be the main source of contamination. This zone also receives the River Ingol, but this is some distance from any shellfish resources. It is therefore recommended that the RMP be located at the mouth of the river Ouse.

Nene Mouth. This zone includes several major beds and lays. The main source of contamination is the Nene outfall. None of the mussel beds are particularly close to the outfall. It is therefore recommended that a cockle RMP on the inshore western tip of the bed just to the east of the channel is used. This should be suitably protective of public health and remove the requirement to sample mussels in this zone as well. The IFCA inform us that access to this site from the Nene channel is however difficult. The ground along the edge of the sandbank at that point is very muddy and crossed with a number of deep creeks. This could be particularly problematic if the site needed to be accessed from shore due to poor weather conditions. This would not be a problem if the sample could be dredged rather than hand-picked, either would be acceptable.

Mare Tail, Gat and Toft. This zone includes several major beds and lays. It lies between the Nene and the Witham/Welland outfalls, but is not particularly close to either. The Welland/Witham outfall is closer and also probably delivers more contamination than the Nene. It is therefore recommended that the RMP be located on the eastern side of the Lays at Toft, the location most exposed to the remnants of the ebb plume from the outfall.

Welland and Witham Inner. This zone only includes the Welland Wall bed, which covers the training wall for the Welland channel, and meets the Witham channel at its northern end. Both the Welland and Witham are the major influences within this zone. The Witham is likely to present the greater risk due to the presence of Boston STW. Class B compliance here is unlikely, so a relatively small zone should be established around this single bed. It is recommended that the existing RMP at Welland Wall, positioned at the northern end of the wall by the Witham outfall, is retained.

Welland and Witham Outer. This zone is also primarily influenced by the Witham and Welland, but the influence will be considerably weaker than at Welland and Witham Inner. To avoid proposing another RMP, the proposed cockle RMP at Black Buoy, adjacent to the Welland Witham channel should be suitably representative of the mussels. There is a small mussel lay about 500 m closer to the Witham/Welland outfall which would theoretically be preferable to monitor but the IFCA adivse that this has never been used. Also, this slight concern may be mitigated to some extent by the tendency for cockles to accumulate *E. coli* to higher levels than mussels.

2.2. Cockles

Given the different distribution of cockles, specifically that they do not extend into the trained outfall channels where peak levels of contamination will arise, and where class B compliance may be borderline, only five zones are proposed for cockles:

Heacham & Hunstanton. This zone only includes cockle stocks which fall within the private fishery. There is no firm information on their distribution but it is thought that the harvestable concentrations lie mainly on the intertidal off Heacham. There may be some underlying influence from the Ouse and Nene river outfalls within the area, which is likely to be more marked at the southern boundary of the zone. Local sources include the Heacham River, and possibly the River Ingol, which discharges to the south of this zone. An RMP located on Stubborn Sand, by the drainage channel from the Heacham River outfall towards the southern end of this zone will capture any localised decrease in water quality around the river outfall as well as any influence from the main river outfalls to the south.

Ouse Mouth. Within this zone there are considerable stocks of cockles on the mud and sandbanks around the mouth of the river Ouse outfall, which is likely to be the main source of contamination. It is therefore recommended that the RMP is located as close to this outfall as stocks extend.

Nene Mouth. Within this zone there are considerable stocks of cockles on the mud and sandbanks around the mouth of the river Nene outfall, which is likely to be the main source of contamination. It is therefore recommended that the RMP is located as close to this outfall as stocks extend.

Witham and Welland. Within this zone there are considerable stocks of cockles on the mud and sandbanks to the east of the combined Witham/Welland outfall, which is likely to be the main source of contamination. It is therefore recommended that the RMP is located at Black Buoy, as close to the combined outfall as stocks extend.

Freiston to Wainfleet. This is a large zone which includes a continuous cockle bed covering the intertidal flats between Freiston and Wainfleet. The main contaminating influence is the rivers Welland/Witham outfall, although the Wainfleet Haven and other smaller outfalls may result in localised hotspots at times. It is therefore recommended that the RMP be located at North Lays (Witham Bank) on the cockle bed in the south west of the zone.

2.3. *Ensis* spp.

Dredging for razor clams in the Wash is banned under 1998 No. 1276 Sea Fisheries, Conservation of Sea Fish, The Razor Shells, Trough Shells and Carpet Shells (Specified Sea Area) (Prohibition of Fishing) Order 1998 managed by Defra. A sampling plan is however provided for the two relatively small areas previously identified for the experimental dredge fishery. These areas will only require sampling and classification should the situation change following a formal request, and subject to the Defra and Eastern IFCA confirming it would be acceptable.

These two areas are several km offshore and lie in the shallow subtidal. As such the primary influences here are likely to be the Ouse and to a lesser extent the Nene. There are no other major sources in the area which may cause significant localised variation. As such there is likely to be relatively low levels of contamination originating from distant sources, and an overall decrease in contamination from the southwest of the inner site to the north east of the outer site. Historical *E. coli* monitoring of the razor clams, although limited, supports this assertion. It is therefore recommend that the former razor clam RMP at Seal Sand be reinstated and may be used to classify both areas.

A specially adapted dredge will be required to sample this species. Sampling should be monthly, unless classification is required more rapidly, in which case a provisional classification may be awarded on the basis of 10 samples taken not less than a week apart. Samples should be of a harvestable size, which is 100mm at present but may possibly be reviewed if a fishery does develop. A tolerance of 100m should allow repeated sampling.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	The Wash (Boston) & The Wash (King's Lynn)
Cefas Main Site Reference	M003 & M004
Ordnance survey 1:25,000 map	Explorer 249, 250 261 & 274
Admiralty Chart	1200

Shellfishery

Species/culture	Cockles Mussels *Ensis* spp.	Wild Wild/cultured Wild
Seasonality of harvest	There is some seasonality to these fisheries, but harvest may potentially occur at any time of the year for all species.	

Local Enforcement Authorities

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3.2. Requirement for Review

The Guide to Good Practice for the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas (EU Working Group on the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas, 2010) indicates that sanitary assessments should be fully reviewed every 6 years, so this assessment is due a formal review in 2019. The assessment may require review in the interim should any significant changes in sources of contamination come to light, such as the upgrading or relocation of any major discharges.

Table 3.1 Number and location of representative monitoring points (RMPs) and frequency of sampling for classification zones within The Wash

Mussel classification zones	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Specied sampled	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Heacham & Hunstanton	B004L	Hunstanton Holmeside[1]	TF 6750 4200	52°56.95'N 00°29.50'E	Mussels	Wild	Hand or dredge	Hand	100m	Monthly	Existing RMP. Please ensure it is located on the south eastern tip of this bed. Foot access RMP.
Ouse Mouth	B04AK	Ouse Mouth[1]	TF 5827 2800	52°49.58'N 00°20.86'E	Mussels	Wild	Hand or dredge	Hand	100m	Monthly	Existing RMP. Please ensure that this is a far up the channel as stocks extend. Boat access.
Nene Mouth	B04AL	Nene Mouth[2]	TF 5005 2801	52°49.72'N 00°13.54'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	This RMP is also used to classify Nene Mouth mussels. Boat access.
Mare Tail, Gat and Toft	B003V	Toft[3]	TF 4423 4098	52°56.81'N 00°08.71'E	Mussels	Wild	Hand or dredge	Hand	100m	Monthly	New RMP. Boat access.
Welland and Witham Inner	B003M	Welland Wall[3]	TF 3990 3920	52°55.92'N 00°04.80'E	Mussels	Wild	Hand or dredge	Hand	100m	Monthly	Existing RMP. Boat access.
Welland and Witham Outer	B04AO	Black Buoy[3]	TF 4140 3986	52°56.25'N 00°06.15'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	New RMP. Boat access.

Cockle classification zones	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Specied sampled	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Heacham & Hunstanton	B04AP	Stubborn Sand[1]	TF 6596 3701	52°54.29'N 00°27.97'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	New RMP. Should be accessible on foot.
Ouse Mouth	B04AM	Ouse Mouth[1]	TF 5827 2800	52°49.58'N 00°20.86'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	New RMP. Boat access.
Nene Mouth	B04AL	Nene Mouth[2]	TF 5005 2801	52°49.72'N 00°13.54'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	This RMP is also used to classify Nene Mouth mussels. Boat access.
Witham and Welland	B04AO	Black Buoy[3]	TF 4140 3986	52°56.25'N 00°06.15'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	This RMP is also used to classify Welland and Witham Outer mussels. Boat access.
Freiston to Wainfleet	B003F	North Lays[3]	TF 4198 4155	52°57.15'N 00°06.72'E	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	New RMP. Boat access.

Razor classification zone	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Specied sampled	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Sunk Sand and Seal Sand	B04AJ	Seal Sand[1]	TF 5800 3700	52°54.43'N 00°20.88'E	*Ensis* spp.	Wild	Dredge	Dredge	100m	Monthly (10 samples 1 week apart for provisional)	**Dredging prohibited** Access by boat.

Local enforcement Authority: [1] Kings Lynn & W Norfolk BC, [2] Fenland DC, [3] Boston BC

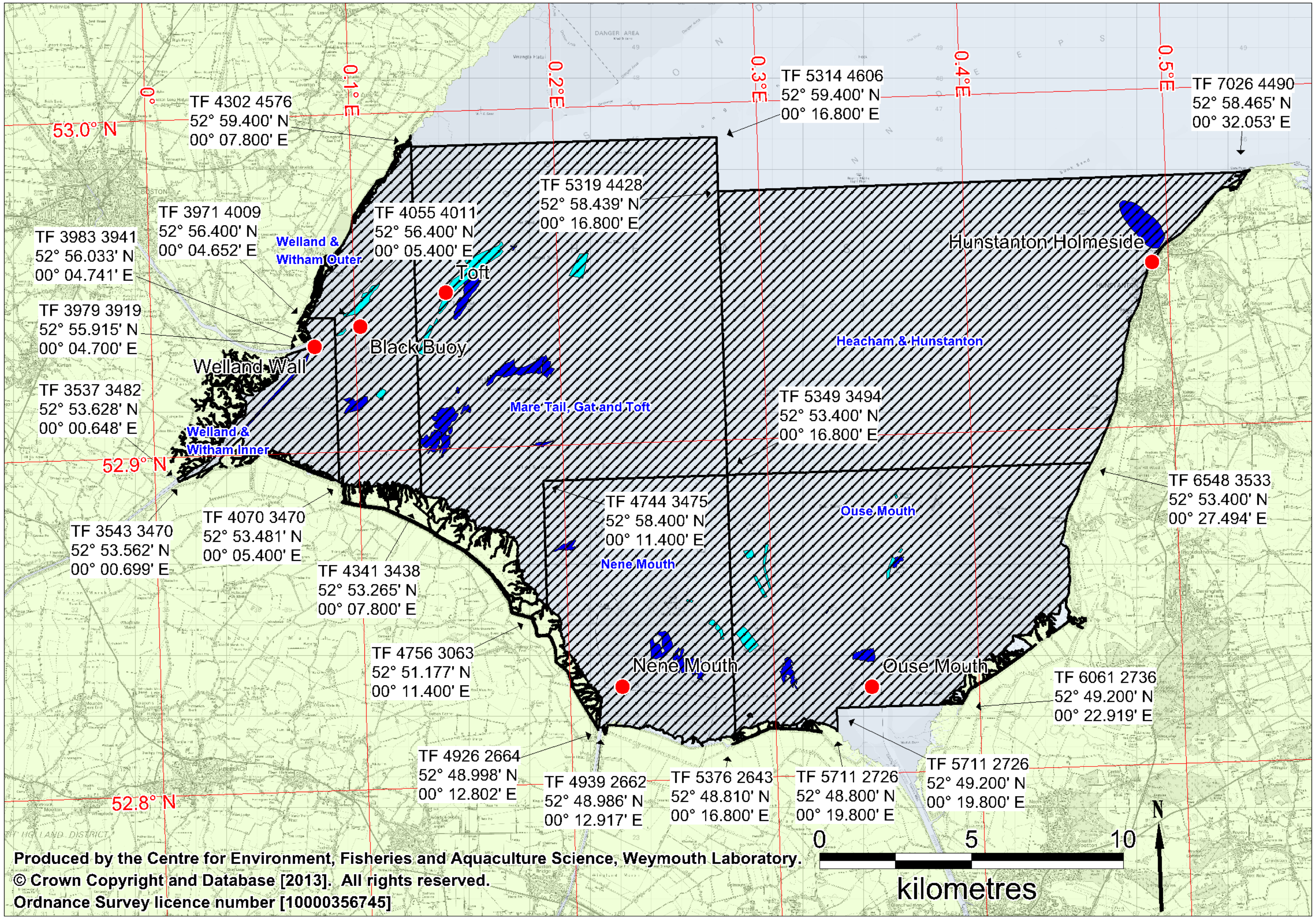

Figure 3.1: Recommended zoning and monitoring arrangements (mussels)
Shellfish data from the Eastern IFCA

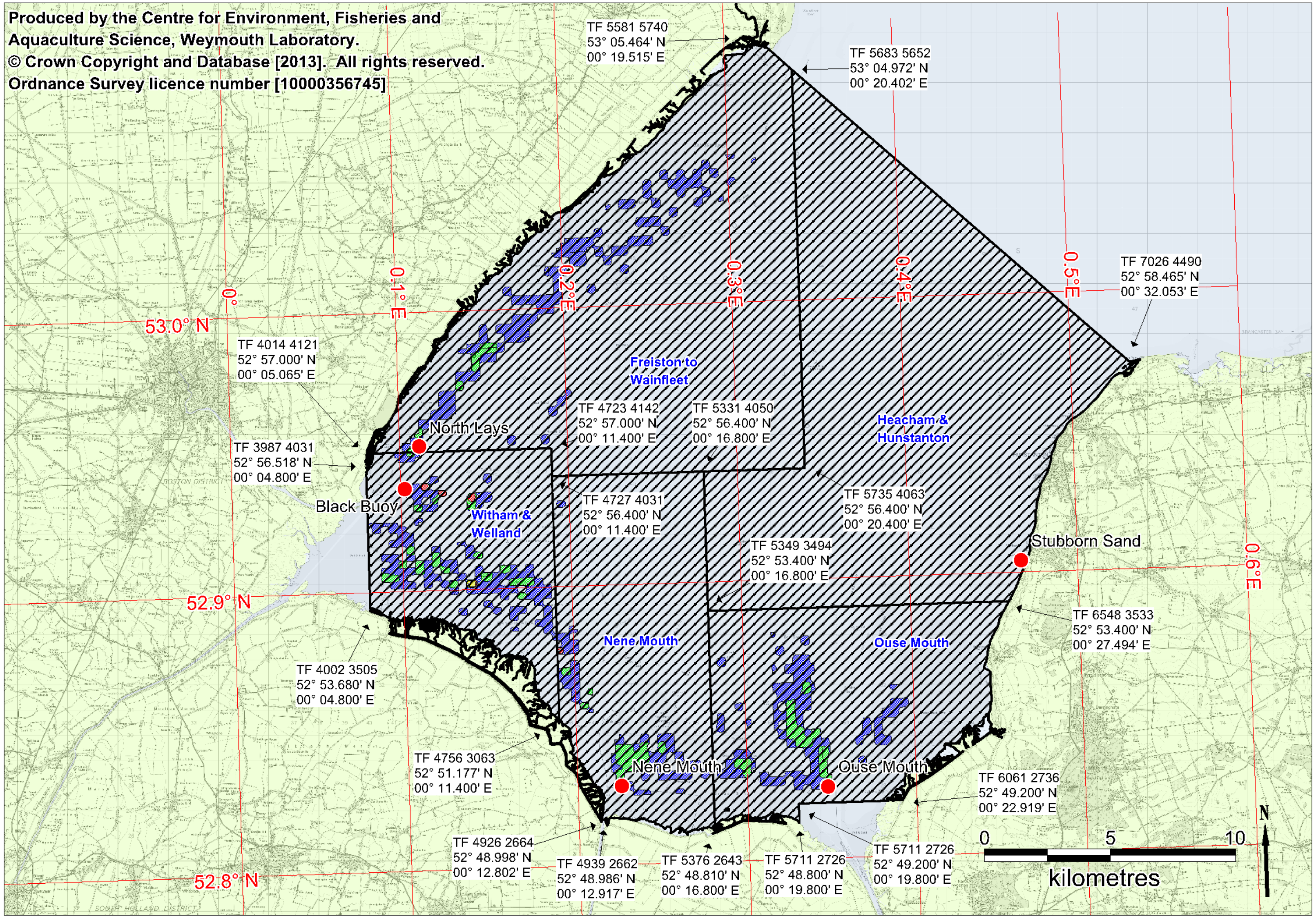

Figure 3.2: Recommended zoning and monitoring arrangements (cockles)

Shellfish data from the Eastern IFCA

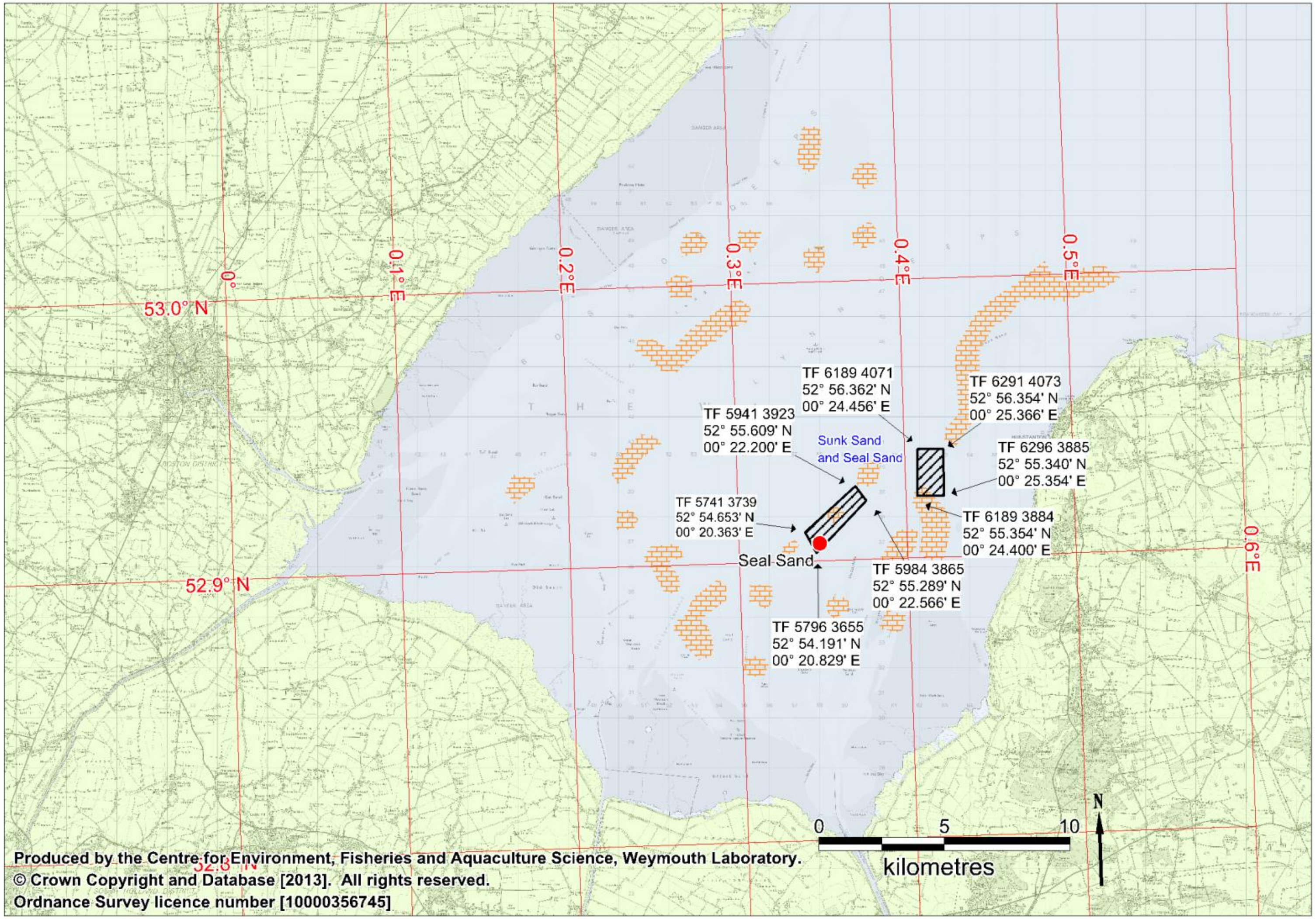

Figure 3.3: Recommended zoning and monitoring arrangements (*Ensis* spp., if required)

Shellfish data from the Eastern IFCA

4. Shellfisheries

4.1. Species, location and extent

The Wash supports major fisheries for cockles and mussels and is currently classified for the harvest of both. There are also likely to be numerous other bivalve species present, but the only other commercial bivalve fishery that has operated in recent years was an experimental dredge fishery for razors (*Ensis directus*). Pacific oyster culture has historically occurred at Toft. Eastern IFCA confirm this was only a small site comprising approximately 20 tables and that between 1996 and 2002 there was a much larger site at Butterwick that supported approximately 2000 tables. In 2009, an interest in culturing native oysters on Thief Sands was expressed, but this was not followed up with an application for classification.

Most of the survey area is managed under The Wash Fishery Order 1992, which covers cockles and mussels as well as clams, scallops and oysters with the Eastern IFCA as the grantee of the order. The remaining area is a private fishery, owned by the Le Strange estate and leased to a tenant fisherman. Whilst the cockle and mussel stocks within the Wash Fishery Order 1992 are subject to regular surveys by the IFCA, there is no current information available on their distribution and status within the Le Strange estate. The exact boundaries of the private grounds are uncertain, and are understood to change as the profile of the foreshore changes. It is reported that they extend ‘as far as a man riding a horse can throw a javelin from the low-tide mark’ (Visitoruk.com, 2013). Due to these changes, the boundary has been subject to repeated legal challenge.

Cockles

Figure 4.1 shows the locations of the concentrations of adult cockle stocks within the Wash Fishery Order, from the 2013 spring cockle survey undertaken by the Eastern IFCA.

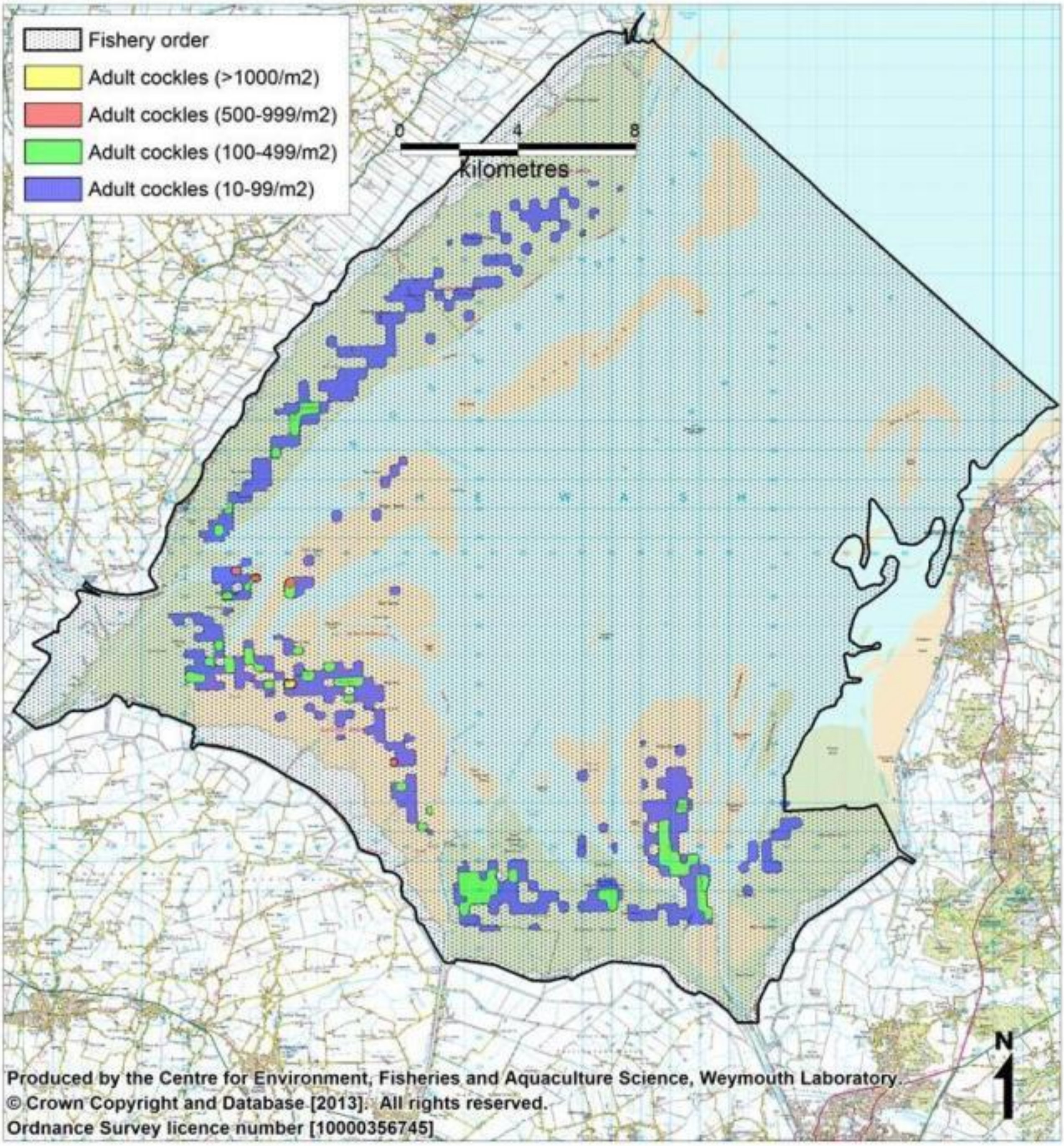

Figure 4.1: Distribution and densities of adult (>14mm) cockles within the fishery order, spring 2013
Shellfish data from the Eastern IFCA

Cockles are widely distributed through the intertidal of the Wash on both the Le Strange Estate and inside the Wash Fishery Order 1992 boundaries. They are present in commercially exploitable densities across large areas. Although the exact distribution of commercially exploitable densities varies slightly it remains broadly similar from year to year. The Eastern IFCA spring cockle surveys in 2012 found 21,106 tonnes of cockles, of which 7,107 tonnes were of 'adult' cockle (greater than 14mm shell width) (Eastern IFCA, 2012). Cockles are also widely distributed in the intertidal off the Heacham and Snettisham area. Cockles within the Le Strange grounds are not surveyed by Eastern IFCA.

Mussels

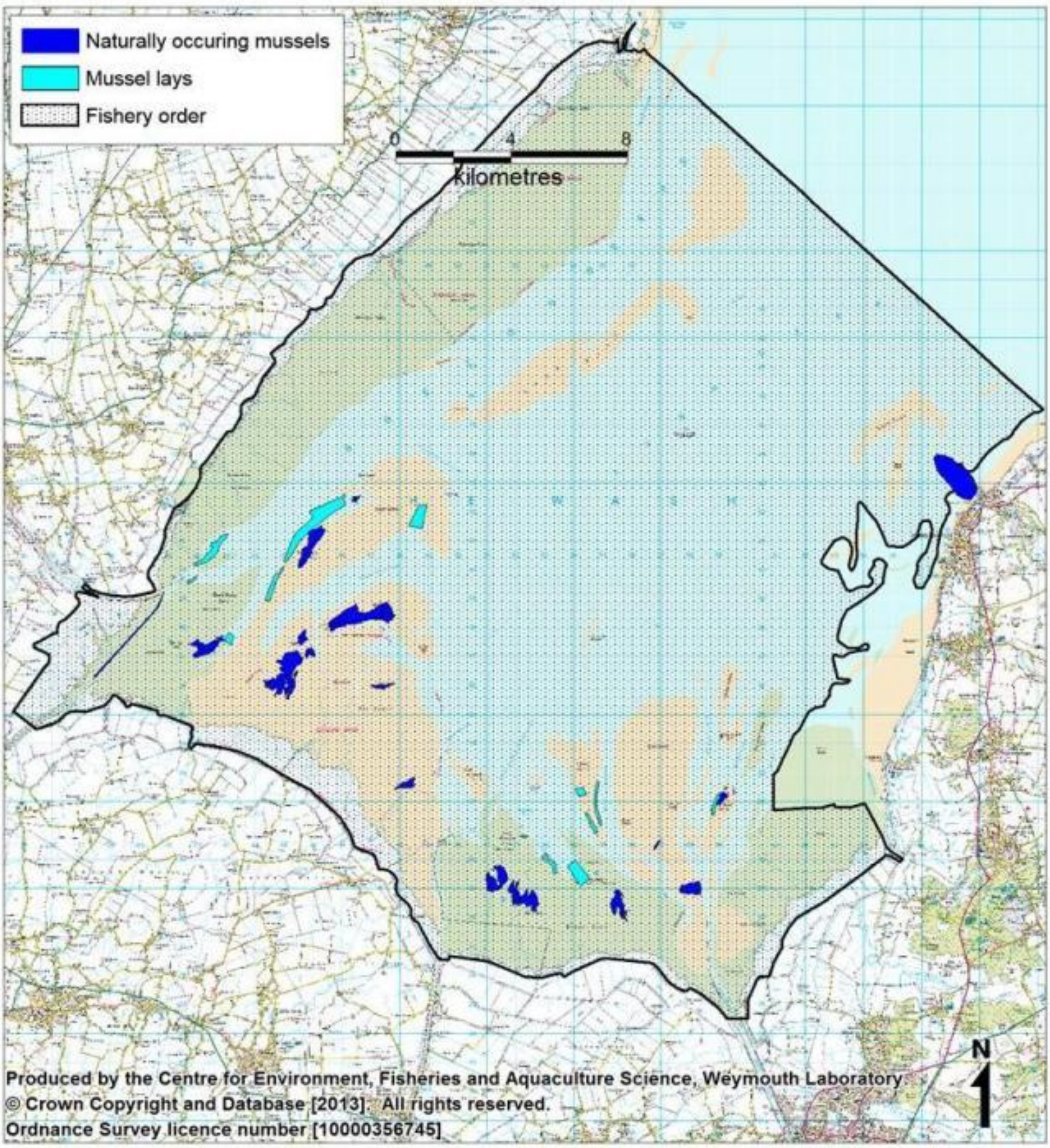

Figure 4.2: Naturally occurring mussel beds (autumn 2012 survey) and mussel lays
Data from the Eastern IFCA

Mussels form discrete, dense raised beds on firm substrates such as stones and shells where there may be as much as 20 kg of mussels per m^2. The 2012 autumn mussel survey estimated there were 12,707 tonnes of mussels present on the surveyed natural beds, of which 4,174 tonnes were of an adult size (Eastern IFCA, 2012). The beds surveyed (including the Welland training wall) covered an area of 408 Ha. According to historical records held at Cefas, there is a mussel bed within the Le Strange fishery off Brancaster. Although mussel beds were present off Snettisham in 1940 (Dare *et al*, 2004) today only the Hunstanton bed persists within the private grounds. Historically, mussels have never colonised the intertidal off the Wrangle to Wainfleet area.

The location of natural mussel beds remains stable year on year, as spat tends to settle on established beds only. The density and size distribution of animals within each individual bed varies significantly from year to year, depending largely on the success of spatfalls. Exceptional spatfalls may result in increases of the area of existing beds, or even the establishment of new beds. Storms and predation may reduce or remove existing beds, particularly those at lower elevations.

The wild mussel fishery mainly targets faster growing stocks with higher meat yields which occur at lower levels. Lower quality stocks from beds at higher elevations may be transplanted to the lay areas further down the shore (Dare *et al*, 2004). The lays are leased to individual fishermen by the IFCA. The focus of recent fisheries has been for seed mussel for relaying onto the private lays.

Razors

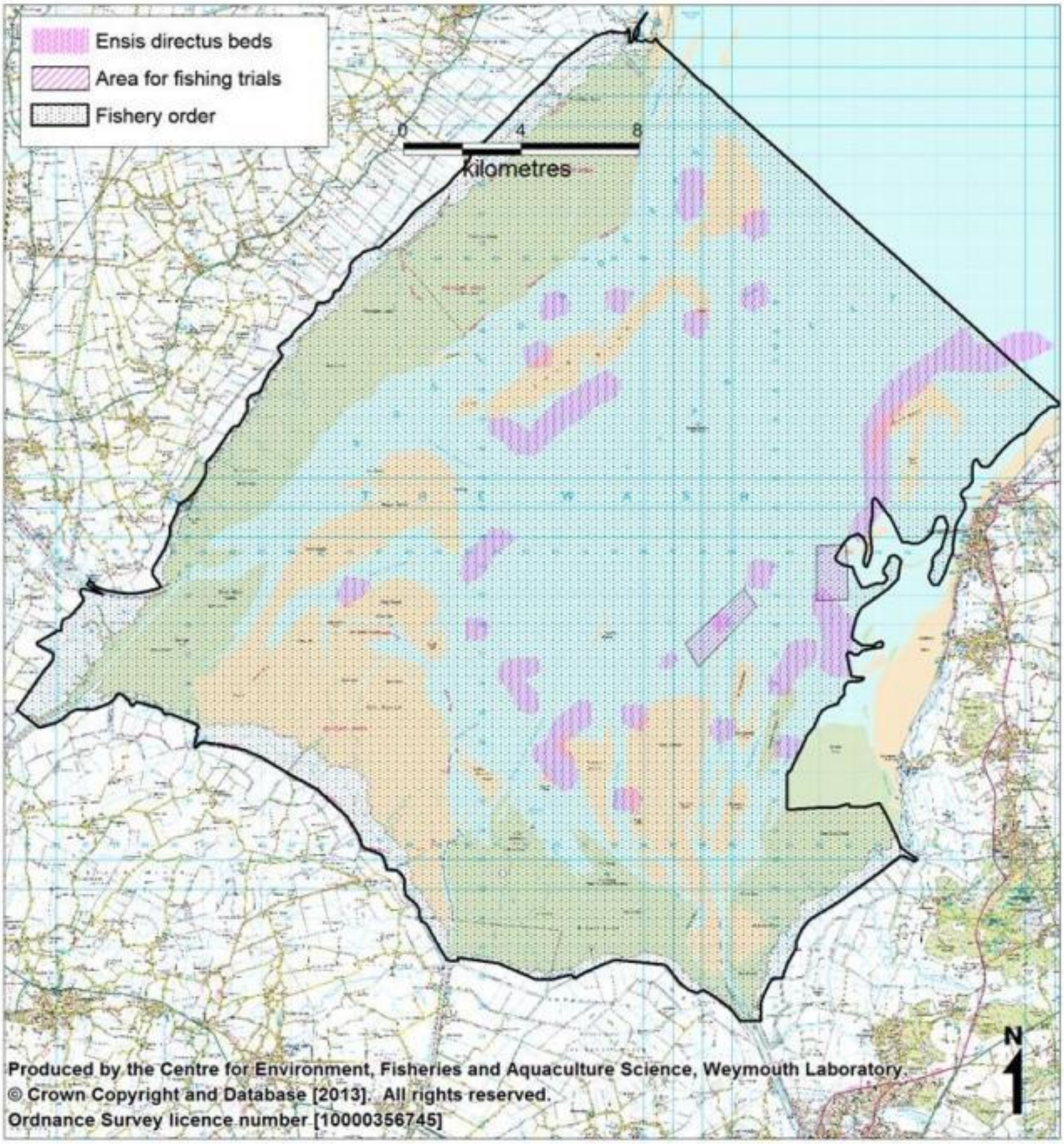

Figure 4.3: Approximate distribution of *Ensis directus* and areas identified for experimental fishery

Razors are mainly found in the shallow subtidal. Most are *Ensis directus*, a non native razor clam more tolerant of lower salinities than the native species. It is a small, relatively slow growing species and majority of stocks are below the minimum landing size of 100mm for Ensis *spp*. Some interest in exploiting these stocks has been expressed by local fishermen at various points since the late 1990s when other local fisheries (cockles, shrimps) were not performing well. Trials identified a suitable dredge configuration as well as two areas supporting relatively high densities of larger animals where the substrate was mobile and so dredge tracks would be of little lasting impact (Addison *et al*, 2006). Applications to exploit these two areas via an experimental commercial fishery were invited, but none has been received to date. Some informal interest has arisen very recently (Dave Palmer, Cefas Lowestoft, pers comm.).

4.2. Growing methods and harvesting techniques

Cockles and razors are both self sustaining wild stocks. As well as naturally occurring wild mussel beds, there are also managed lays where they are ongrown from seed. Seed stocks are transplanted from areas where growth is poor, typically from mussel settlements higher up the intertidal, and cultured on the seabed within the lay areas.

Currently, cockle stocks within the Wash Fishery Order are harvested via hand gathering. Boats beach on the sandbanks and fishermen hand gather the cockles over low water on foot. A technique referred to as 'prop washing' may be used, whereby the boats propeller wash is used to erode the substrate over the beds, thereby exposing the cockles to facilitate subsequent hand gathering. Suction dredging may be used under certain circumstances. Within the Le Strange private grounds harvesting of cockles is via suction dredging. The harvest of mussels from the Wash is either via hand gathering or dredging. The potential razor fishery, if permitted at some point in the future would require a specially configured fluidised dredge to extract them from the substrate whilst keeping damage rates as low as possible.

4.3. Seasonality of harvest, conservation controls and development potential

The cockle fishery within the fishery order is managed via annual quotas. Eastern IFCA base the total alloable catch (TAC) on adult stocks that have attained 14mm width, although there is no MLS for cockles in the Wash. To an extent market drivers limit exploitation of stocks below this size and IFCA policy is to keep areas of predominantly juvenile stocks closed. The fishery has 67 entitlements for which 65 licences are currently active. There are a set of agreement management policies that set out biological and biodiversity limits to operating the fishery. Surveys are undertaken in the spring, and following this fishery proposals are made, the industry are consulted, and appropriate assessments undertaken. The fishery usually opens in June or July, and usually finishes in the early autumn when the quota is exhausted. Some years it may resume in the late spring if the quota remains unused. Presently the fishery is hand gathering only, although the use of dredges may be permitted in some areas under certain circumstances, for example where the proportion of undersize cockles is low or rapid atypical dieoff is occurring and stocks would otherwise be lost. Some areas may be closed entirely, for example where the stock is mostly young of the year settlement. Landings will vary from year to year with natural fluctuations in stocks but the current management regime diminishes the chance of overexploitation and attempts to maintain a relatively stable fishery.

The management philosophy for natural mussel beds within the fishery order is very similar to that for cockles. It is only open to the licence holders when management policies and objectives are met.. Surveys are undertaken in the autumn, after which annual quotas are set. Traditionally, market mussels have been mainly harvested in January and February, but in recent years mussel harvests have occurred in early autumn of the following year immediately after the cockle fishery finishes. As the lays are effectively private fisheries with no controls, no conservation controls apply to stocks on the managed lays, and these are not included in stock biomass estimates used for quota setting.

Any fishery for *Ensis* would be subject to a minimum size of 100mm. This is approaching the maximum size for *Ensis directus*, and the majority of stocks are undersized. It is possible the minimum size could be reduced on the grounds that this is not a native species. There is no formal closed season for this species. An appropriate assessment would be required before any *Ensis* fishery could be opened, and it is likely that additional conservation controls would result from this.

The fisheries within the Le Strange grounds are private and fall outside the Eastern IFCA's district, so are not subject to any conservation controls aside from those in national and European legislation. Harvesting here may occur at any time of the year.

4.4. Current zoning / monitoring arrangements and sampling considerations

The Wash is divided into six zones, each of which is monitored and classified by between one and three RMPs (Figure 4.4).

Figure 4.4: Current zoning and monitoring arrangements

The zone boundaries were originally proposed by the Eastern Sea Fisheries Joint Committee (ESFJC, now the Eastern IFCA) as practically enforceable areas using sand banks, river channels, and known (discrete) shellfish areas. They are used for biotoxin monitoring as well as hygiene classification purposes so introducing a new hygiene zonation may have some knock on effects for this programme.

In a review of hygiene monitoring undertaken in 2008, the ESFJC indicated that if the zonation was to be altered, the preference is for the boundary lines to follow simple rounded lines of latitude and longitude. The use of channels and buoys to delineate zones would be problematic as the channels are mobile and the buoys are moved as the bathymetry changes.

Sampling at all the RMPs, aside from the mussel RMP at Hunstanton, is undertaken by Eastern IFCA on behalf of the local authorities. This involves taking a vessel out from Sutton Bridge, and deploying a sampling team from this vessel on a rigid inflatable, which beaches on the sandbanks where the samples are collected. Two sampling days are required each month to get around all the sampling locations, and this incurs significant costs which are not fully offset by the local authorities. An increase in the number of RMPs may require an additional days sampling run, and should be avoided if possible.

Tide sizes and times constrain the dates on which this can occur, and weather conditions may prevent sandbanks becoming exposed or possibly prevent the vessel leaving port altogether. Some of the RMPs can be accessed on foot if required, but this is more labour intensive. Accessing from land is a good alternative when weather conditions prevent the vessel putting to sea. Inevitably some months not all RMPs are successfully sampled. RMPs at higher elevations are exposed for longer and can therefore be sampled over a longer time window.

In some zones, only one species is monitored and the results are used for the classification of both cockles and mussels. This approach was justified on the basis of the compliance with classification thresholds at the various RMPs when the sampling plan was reviewed in 2008. There is no formal policy for the use of surrogate species at present, but it has been reported that whilst the two species accumulate *E. coli* to similar levels in statistical terms, a tendency for cockles to return more extreme high results has been noted (Younger & Reese, 2011). As such, the use of cockles to classify mussels can be justified as suitably protective of public health, but not the reverse. Where there is the possibility of class A compliance, or where class B compliance is borderline, the species sampled should be the species to be classified to be sure a fair classification results. Most of The Wash complies solidly with a B classification so the use of cockle results to classify both species will be acceptable. In the vicinity of the river outfalls class B compliance is more marginal, but the main species present here are mussels on the training walls which do not form a major bed for the fishery, and are often used to as seed for relaying onto lays both inside and outside the Wash.

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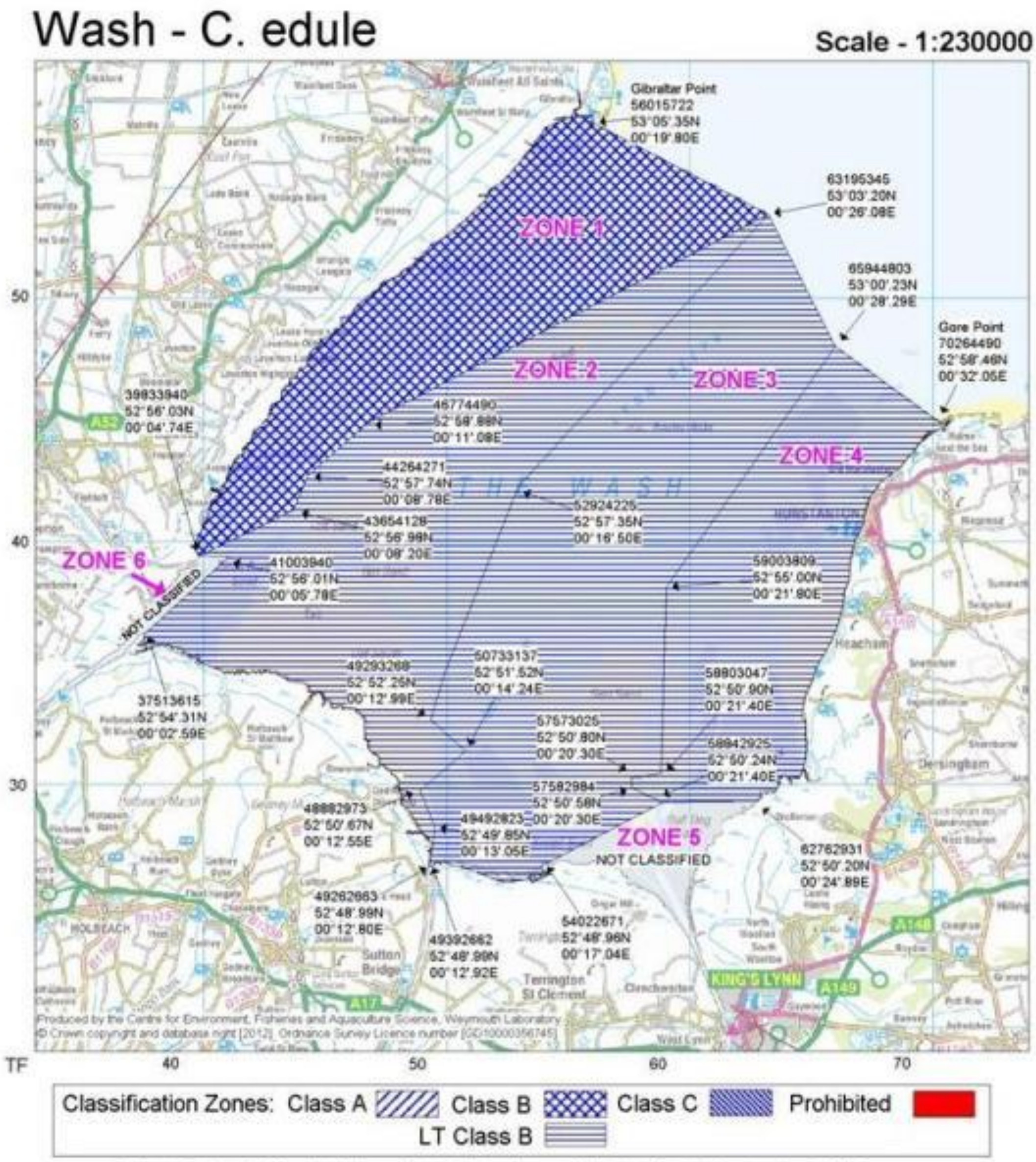
4.5. Hygiene Classification

Table 4.1: Classification history for the Wash, 2004 onwards

Bed name	Species	2004	2005	2006	2007	2008	2009	2010	2011	2012
Toft Ridge	C. gigas	B								
Toft South	C. gigas	B								
Toft Lays	Cockles						B-LT	B-LT	B-LT	B-LT
Herring Hill	Cockles						B-LT	B-LT	B-LT	B-LT
Black Buoy	Cockles						B-LT	B-LT	B-LT	B-LT
Holbeach	Cockles						B-LT	B-LT	B-LT	B-LT
Friskney	Cockles			B	B	B	B	B	B	B
Butterwick	Cockles			B	B	B	B	B	B	B
Gat Sand	cockles			B	B	B	B-LT	B-LT	B-LT	B-LT
Maretail/E. of Welland	Cockles				B	B	B-LT	B-LT	B-LT	B-LT
Wrangle	Cockles						B	B	B	B
Toft Ridge	Cockles						B-LT	B-LT	B-LT	B-LT
Toft South	Cockles						B-LT	B-LT	B-LT	B-LT
Stylemans	Cockles						B-LT	B-LT	B-LT	B-LT
Ferrier Sand	Cockles						B-LT	B-LT	B-LT	B-LT
South Daseleys	Cockles							B-LT	B-LT	B-LT
Heacham	Cockles	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Breast Sand	Cockles			B	B	B	B	B-LT	B-LT	B-LT
Breast Sand (Inner West)	Cockles						B	B-LT	B-LT	B-LT
Daseleys	Cockles						B	B-LT	B-LT	B-LT
Thief	Cockles						B	B-LT	B-LT	B-LT
Pandora	Cockles						B-LT	B-LT	B-LT	B-LT
Sunk Sand	*Ensis* spp.				B					
Seal Sand	*Ensis* spp.				B					
Witham Bank/North Lays	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Toft Sands	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Herring Hill	Mussels						B-LT	B-LT	B-LT	B-LT
Black Buoy	Mussels						B-LT	B-LT	B-LT	B-LT
Holbeach	Mussels						B-LT	B-LT	B-LT	B-LT
Gat Sand	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Maretail	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Welland Wall	Mussels	B	B	B			B	B	C	C
Toft Ridge	Mussels						B-LT	B-LT	B-LT	B-LT
Toft South	Mussels						B-LT	B-LT	B-LT	B-LT
Daseleys	Mussels	B	B-LT	B-LT	B-LT	B-LT	B	B-LT	B-LT	B-LT
Hunstanton	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Thief	Mussels	B	B-LT	B-LT	B-LT	B-LT	B	B-LT	B-LT	B-LT
Stylemans	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Pandora	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Ferrier Sand	Mussels						B-LT	B-LT	B-LT	B-LT
South Daseleys	Mussels						B-LT	B-LT	B-LT	B-LT
Nene	Mussels	B	B-LT	B-LT	B-LT	B-LT				
Scotsman's Sled	Mussels						B	B-LT	B-LT	B-LT
Training Wall	Mussels		B	B				B-LT	B-LT	B-LT
Breast Sand	Mussels	B	B	B-LT	B-LT	B-LT	B	B-LT	B-LT	B-LT

Currently, only cockles and mussels are classified. All classifications in recent years have been B, aside from for mussels growing on the training wall of the Welland Channel. Pacific oysters have been classified at Toft, but not since 2004. Razors were briefly classified in 2007 at Seal Sand and Sunk Sand. Current classification maps are shown for cockles in Figure 4.5 and mussels in Figure 4.6.



Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2012

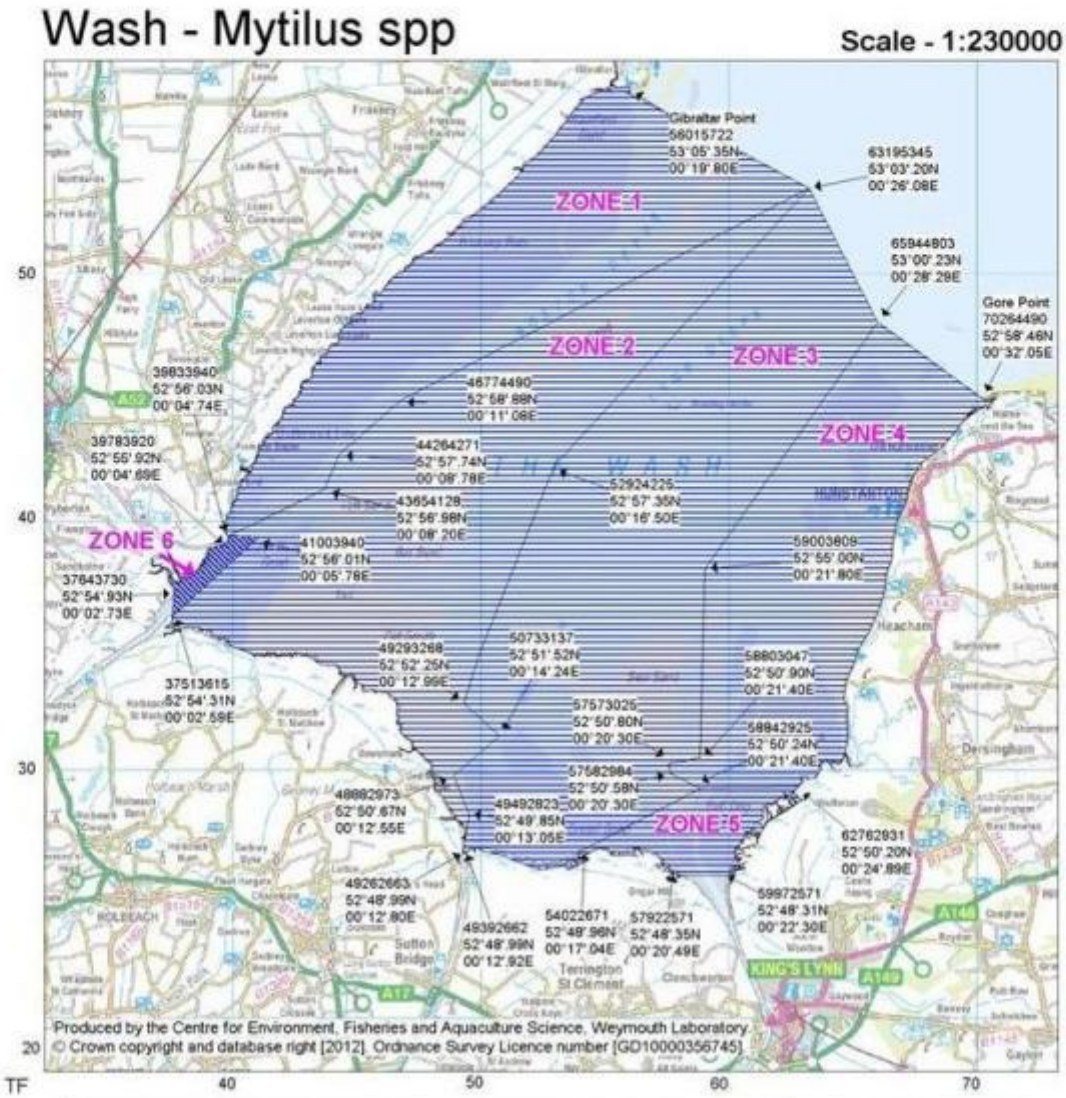
The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

Further details on the classified species and the areas may be obtained from the responsible Food Authority. Enquiries regarding the maps should be directed to: Shellfish Microbiology, CEFAS Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset DT4 8UB. (Tel: 01305 206600 Fax: 01305 206601)

N.B. Lat/Longs quoted are WGS84
Separate map available for Mytilus spp. for the Wash

Food Authorities: Borough Council of Kings Lynn and West Norfolk (Heacham and Breast Sand)
Boston Borough Council (Gat Sand, Maretail, Butterwick and East of Welland)
East Lindsey Borough Council (Friskney)

Figure 4.5: Current classifications for cockles.



Classification Zones: Class A Class B Class C Prohibited LT Class B

Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2012

The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004

Further details on the classified species and the areas may be obtained from the responsible Food Authority. Enquiries regarding the maps should be directed to: Shellfish Microbiology, CEFAS Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset DT4 8UB. (Tel: 01305 206600 Fax: 01305 206601)

N.B. Lat/Longs quoted are WGS84

Separate map available for C. edule for the Wash

Food Authorities: Borough Council of Kings Lynn and West Norfolk
(Daseleys, Hunstanton, Heacham, Thief, Stylemans and Pandora)
Boston Borough Council
(Welland Wall, Witham Bank, Toft Sands, Gat Sand and Maretail)
Fenland District Council (Nene and Breast Sand)

Figure 4.6: Current classification for mussels

Table 4.2 summarises the post-harvest treatment required before bivalve molluscs can be sold for human consumption.

Table 4.2: Criteria for classification of bivalve mollusc production areas.

Class	Microbiological standard[1]	Post-harvest treatment required
A[2]	Live bivalve molluscs from these areas must not exceed 230 Most Probable Number (MPN) of *E. coli* $100g^{-1}$ Fluid and Intravalvular Liquid (FIL)	None
B[3]	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution MPN test of 4,600 *E. coli* $100g^{-1}$ FIL in more than 10% of samples. No sample may exceed an upper limit of 46,000 *E. coli* $100g^{-1}$ FIL	Purification, relaying or cooking by an approved method
C[4]	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution Most Probable Number (MPN) test of 46,000 *E. coli* $100g^{-1}$ FIL	Relaying for, at least, two months in an approved relaying area or cooking by an approved method
Prohibited[6]	>46,000 *E. coli* $100g^{-1}$ FIL[5]	Harvesting not permitted

[1] The reference method is given as ISO 16649-3.
[2] By cross-reference from EC Regulation 854/2004, via EC Regulation 853/2004, to EC Regulation 2073/2005.
[3] From EC Regulation 1021/2008.
[4] From EC Regulation 854/2004.
[5] This level is not specifically given in the Regulation but does not comply with classes A, B or C. The competent authority has the power to prohibit any production and harvesting of bivalve molluscs in areas considered unsuitable for health reasons.
[6] Areas which are not classified and therefore commercial harvesting of LBMs cannot take place. This also includes areas which are unfit for commercial harvesting for health reasons e.g. areas consistently returning prohibited level results in routine monitoring and these are included in the FSA list of designated prohibited beds

5. Overall Assessment

5.1. Aim

This section presents an overall assessment of sources of contamination, their likely impacts, and patterns in levels of contamination observed in water and shellfish samples taken in the area under various programmes, summarised from supporting information in the previous sections and the Appendices. Its main purpose is to inform the sampling plan for the microbiological monitoring and classification of the bivalve mollusc beds in this geographical area.

5.2. Shellfisheries

The Wash supports major fisheries for cockles and mussels, which occur naturally in the area. As well as naturally occurring mussels, there are a number of managed lays to which seed is transplanted and ongrown. Most of The Wash bivalve fishery is managed via The Wash Fishery Order, under which there are up to 68 licence holders. The remainder falls within a private fishery (the Le Strange fishery) off the Hunstanton/Heacham shore, the rights to which are leased to one individual. The areas currently classified for the harvest of cockles and mussels require continued classification. Although there is some seasonality in these fisheries, the timing can vary from year to year so classifications must be year round. A sampling plan is also provided for razors within a much more limited area, where it has been established that razor dredging is likely to cause little harm to the environment.

When redefining the zonation of the area, the Eastern IFCA, who manage the fishery and enforce the regulations, have indicated a preference for boundary lines to follow simple rounded lines of latitude and longitude. The local authorities do not have the capacity to sample 9 of the 10 current RMPs due to their offshore locations, so this is undertaken by the IFCA. The monthly sampling run uses 2 days of vessel time, and so involves considerable resource. An increase in the number of RMPs should therefore be avoided if possible.

Cockles and mussels accumulate *E. coli* to similar levels, but a tendency for cockles to return more extreme high results has been noted. As such, cockles would be the preferred species to monitor on public health protection grounds, although a formal policy on the use of surrogate species is yet to be developed. As compliance with class B is solid in both species throughout most of the classified area, such an approach is unlikely to result in an unfairly poor classification for the fishery. The exceptions are the areas around the river mouths. Here the species present are mussels, which grow on the training walls in some places. As such they are likely to display higher levels of contamination than the cockles by virtue of their location, so using mussels to classify both species in relatively small areas around the outfalls should be suitably protective of public health.

5.3. Pollution Sources

Freshwater Inputs

All watercourses carry some contamination from land runoff and so will require consideration in this assessment. Their impacts will be greatest where they enter the area, and within or immediately adjacent to any drainage channels they follow across the intertidal area.

The Wash has a large catchment area, covering 12% of the land area of England. There are four main rivers which discharge into The Wash; the Witham (The Haven), Welland, Nene and Great Ouse. These have catchment areas of 3000, 1680, 2270 and 8596 km^2 respectively. They are highly regulated lowland rivers with sluggish flows, and all have lengthy canalised estuaries which discharge into The Wash. Bacterial indicators discharged or washed into their more inland reaches are therefore likely to die off before reaching any shellfish beds. It was not possible to estimate their discharge volumes from the available flow gauging records. Mean and maximum combined freshwater inputs to The Wash have been estimated at 44.05 and 406.1 m^3/s respectively. The four rivers will carry almost all of this, divided between them in approximate proportion to their catchment sizes. Water samples taken from their tidal reaches during the shoreline survey whilst the tide was ebbing contained relatively low levels of *E. coli* (60-190 cfu/100ml) at the time. Nevertheless, they are likely to be the most significant contaminating influences to the area, and the zoning and monitoring plan should be designed to reflect this.

As well as the main rivers, there are a series of small freshwater outfalls around the perimeter of The Wash. These mostly serve networks of land drains, although there is the occasional natural watercourse. There are 11 pumped outfalls and three gravity outfalls discharging to the foreshore of The Wash. Water samples were taken from the drains behind these outfalls during the shoreline survey, and these contained low to moderate concentrations of *E. coli* (up to 5000 cfu/100ml). The capacity of the 11 pumped outfalls ranges from 0.4 to 4.71 m^3/sec, and they are reported to run intermittently at a rate equivalent to about 5% of the total installed capacity on average. There are gravity outfalls for the Heacham River, and to the Wainfleet Haven, and a much smaller gravity outfall from a drain just west of the mouth of the Ouse Estuary. These may create hotspots of contamination in the vicinity of the drainage channels they follow across intertidal areas and RMPs located in their paths would best capture these.

There is likely to be some seasonality in the impacts of both the smaller outfalls and the main rivers deliver to The Wash. Bacterial dieoff rates will be considerably lower on average under winter conditions compared to summer conditions, so they may carry higher overall loadings during the colder months of the year assuming inputs to them remain similar. The volumes discharged will also be higher in the winter, particularly for the pumped outfalls from the field drains where abstraction occurs for irrigation during the warmer months. This will be further complicated by holiday population and agricultural practices (e.g. manure spreading).

Human Population

The Wash catchment area has a total resident population of approximately 3.6 million. Most of the population resides a significant distance inland so will be of little impact. There are however significant conurbations on the banks of the tidal Ouse (King's Lynn) and the tidal Witham (Boston). Hunstanton and Heacham lie on the east shore of The Wash, and Skegness lies on the Lincolnshire coast just outside the mouth of The Wash. Aside from these settlements the shores of The Wash are rural in character and sparsely populated.

Hunstanton, Heacham and Skegness are all seaside holiday resorts, so significant increases in the population of these towns occur during the summer months. Increased population numbers will result in increased volumes of sewage received by sewage works serving these towns. There may therefore be some seasonality in the bacteriological loadings generated by these.

Sewage Discharges

Within the hydrological catchment area of The Wash, there are nearly 9,000 consented discharges, including 630 water company owned sewage treatment works which serve the vast majority of the 3.6 million residents. Most of these discharge to one of the four main rivers or tributaries thereof, and most are sufficiently far inland to be of no impact to the shellfisheries. Of the 630 water company sewage works, only 61 discharge within a 20km radius of the Wash. None discharges directly to The Wash.

The tidal Ouse receives effluent from two significant sewage works (King's Lynn and Watlington) which generate a combined bacterial loading of around 7.5×10^{13} faecal coliforms/day and discharge about 3km and 15km from its mouth. The tidal Nene receives effluent from two major sewage works (Sutton Bridge and Wisbech) which generate a combined bacterial loading of about 5.8×10^{13} faecal coliforms/ day and discharge 3.5 and 13km from the estuary mouth. The Welland estuary receives effluent from Spalding STW (estimated loading of 5.2×10^{13} faecal coliforms/day) just downstream of its tidal limit, or about 16km from its mouth. The Witham estuary receives sewage from Boston STW, which generates an estimated bacterial loading of 3.3×10^{13} faecal coliforms/day and discharges about 5km from its mouth. All these estuaries also receive sewage from a number of smaller but nevertheless potentially significant works discharging to the rivers and their tributaries within 20km of The Wash. It is therefore concluded that the four main river estuaries are subject to contamination of sewage origin to a significant extent. King's Lynn STW will probably be of most overall impact as it is the largest and is closest to the mouth of its estuary.

As well as the main rivers, several other drains and watercourses receive effluents from water company owned sewage works. The Wainfleet Haven and associated watercourses and drains receive effluent from Spilsby and Wainfleet STWs, which are mid sized works generating a combined bacterial loading of about 7.3×10^{12} faecal coliforms/day. It also receives effluent from four much smaller STWs. The River Ingol receives effluent from Ingoldisthrope STW, which generates an estimated loading of 4.6×10^{12}. Heacham STW feeds into the Heacham River, but this works has UV treatment, and so will have a minimal contaminating influence. Final effluent testing data indicate that the UV is generally effective, and the average loading this works generates is only about 2.2×10^{9} *E. coli*/day. Additionally, there are some privately owned sewage discharges which may contribute to the levels of faecal indicator bacteria in the watercourses draining to the foreshore of The Wash. These include the North Sea Camp prison discharge, which is consented to discharge up to $100m^3$/day of secondary treated effluent. Its outfall is to a field drain just behind the seawall at Freiston shore. A caravan park at Diglea is consented to discharge up to $50m^3$/day of treated sewage to a tributary of the Ingol. There are also some smaller private discharges feeding into the Ingol, some of the field drains between the Nene and the Welland, and some of the field drains between the Witham and Wrangle.

Finally, Skegness is served by the Ingoldmells STW, which discharges via long sea outfall about 2km offshore, and 11km north of Gibraltar Point. The estimated bacterial loading generated by this discharge is about 3.4×10^{13} faecal coliforms/day. The plume from this will be carried towards the Wash during the flooding tide and so its highest potential impacts are on any shellfish resources in the north west corner of The Wash.

There are several intermittent (overflow) discharges associated with the water company sewerage networks. There are clusters of these around the towns of Hunstanton, Skegness, Boston and King's Lynn, as well as a few to the tidal Nene. Intermittent sewage discharges can potentially deliver large volumes of untreated storm sewage to coastal waters from time to time. No spill records were available for any of the intermittent discharges potentially impacting on the survey area. It is therefore difficult to make any meaningful assessment of their relative significance aside from noting their locations and their potential to deliver large bacterial loadings. Their geographic distribution suggests that the Hunstanton area, and the tidal Witham, Ouse and Nene may be most affected. Those discharging at Hunstanton are in closest proximity to shellfish resources so have the greatest potential to directly contaminate them. Spills will mainly be associated with wet weather events, particularly within the sewerage networks which collect larger amounts of surface water, and some catchments and individual outfalls may have a greater tendency to spill than others. Spill event reporting is being promoted in forcoming water company investment schemes for overflows within 3km of shellfish waters. This should be available by 2020, and if available will be assessed at the next review.

Intermittent discharges create issues in management of shellfish hygiene however infrequently they spill. Their impacts' are not usually captured during a year's worth of monthly monitoring from which the classification is derived as typically they only operate occasionally. Thus when they do have a significant spill, heavily contaminated shellfish may be harvested under a better classification than the levels of *E. coli* within them may merit. A reactive system alerting relevant parties to spill events in real time may therefore convey better public health protection.

Agriculture

The majority of agricultural land within the hydrological catchment is used for arable farming, and organic fertilisers may be applied to these areas periodically, with timing depending on crop cycles. There are also significant areas of pasture where grazing animals will deposit faecal matter directly. Although there are large numbers of grazing animals within the catchment (over 200,000 cattle and 600,000 sheep) the overall density of grazers is not particularly high. They are widespread throughout the entire catchment, although there are generally lower numbers in subcatchments bordering the south eastern shore of The Wash. There are also almost 25 million poultry and almost 500,000 pigs within the catchment. Highest pig densities are found in the eastern most parts of the catchment. Poultry are generally widespread although there are few in subcatchments bordering the south eastern shore of The Wash.

Agricultural practices within the areas immediately adjacent to The Wash will have the most influence on shellfish hygiene, as the catchment is large and generally drained by slow flowing watercourses. Bacterial indicators washed into watercourses further inland will therefore generally die off before reaching coastal waters. Agricultural lands bordering The Wash are particularly fertile, and are mainly used for growing crops such as brassicas, potatoes and cereals. Shoreline survey observations indicate a few fields adjacent to The Wash are used for grazing. Perhaps of greater significance is the practice of grazing cattle on the saltmarsh on the seaward side of the sea banks. This was directly observed, or signs of recent grazing (hoof prints, dung) were seen on most saltmarsh areas during the shoreline survey. The exception was the area used for military exercises between the Nene and the Welland. Contamination from these will be carried directly into The Wash via tidal inundation, so peak fluxes are likely to occur on the larger spring tides when more of the saltmarsh is covered. Saltmarsh creeks and the drainage channels they follow across the intertidal are likely to be subject to peak levels of contamination associated with saltmarsh grazing.

Aside from tidal inundation of grazed saltmarsh, the primary mechanism for mobilisation of faecal matter deposited or spread on farmland to coastal waters is via land runoff. Fluxes of agricultural contamination into the area will be highly rainfall dependent. Rainfall and river flows (or pumping station operation) are typically highest during the winter months, but high rainfall events may occur at any time of the year. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the ‘first flush’).

Numbers of sheep and cattle will increase in the spring with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. The seasonal pattern of application of manures and slurries (e.g. from pig and poultry operations) is uncertain. Cattle may be housed indoors in winter so applications of slurry to pastures in these farms may be more likely during the winter and spring, whereas impacts from saltmarsh grazing will be lower. Poultry/pig manure and sewage sludge may be spread at any time of the year. Therefore peak levels of contamination from livestock may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised and possibly more intense basis if wet weather follows a slurry application which is more likely in winter or spring. The seasonal pattern of impacts from adjacent reclaimed farmland will also be influenced by the seasonal patterns by which water is pumped from the drains out into the Wash, or recycled for irrigation.

Boats

There is significant boat traffic within The Wash, mainly associated with the four commercial ports (Boston, King's Lynn, Sutton Bridge and Wisbech). Shipping largely consists of merchant ships transporting cargoes, but these are not permitted to make overboard discharges within 3 nautical miles of land. They may therefore empty their tanks in the deeper central and outer areas of The Wash, but not in the vicinity of the cockle and mussel beds. In fact, it is possible that the emptying of ships tanks in the outer Wash occurs regularly as this represents the last opportunity to do so before entering port, and the first opportunity to do so after leaving port. There are about 1600 shipping movements per year.

There is a sizable commercial fishing fleet operating from and within The Wash, the majority of which are based at King's Lynn. Recreational boat traffic (e.g. yachts and cabin cruisers) is relatively light. There are two marinas within the rivers that lead into The Wash which offer around 100 berths, neither of which have sewage pumpout facilities. There were 23 yachts in a tidal creek at Gibraltar Point at the time of shoreline survey and three yachts moored or anchored off Heacham. Private vessels such as yachts, motor cruisers and fishing vessels of a sufficient size are likely to make overboard discharges from time to time. This may be most likely to occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the relative calm of the river estuaries. However, most moorings and marinas are located a significant distance up the estuaries and therefore it is likely that any microbiological pollution derived from boats moored will be diluted by the time it reaches the shellfish beds in the Wash. Therefore, the areas at highest risk from microbiological pollution are river estuaries, and the main navigation routes through the Wash. The Wainfleet Haven may also be affected to some extent.

Peak pleasure craft activity is anticipated during the summer, so associated impacts may be higher during the summer. Other vessel types will operate on a year round basis. Overall, their impacts are anticipated to be relatively minor and largely confined to the river estuaries, or in the case of cargo vessels the outer central Wash. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Wildlife

The Wash supports large aggregations of birds and seals, and both of these are likely to contribute to the *E. coli* counts found in shellfish within The Wash at times. It supports the largest aggregation of overwintering waterbirds (wildfowl and waders) in the UK, with an average total count of 379,164 birds/ year over five winters up to 2010/11. Some species will mainly frequent the salt marshes and adjacent fields, where their faeces will be carried into coastal waters via runoff or through tidal inundation. Therefore, the drainage channels associated with saltmarsh creeks and freshwater inputs will be most exposed to contamination from these birds. Others will forage (and defecate) directly on any shellfish beds on the intertidal. They may tend to aggregate in certain areas holding the highest densities of bivalves of their preferred size and species, but this will probably vary from year to year. Due to the diffuse and spatially unpredictable nature of contamination from birds foraging on the intertidal flats it is difficult to select specific RMP locations to best capture their impacts.

Birds such as gulls and terns and relatively small numbers of waders remain in the area to breed in the summer, but the majority migrate elsewhere outside of the winter months. Bird numbers and potential impacts on the hygiene status of the fisheries are therefore much lower during the summer. A total of 6,686 breeding pairs of terns and gulls along the perimeter of The Wash were recorded during a census in 2000. The largest aggregation, of 4,200 pairs of the Sandwich Terns, was on the eastern edge of the mouth of The Wash. Seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. It is therefore concluded that the impact of birds during the summer will be much less than during the winter, and may be more concentrated in the Hunstanton area.

There is a major seal colony within The Wash, with almost 3000 individuals recorded in 2011, and further colonies at Donna Nook, just south of the Humber estuary, and at Blakeney, on the North Norfolk coast. They forage widely, and at lower states of the tide they haul out and rest on intertidal sandbanks. They are gregarious at their preferred haulout sites and a large number of individuals may be present in a small area. Therefore, if their haulout sites coincide with a shellfish bed, they may represent a highly significant but localised contaminating influence. The haulout sites they use are widely distributed throughout The Wash, but are most concentrated in the inner eastern corner, with fewer in the outer reaches, particularly on the eastern side. Their haulout sites may coincide with the location of some cockle beds, particularly those along the inner (south) shore and also along the west shore to a lesser extent. However, as their spatial use varies from year to year, as do the exact locations of the highest density cockle beds, it is difficult to predict exactly where the two will coincide. It is therefore not possible to propose an RMP which will reliably capture their peak impacts, although should an unexpected high monitoring result arise in certain areas this may be a consequence of their presence. One of the fishery management policies is to close fisheries in the immediate vicinity of known/regular haulout sites to prevent disturbance, which will mitigate their impacts to some extent.

Domestic animals

Dog walking takes place on beaches and paths adjacent to the shoreline of the survey area and could represent a potential source of diffuse contamination to the near shore zone. The intensity of dog walking is likely to be higher closer to the more urban areas, namely the Hunstanton/Heacham area. As a diffuse source, this will have little influence on the location of RMPs.

Summary of Pollution Sources

An overview of sources of pollution likely to affect the levels of microbiological contamination to the shellfish beds is shown in Table 5.1 and Figure 5.1.

Table 5.1: Qualitative assessment of seasonality of important sources of contamination.

Pollution source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Continuous sewage discharges												
Agricultural runoff												
Saltmarsh grazing												
Intermittent sewage discharges	No overflow spill data available											
Urban runoff												
Waterbirds												
Seals												
Boats												

Red - high risk; orange - moderate risk; yellow - lower risk

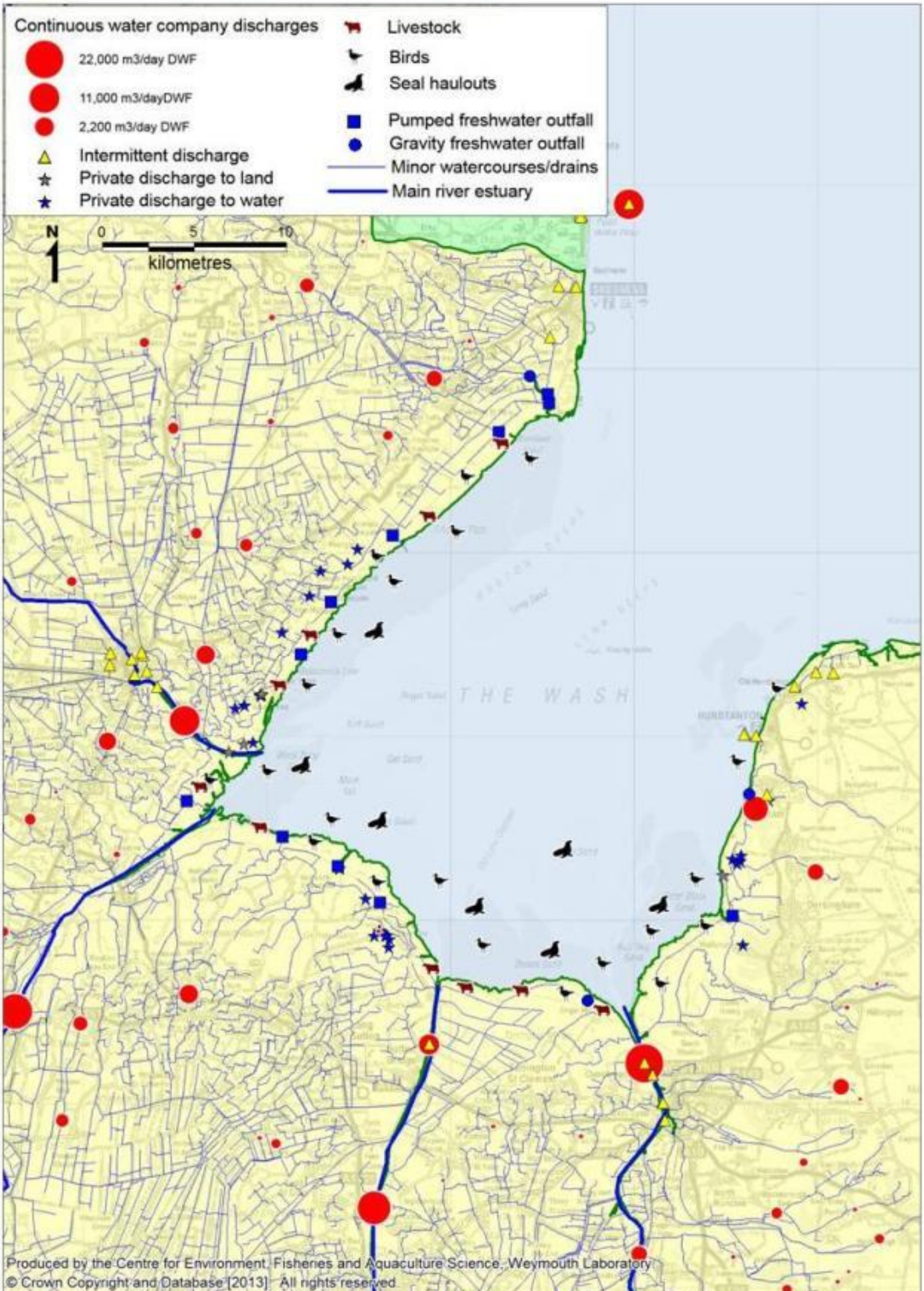


Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The Wash is a large embayment of the North Sea, which has some estuarine characteristics due to freshwater inputs from four major rivers. It covers an area of about 667km^2, of which 298km^2 are intertidal. It is characterised by a series of mobile sandbanks separated by parallel subtidal channels. In the main outer subtidal channel (Lynn Deeps) depths exceed 30m. There is a second, narrower and shallower subtidal channel (Boston Deeps) to the west of the Lynn Deeps. Sediment types range from gravels in the deeper outer reaches to mud in the more sheltered inner areas. Most of its shoreline is fringed by a strip of saltmarsh, backed by earth banks, although there is a shingle ridge in the Heacham area, cliffs at Hunstanton, and dunes at Gibraltar Point.

The four main rivers have canalised estuaries extending a significant distance inland. They join the Wash on the inner (southern) shore, and initially follow trained channels through its inner reaches. The Welland and Witham join to follow a shared channel in the south western corner. Deltas have formed where the trained channels end. There are also many smaller, natural drainage channels cutting across the intertidal flats, some of which carry the smaller freshwater inputs. Relatively high levels of contamination are anticipated within the trained channels, and possibly the smaller intertidal drainage channels if they receive freshwater inputs or contamination from birds or cattle washed off the saltmarshes. This will be most acute around low water when dilution potential is lowest.

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. Tidal amplitude is large at 6.36m on spring tides, and 3.18m on neap tide at Tabs Head, and this drives extensive water movements within the area. Tidal streams are bi-directional, with water from the North Sea entering and moving up The Wash on the flood tide, and the reverse occurring on the ebb. Current speeds on spring tides in the main channels peak at 1.0-1.2m/s and 0.5-0.7m/s over the intertidal flats, and are just under half of that on neap tides. Tidal diamonds suggest a tidal excursion through the channels in the approximate order of 10-20km on spring tides and 5-10km on neap tides. Therefore, contamination discharged to the inner reaches of The Wash, such as that from the four main rivers, will not be carried out into the North Sea before tides reverse, even on large spring tides. The remnants of any plume from the sewage outfall off Skegness will reach the outer parts of the Boston Deeps during spring tides, but not on neap tides. As such it is possible that it is a slight influence on the cockle beds on the intertidal just south of Gibraltar Point.

Within the four main tidal rivers, approximate estimates of the ebb tidal excursion could be made for the Nene (circa 14km on spring tides) and more tentatively for the Ouse (about 20km on spring tides) but not for the Welland or Witham. Excursion will be around half these values on neap tides. This means that contamination released to these estuaries (e.g. from King’s Lynn STW) from sources a considerable distance inland will reach the estuary mouths before the tide reverses, although obviously the closer a source is to the estuary mouths the greater its impact will be on the shellfisheries.

Freshwater inputs can modify circulation patterns via density effects. For The Wash as a whole, the volumes of water exchanged each tide are several orders of magnitude greater than the volumes of freshwater inputs so there is little possibility of any significant density driven circulation arising. Such effects may arise within the tidal rivers, and may possibly arise in the immediate vicinity of the river outfalls. If and when such effects occur, they will result in a shear between surface and bottom currents, with less dense freshwater moving in a net seaward direction at the surface, and a net movement of more saline water up-estuary lower in the water column.

Salinity is a useful predictor of levels of runoff borne contamination. For example, a strong correlation between salinity and faecal coliform concentrations was detected at the West Wash shellfish water monitoring point. Average salinity exceeds 31ppt apart from in the immediate vicinity of the river outfalls, where it drops to below 20ppt. This indicates that any areas of decreased water quality around the outfalls do not generally extend particularly far into the main body of The Wash. Zoning arrangements should reflect this, with relatively small classification zones around the estuary mouthswhere water quality is likely to be lower. Much larger zones will be appropriate for the rest of the area, where spatial variation in indicator bacteria concentrations will be much less marked.

Strong winds may modify tidal circulation at times by driving surface currents. These in turn create return currents at depth or along sheltered margins. The Wash is most exposed to the north and east, whereas the prevailing wind is from the south west. A large proportion of the surrounding land is low lying, and will offer little shelter from the prevailing winds. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Due to the unpredictable nature of these effects it is not possible to account for them in the sampling plan.

Where strong winds blow across a sufficient distance of water they may create wave action, and where these waves break contamination held in intertidal sediments may be resuspended. Due to the large size of the embayment, strong winds from any direction will blow across a considerable distance of water, and so nowhere in The Wash is particularly sheltered from an onshore wind. The area is most exposed from north easterly winds blowing in off the North Sea, and under these conditions much larger swells from the open sea will travel into The Wash. The Brancaster/Heacham area is likely to be most exposed to such swells.

5.5. Summary of Existing Microbiological Data

The Wash has been subject to considerable microbiological monitoring over recent years, deriving from Bathing Waters and Shellfish Waters monitoring programmes as well as shellfish flesh monitoring for hygiene classification purposes. Figure 5.2 shows the locations of the monitoring points referred to in this assessment. Data from 2003 until the present time are considered in this assessment.

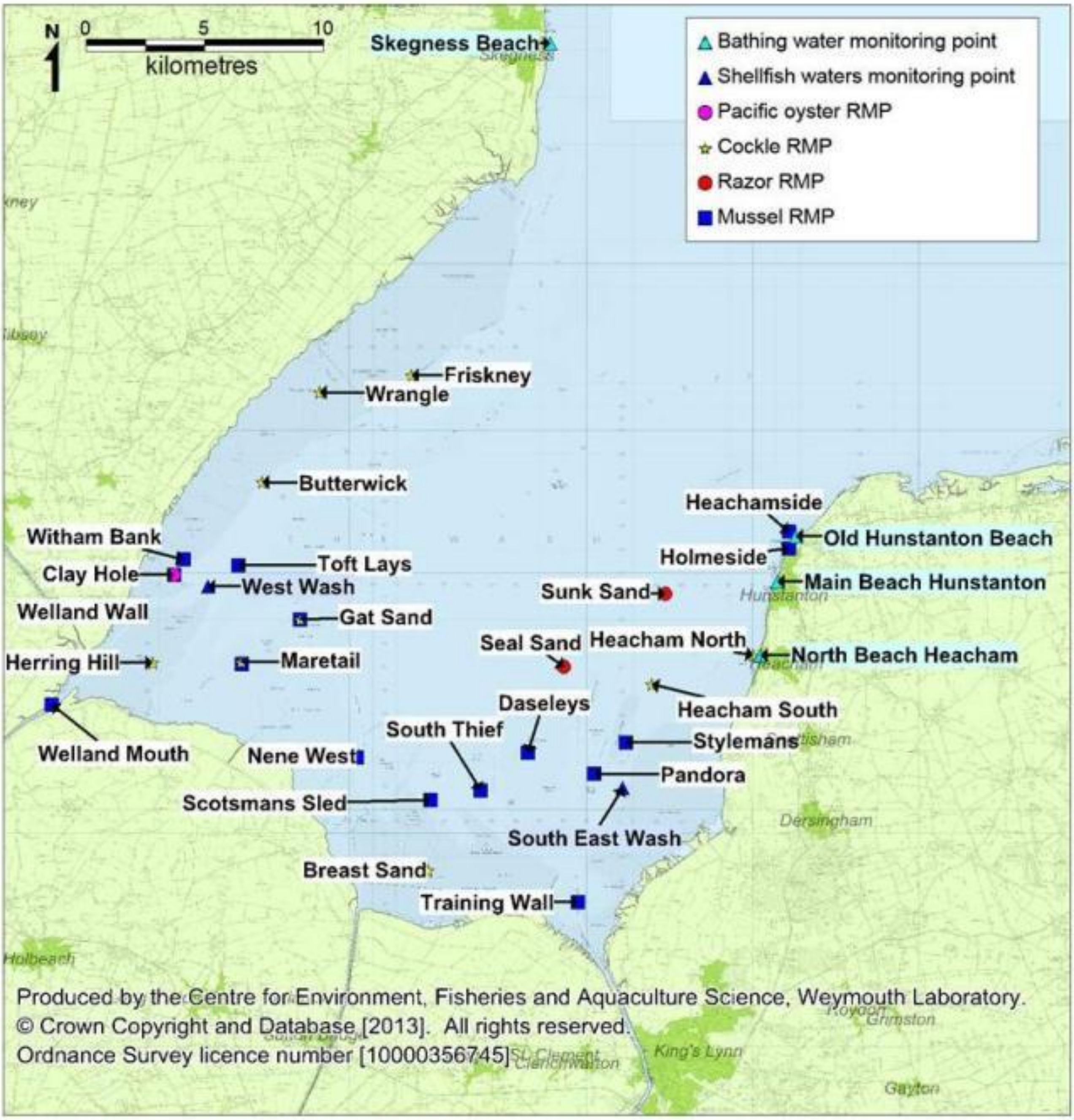


Figure 5.2: Microbiological sampling sites

Bathing waters

Four sites were sampled under the Bathing Waters monitoring programme, where around 20 water samples were taken each bathing season (May-September) and enumerated for faecal coliforms. Three were along the Heacham to Hunstanton stretch of coast, and one was outside The Wash at Skegness Beach. Across the three sites on the Norfolk coast, there was a decrease in geometric mean faecal coliform concentration from south to north, to the extent that results at North Beach Heacham were significantly higher on average than those recorded at Old Hunstanton Beach. Results at Skegness were significantly lower than at all three of the Norfolk sites. These differences tentatively suggest that concentrations of faecal indicator bacteria increase from the open North Sea towards the inner reaches of The Wash. A comparison of paired (same day) samples revealed that results at all three Norfolk sites were strongly correlated on a sample by sample basis, suggesting they are all under similar influences. No such correlations were found between faecal coliform concentrations at Skegness and any of the Norfolk sites. Since 2003, there appears to have been a slight decrease in faecal coliform levels at all four monitoring points.

A significant influence of the high/low tidal cycle was found for Old Hunstanton Beach and Main Beach Hunstanton. Most samples were taken from late in the flood tide through to the middle of the ebb. In both cases concentrations of faecal coliforms increased through this period, suggesting sources to the south were an influence. Significant variation across the spring/neap tidal cycle was detected at all monitoring points except North Beach Heacham. At Skegness Beach, higher results tended to occur during neap tides suggesting local sources are the main influence here. At Old Hunstanton Beach, higher results tended to occur around and just after spring tides. The same was true of Main Beach Hunstanton, but higher results tended to continue to occur as tide size declined towards neap tides. At Old Hunstanton Beach and Main Beach Hunstanton, rainfall events appeared to rapidly increase the level of faecal coliforms and continue to do so for several days. Little effect of rainfall was seen at North Beach Heacham. This may suggest that local rainfall dependent sources are an influence in the Hunstanton area, which may be urban runoff or spills from the intermittent sewage discharges here. At Skegness Beach, the influence of rainfall was weak and delayed.

Shellfish waters

There are three shellfish waters within The Wash, where faecal coliforms in waters are monitored on a quarterly basis. One of these uses a subset of the results from the bathing waters point at Old Hunstanton Beach to assess compliance, the results of which have been discussed above. The other two waters are monitored from independent points at West Wash and South East Wash. Across these two points, results were significantly higher at South East Wash than West Wash. Since 2003, faecal coliform levels at West Wash appear to have declined slightly at first, but have been increasing since 2009. At South East Wash, faecal coliform levels have fluctuated since 2003 and appear to have been decreasing since 2009.

A similar seasonal pattern was observed at both, with lower results in the spring and higher results in the winter, but the variation was much less marked at West Wash. Seasonal variation was only statistically significant at South East Wash. A significant influence of the high/low tidal cycle was found at both. At South East Wash there appeared to be a tendency for higher results to arise as the tide flooded, which is perhaps surprising as it is anticipated that the Ouse outfall is the main source in this area. No strong pattern was apparent for West Wash when the data were plotted. Weak but statistically significant influences of the spring/neap tidal cycle were found for both points, but again, no pattern was apparent when the data were plotted. Rainfall had some limited effect on faecal coliform levels at both sites. The effect was more delayed at South East

Wash, perhaps as it lies farther from the nearest river outfall. A strong negative correlation between salinity and faecal coliform levels was observed at West Wash, while no correlation was found for South East Wash despite a greater variation in salinity at this point. This suggests that either freshwater inputs on the eastern side are less contaminated. Alternatively it may indicate that the greater time it takes for contamination from the tidal Ouse to reach the South East Wash sampling point compared to the time it takes contamination from the Witham/Welland to reach West Wash results in more bacterial dieoff on passage.

Shellfish hygiene classification monitoring

There are two production areas in the Wash, Boston in the west and King's Lynn in the east. Between them, a total of 30 hygiene RMPs have been sampled since 2003. Ten RMPs are for cockles, 17 are for mussels, one is for Pacific oysters and two are for razor clams. Some were sampled on less than 10 occasions, so provided insufficient data to be included in any statistical analyses.

Across the 12 mussel RMPs sampled on more than 10 occasions, the highest average and peak result was recorded at Welland Wall. This was the only site where the proportion of results over 4600 *E. coli* MPN/100g exceeded 10% and where a prohibited level result was recorded. The second highest average result was recorded at Training Wall, where the proportion of results over 4600 *E. coli* MPN/100g was 6.2%. Results at Breast Sand were also noticeably higher on average than at the other mussel RMPs, although only exceeded 4600 *E. coli* MPN/100g on 1.9% of occasions. The results at these three sites were significantly higher on average than at most other RMPs, almost certainly as a consequence of their relative proximity to the river outfalls. The distribution of results at RMPs other than Welland Wall, Training Wall and Breast Sand were generally similar, although there were some significant differences in average results between them. Notably, Holmeside was significantly higher than some others, and Gat Sand was significantly lower than most others. The slightly elevated average result at Holmeside suggests that there are local shoreline sources in the area which are of some influence from time to time. A comparison of paired (same day) samples revealed that results at Welland Wall, Witham Bank, Toft Lays and Gat Sand were largely influenced by similar sources; as were Breast Sand, Nene Wash, South Thief, Daseleys, and Stylemans, as evidenced by significant correlations.

Across the six cockle RMPs sampled on more than 10 occasions, both average and peak results were higher at the three RMPs on the King's Lynn side, as well as in % occurrence of results exceeding 4,600 *E. coli* MPN/100g,. The King"s Lynn RMPs had significantly higher average results than the Boston RMPs. Only two paired (same day) comparisons were possible. Heacham South and Heacham North were significantly correlated, suggesting that they share similar environmental influences. Breast Sand and Heacham South were not significantly correlated, suggesting that they did not share similar environmental influences. However, it must be noted that peak contamination events, for example during river floods, may arrive at the different RMPs several days apart.

Neither of the two razor RMPs or the Pacific oyster RMP were sampled on more than 10 occasions. Across the two razor RMPs, which were sampled in parallel on 9 occasions, slightly higher average and peak results were recorded at Seal Sand, the inner of the two. Despite its name, this RMP is subtidal and so is not a seal haulout.

E. coli levels in mussels have remained fairly constant since 2003 at Witham Bank and Maretail, but increased between 2003 and 2008 at Welland Wall. On the King's Lynn side, *E. coli* levels in mussels have remained fairly consistent from 2003 onwards. However, levels at Daseleys dropped between 2003 and the discontinuation of the RMP in 2008. Levels of *E. coli* in cockles remained about the same from 2003 to 2013. However, there were fluctuations in *E. coli* levels at Friskney and there has been a slight reduction in *E. coli* levels at Heacham South, Breast Sand and Wrangle from late 2011 to present.

Across the mussel RMPs, there was a general tendency for higher results during the winter on the Boston side, the exception being Welland Wall, where results were highest on average in summer. On the King's Lynn side, seasonal patterns were not apparent at most RMPs, the exceptions being Training Wall and Holmeside, where there was a tendency for higher results in the summer and autumn. Statistically significant variations in *E .coli* levels in mussels between seasons were found at Witham Bank, Maretail, Gat Sand and Holmeside. At Witham Bank, winter levels were higher than spring levels. At Maretail winter levels were higher than summer levels. At Gat Sand winter levels were higher than both spring and summer levels. At Holmeside summer and autumn levels were higher than spring levels. Significant seasonal variation was observed at two of the cockle RMPs. At Breast Sand, spring and summer had significantly higher levels of *E. coli* than the autumn. At Heacham South, spring had significantly lower *E. coli* levels than the other seasons.

The influence of tidal cycles on levels of *E. coli* was investigated for RMPs where more than 30 samples had been taken. However, as sampling was necessarily targeted towards low water on spring tides, the results of these analyses are of limited value. Where correlations were found, they were usually weak and no pattern was apparent when the data were plotted. Across the high/low cycle, results tended to be higher at low water at Welland Wall. No strong patterns in relation to the spring/neap tidal cycle were detected at any of the RMPs.

Correlations between antecedent rainfall and *E. coli* levels indicated that rainfall did not have a significant effect at any RMP until at least 2 days after a rainfall event. This is consistent with the generally sluggish nature of the watercourses draining to the area. There appeared to be a greater influence of rainfall on the Boston side than the King's Lynn side.

Bacteriological survey

Due to the extensive monitoring history it was considered that there was little to be gained through undertaking a limited bacteriological survey. The logistical difficulties and expense that would be involved (three vessel days) meant that this was outside the scope of what could be performed under the available resources, even assuming the IFCA was able to take part, particularly given that a total of 9 days (including travel time) had already been spent in the field undertaking the shoreline survey.

Appendices

Appendix I. Human Population

Figure I.1 shows population densities in census output areas within or partially within the Wash catchment area derived from the 2011 census.

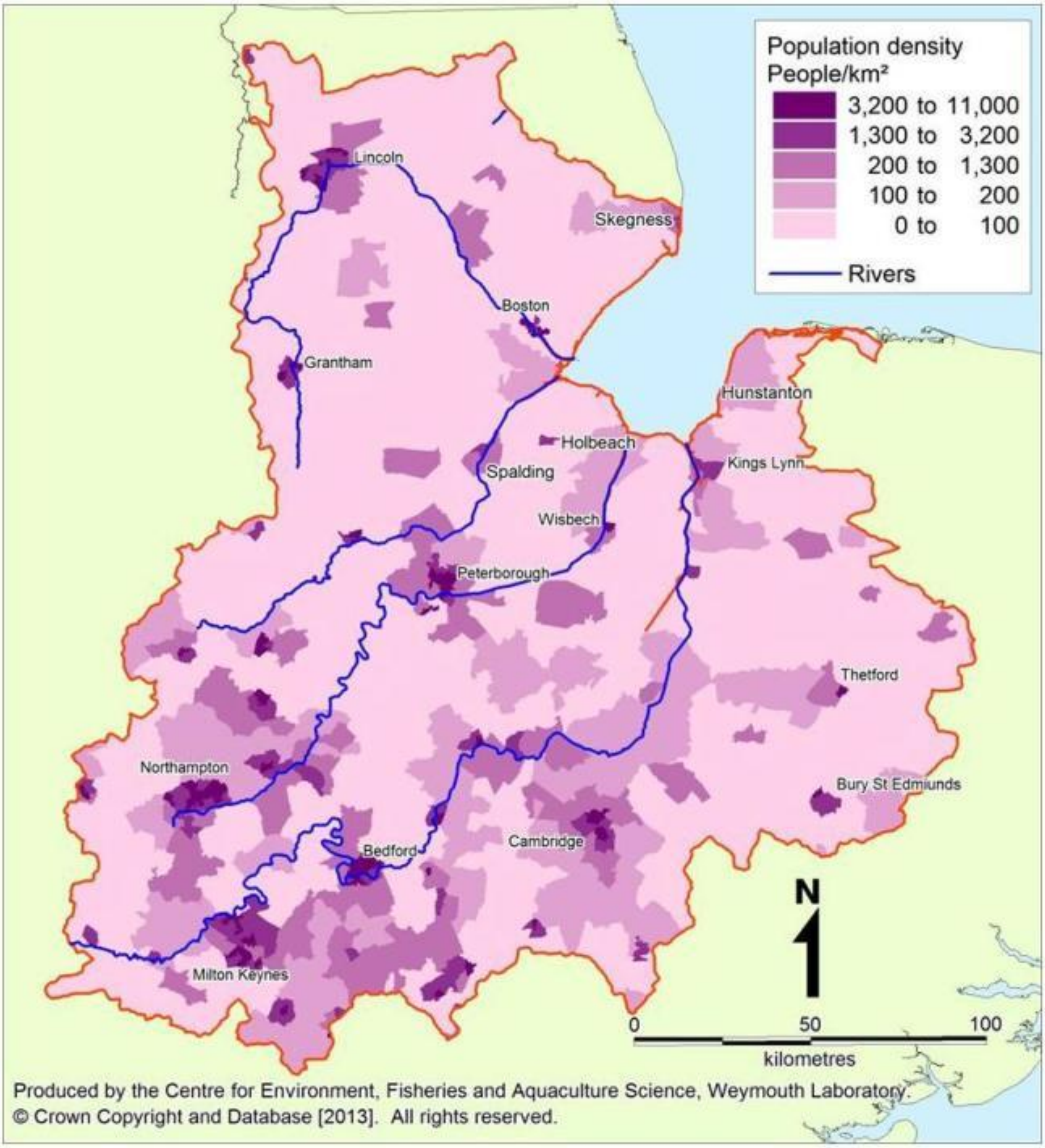


Figure I.1: Human population density in census areas in the Wash catchment.

The Wash catchment area has a total resident population of approximately 3,600,000, which is just under 7% of the population of England. Population densities are highest around the main rivers. The largest conurbations in the catchment, Northampton, Milton Keynes and Bedford are located more than 100 kilometres upstream of the estuary mouths (fluvial distance) and other significant conurbations such as Lincoln, Peterborough and Cambridge are between 50 and 70 km upstream of the estuary mouths. Therefore these high population areas may not have as large an impact on shellfish hygiene as the smaller population centres of Boston, Spalding, Holbeach, King’s Lynn and Hunstanton, which are close to the shoreline.

There is no major tourism across most of the Wash. However, the town of Hunstanton is a significant seaside resort, and there are caravan parks and holiday homes along the sea front from Hunstanton to Heacham. During the peak season (summer), the population of Hunstanton roughly doubles due to holiday makers (King’s Lynn Borough Council, pers comm.). The seasonal increase in population at Hunstanton means that there will likely be an increase in sewage outputs from treatment works serving this area during the summer, while there will be little seasonal variation in other parts of the Wash.

Appendix II. Sources and Variation of Microbiological Pollution: Sewage Discharges

Details of all consented discharges in the Wash hydrological catchment were taken from the most recent update of the Environment Agency national permit database (March 2013). Altogether there are nearly 9000 discharges into the Wash hydrological catchment serving a total population of around 3.6 million. Table II.1 details the number of discharges within this area by category.

Table II.1: Numbers of consented discharges in entire hydrological catchment

Discharge type	Number of discharges in catchment
Water company continuous sewage works	630
Water company intermittent discharge	1639
Trade discharge	330
Private discharges	5131
Surface water discharge	432
Agricultural discharge	820

Data from the Environment Agency.

These discharges will have varying degrees of microbiological loadings and the amount of contamination reaching the shellfisheries will depend on the volume, treatment level, nature of discharge, retention time in watercourses, and distance from The Wash. It is beyond the scope of this report to present information on all of these, and also of little direct relevance. They almost all discharge to one of the four main rivers, which are highly regulated lowland rivers through which transit times will be lengthy. As such, most bacterial indicators are likely to die off before reaching the shellfisheries, and any actually reaching The Wash will be delivered via the four main rivers. Therefore the sewage discharges discussed in this section will be limited to those within a 20km radius of The Wash coastline. Figure II.1 shows the location of significant continuous discharges within 20km of The Wash, private discharges >50m^3/day within 20km of The Wash and of other discharges (private discharges >5m^3/day and intermittent discharges) within 2km.

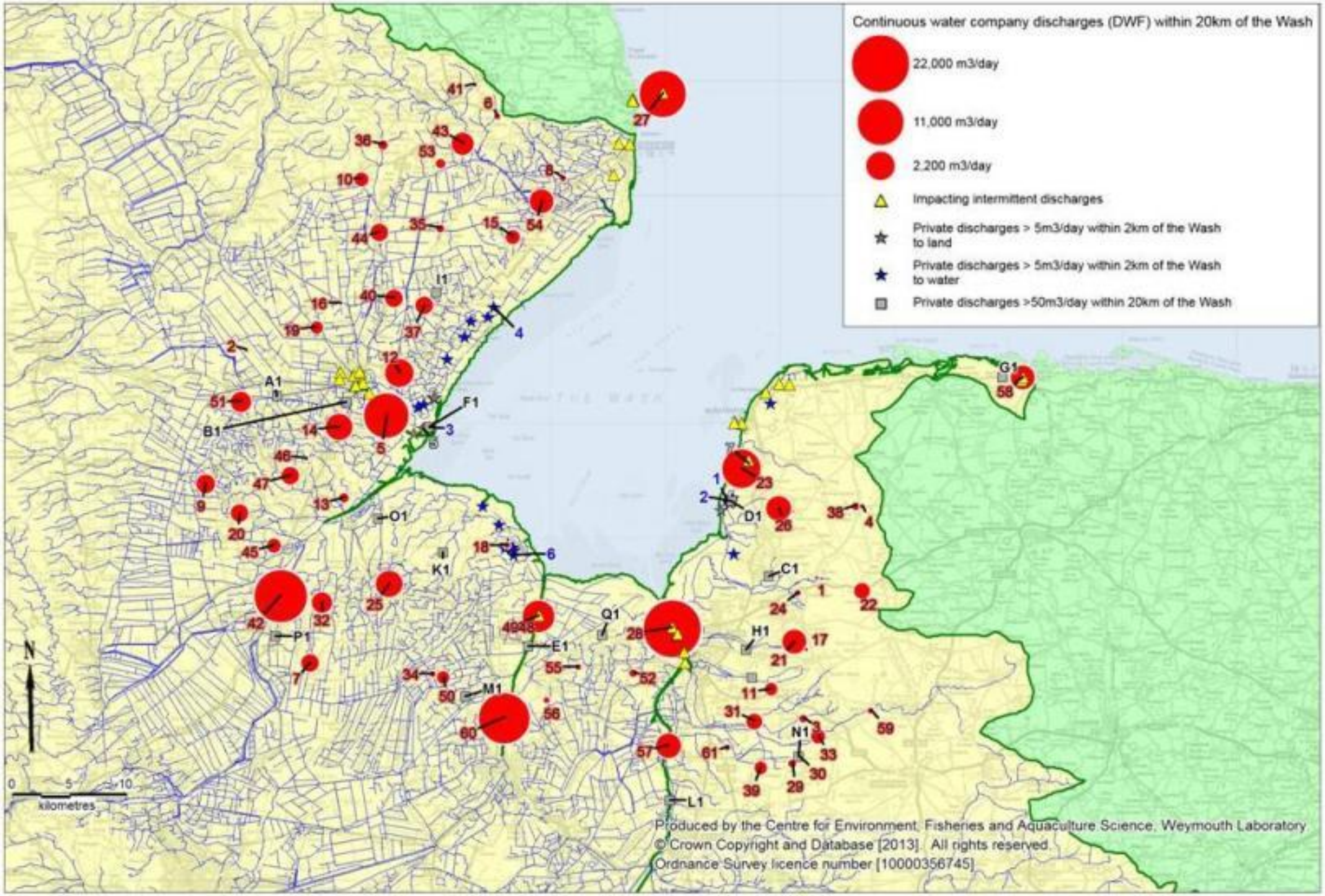


Figure II.1: Sewage discharges within a 20km buffer of the Wash coast

There are 61 continuous water company discharges within 20km of the Wash, details of which are presented in Table II.2.

Table II.2: Details of continuous water company sewage works

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
1	Abbey Road STW	TF7321026590	Biological Filtration	2.25	7.43×10^{9}	Land Via Soakaway
2	Amber Hill STW	TF2320046500	Unspecified	-	-	Gill Syke North Forty Foot Drain
3	Bilney Road	TF7203014300	Unspecified	36	-	Country Drain
4	Bircham Tofts STW	TF7720032900	Biological Filtration	9	2.96×10^{10}	To Land
5	Boston STW	TF3554040900	Biological Filtration	10000	3.3×10^{13}	Witham Haven
6	Candlesby STW	TF4520067000	Septic Tank***	10	1.0×10^{11}	Lady Waths Beck
7	Cowbit STW	TF2884019130	Biological Filtration	471	1.55×10^{12}	Moulton Mere Drn River Nene N
8	Croft STW	TF5101061580	Biodisc	17	5.61×10^{10}	unnamed trib Steeping River
9	Donington STW	TF1970034800	Unspecified	540	-	Mill Drain
10	East Kirby STW	TF3334061490	Biological Filtration	200	6.6×10^{11}	Trib West Fen Catchwater
11	East Winch STW	TF6923016860	Unspecified	159	-	Devils Bottom Stream Middleton
12	Fishtoft STW	TF3667044500	Biological Filtration	2050	6.77×10^{12}	Hobhole Drain
13	Fosdyke (Bell Lane) STW	TF3181033610	Package Plant	74.25	2.45×10^{11}	Whitehouse Farm Drain
14	Frampton STW	TF3135039790	Biological Filtration	1741	5.75×10^{12}	Frampton Town Drain
15	Friskney STW	TF4660056440	Biological Filtration	205	6.77×10^{11}	unnamed trib Fodder Dyke
16	Frithville STW	TF3148050660	Unspecified	0	-	Trib of West Fen Drain
17	Gayton (Norfolk) STW	TF7230020300	Unspecified	0	-	Gaywood River
18	Gedney Drove Ed STW	TF4607029450	Biological Filtration	18	5.94×10^{10}	Unnamed Drain
19	Gipsey Bridge STW	TF2938248488	Biodisc	169	5.58×10^{11}	River Witham
20	Gosberton STW	TF2266032260	Biological Filtration	480	1.58×10^{12}	Coll Drain
21	Grimston STW	TF7127020990	Unspecified	1295	-	Watery Lane Drain Gaywood Rive
22	Harpley STW	TF7720025490	Activated Sludge	325	1.07×10^{12}	Babingley River
23	Heacham STW	TF6662036090	UV disinfection	5968	2.17×10^{9}**	Heacham Parish Drain River Heacham
24	Hillington STW	TF7158025290	Biological Filtration	14	4.62×10^{10}	River Babingley
25	Holbeach STW	TF3575026020	Biological Filtration	1910	6.30×10^{12}	Holbeach River
26	Ingoldisthorpe STW	TF6987032650	Biological Filtration	1400	4.62×10^{12}	River Ingol
27	Ingoldmells STW	TF5599067610	Biological Filtration	10433	3.44×10^{13}	North Sea

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
28	King Lynn STW	TF6054022220	Activated Sludge	21600	$7.13x10^{13}$	Tidal River Great Ouse
29	Marham STW	TF7107010370	Unspecified	29	-	Trib Polver Drain
30	Marham WTW	TF7168010890	Unspecified	12*	-	tributary Fourteen Foot Drain
31	Middleton (Norfolk) STW	TF6776014060	Activated Sludge	307	$1.01x10^{12}$	County Drain River Nar NT
32	Moulton STW	TF2983024400	Biological Filtration	792	$2.61x10^{12}$	Moulton Mere Drain
33	Narborough STW	TF7338012690	Unspecified	250	-	Ketlam Drain River Nar NT
34	Needham Drive	TF3958218177	Unspecified	17	-	Village Drain
35	New Leake (Eastville) STW	TF4020057200	Activated Sludge	41	$1.35x10^{11}$	Fodder Dyke Hobhole Drain NT
36	Old Bolingbroke STW	TF3520064480	Package Plant	50	$1.65x10^{11}$	Trib of Hagnaby Beck
37	Old Leake (Skipmarsh)	TF3892050130	High Rate biological	475	$1.57x10^{12}$	Leak Gride Drain
38	Prems Adj 12 Fring Rd	TF7663032860	Package Plant	26	$8.58x10^{10}$	Land
39	Shouldham STW	TF6802009932	Biological Filtration	170	$5.61x10^{11}$	Trib Polver Drain
40	Sibsey STW	TF3616051080	Biological Filtration	414	$1.37x10^{12}$	Mallows Drain Hobhole Drain
41	Skendleby STW	TF4324069820	Screening	8	$8.00x10^{12}$	Trib of River Lymn
42	Spalding STW	TF2625025040	Activated Sludge	15720	$5.19x10^{13}$	River Welland
43	Spilsby STW	TF4220064540	Biological Filtration	1004	$3.31x10^{12}$	River Lymn
44	Stickney STW	TF3487056800	Package Plant	395	$1.3x10^{12}$	East Fen Catchwater Drain
45	Surfleet STW	TF2568029400	Biological Filtration	186	$6.14x10^{11}$	Latham Lode Seasend
46	Sutterton Ropers Ln STW	TF2850037000	Primary Settlement	unknown	-	Three Towns Drain South Forty
47	Sutterton/Wigtoft STW	TF2712035520	Biological Filtration	409	$1.35x10^{12}$	Trib River Welland T
48	Sutton Bridge STW	TF4643022940	Oxidation Ditch	3247	$1.07x10^{13}$	River Nene
49	Sutton Bridge STW	TF4649022910	Package Plant	unknown	-	River Nene
50	Sutton St James STW	TF4045017890	Package Plant	178	$5.87x10^{11}$	Trib of Sutton St James Drain
51	Swineshead STW	TF2276041990	Activated Sludge	660	$2.18x10^{12}$	New Hammond Beck
52	Tilney All Saints STW	TF5710018280	Screening	23	$2.30x10^{12}$	West of Ouse Drain
53	Toynton St. Peter STW	TF4028062840	Biological Filtration	49	$1.62x10^{11}$	William 4th IDB W'Course 3/38
54	Wainfleet STW	TF4921059670	Biological Filtration	1200	$3.96x10^{12}$	Trib River Steeping NT
55	Walpole St. Andrew STW	TF5232018810	Unspecified	20	-	Trib West Lynn Drain
56	Walpole St. Peter STW	TF4957015860	Unspecified	11	-	Trib of Smeeth Lode
57	Watlington STW	TF6025011880	Activated Sludge	1343	$4.43x10^{12}$	River Great Ouse T

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
58	Wells-next-the-Sea STW	TF9128044090	UV Disinfection	1125	$1.27x10^{9}$	Trib of Wells Creek
59	West Acre STW	TF7793014940	Package Plant	14.6	$4.82x10^{10}$	Land
60	Wisbech (West Walton) STW	TF4585014350	Activated Sludge	14421	$4.76x10^{13}$	Tidal River Nene
61	Wormegay STW	TF6539011720	Unspecified	17	-	Trib Polver Drain

*Faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs providing secondary treatment (Table II.3). This does not consider effluent testing data from the actual sewage works, so may be inaccurate.

** *E. coli* (cfu/day) based on geometric mean final effluent testing data (Table II.4)

***Septic tank taken as being primary treatment

****No DWF provided, so Max Flow used instead

Table II.3: Summary of reference faecal coliform levels (cfu/100ml) for different sewage treatment levels under different flow conditions.

Treatment Level	Flow			
	Base-flow		High-flow	
	n	Geometric mean	n	Geometric mean
Storm overflow (53)	-	-	200	$7.2x10^{6}$
Primary (12)	127	$1.0x10^{7}$	14	$4.6x10^{6}$
Secondary (67)	864	$3.3x10^{5}$	184	$5.0x10^{5}$
Tertiary (UV) (8)	108	$2.8x10^{2}$	6	$3.6x10^{2}$

Data from Kay et al. (2008b).

n - number of samples.

Figures in brackets indicate the number of STWs sampled.

Two of these continuous water company discharges, Heacham STW and Wells-next-the-Sea STW, are treated by UV disinfection. Wells-next-the-Sea STW is located at the furthest eastern edge of the hydrological catchment, approximately 20km from the classification zone. It discharges into a tributary of Wells Creek, which leads to Wells harbour and as such will have no impact on water quality at the fisheries in the Wash. Table II.4 and Figure II.2 summarise the results of bacteriological testing of the final effluent for Heacham STW, which discharges to the Heacham River.

Table II.4: Summary statistics for final effluent testing data from UV treated works, January 2008 to December 2012

Sewage works	No.	Geometric mean result (*E. coli* cfu/100ml)	Minimum	Maximum
Heacham STW	88	36.35	<0.5	21,000

Data from the Environment Agency

Bacteriological testing results for the final effluent at Heacham STW indicates that disinfection is usually very effective, although occasional high results do occur. The estimated (average) bacterial loading it generates is therefore very small, although the maximum concentration of faecal coliforms recorded is over three orders of magnitude higher than the average. It must be noted that UV disinfection is less effective at eliminating viruses than bacteria (e.g. Tree et al, 1997).

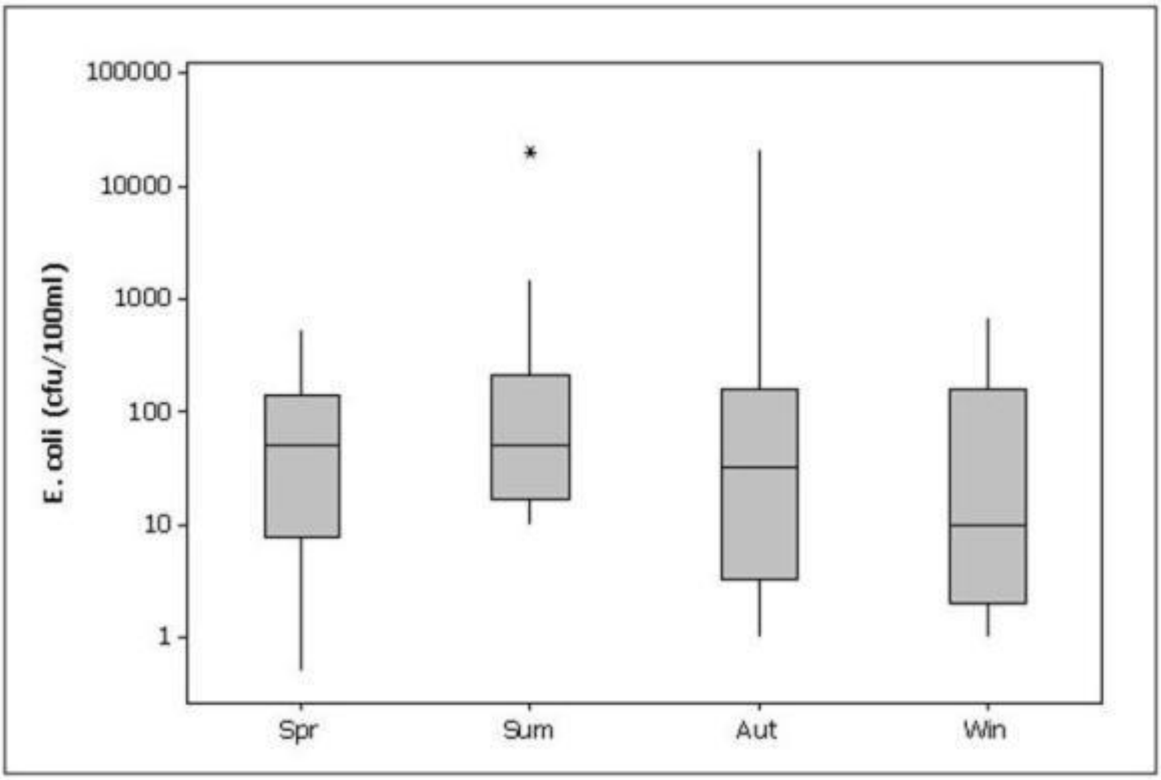


Figure II.2: Boxplot of *E. coli* concentrations in final effluent by season at Heacham STW
Data from the Environment Agency.

There is no significant variation in *E. coli* concentrations by season but a tendency for fewer very low results in the summer.

Altogether there are 61 continuous water company discharges within a 20km radius of the coast of the Wash. Several of these discharges will impact on microbiological water quality at the shellfisheries due to their large volumes and proximity to the classification zones. The potential impact from Heacham STW is discussed above. King's Lynn STW is the largest discharge in the vicinity of the Wash, with a consented dry weather flow (DWF) of 21,600 m^3/day of secondary treated effluent, to the tidal Great River Ouse approximately 3.7km from the edge of the nearest classification zone. From 1997 UV disinfection was applied voluntarily by Anglian Water services to treat one third of the effluent flow at King's Lynn STW. This was not formally consented and analysis of the UV efficacy data demonstrated ineffective disinfection. As such, this level of treatment was removed in 2005 with the agreement of the Environment Agency, Cefas and the local shellfish industry and the plant now utilises secondary treatment only. King's Lynn STW is very large and is located relatively close to the classification zone and so will have significant impact particularly in the south east part of the Wash. Spalding STW and Wisbech (West Walton) STW both receive secondary treated effluent and are of a similar size, 15,720 and 14,421 m^3/day (DWF) respectively. Spalding STW discharges into the River Welland approximately 16km from the edge of the nearest shellfishery and Wisbech (West Walton) STW discharges to the Tidal River Nene about 13km from the shellfisheries in the Wash. These are large discharges and although they are located at some distance from the fishery, will contribute to loading in the watercourses entering the Wash in the south western and southern regions. Boston STW has a consented DWF of 10,000 m^3/day secondary treated effluent, discharging into Witham Haven approximately 4km from the edge of the shellfisheries and as such will have an influence on the shellfisheries in the south west of the Wash. Ingoldmells STW is located outside of the Wash and its hydrological catchment, offshore from the coast to the north of the Wash. This is a large discharge, with a consented DWF of 10,433 m^3/day of secondary treated effluent. This discharge may potentially impact on water quality towards the mouth of the Wash in the north west corner of the Wash, depending on currents locally, although impact will be minimal given the large amount of dilution in the North Sea. Sutton Bridge STW uses secondary treatment and has a consented DWF of 3,247 m^3/day, discharging to the River Nene about 3.5km from the edge of the nearest classification zone in the south of the Wash. There is also a package treatment plant associated with Sutton Bridge STW, which discharges secondary treated effluent, also to the River Nene very close to the main STW, but no information on volume was available for this discharge. These discharges will contribute to microbiological loadings in this part of the Wash. Ingoldisthorpe STW has a consented DWF of 1,400m^3/day, discharging secondary treated effluent to the River Ingol approximately 8.5km from the Wash classification zone. This discharge will impact on microbiological loading in the east part of the Wash. Holbeach STW discharges 1,910 m^3/day (DWF) of secondary treated effluent to Holbeach River, about 16km from the Wash; Fishtoft STW discharges 2,050 m^3/day (DWF) secondary treated effluent about 8km from the Wash and Wainfleet STW discharges 1,200 m^3/day (DWF) secondary treated effluent about 10km from the Wash. These three discharges will add to the loadings in the watercourses entering the Wash and thereby potentially impacting on the shellfisheries.

These eleven larger discharges, entering the various pathways to the shellfisheries will contribute significantly to the microbiological loading in the classification zones. The closer the discharges are located to the classification zone and the larger they are, the greater the microbiological impact will be.

There are many smaller continuous water company discharges located throughout the 20km zone around the Wash. All of these will contribute microbiological loading that will enter watercourses discharging to the Wash. Depending on flow rates and therefore how long the effluent takes to reach the Wash some natural die-off of micro-organisms will take place between point of discharge and the shellfisheries.

In addition to the continuous sewage discharges, there are various intermittent water company discharges associated with the sewerage networks also shown on Figure II.1. Details of those within 2km of the Wash or thought to be potentially significant are shown in Table II.5.

Table II.5: Intermittent discharges potentially impacting on the shellfisheries (within 2km of the Wash and/ or in the EA Pollution Reduction Plans)

No.	Name	Grid reference	Receiving water	Type
A	Beach Rd SPS	TF6989043500	River Hun	Pumping Station
B	Church Road SPS	TF3343043540	Unknown trib. Maud Foster Drain	Storm Overflow/ Storm Tank
C	Churchill Avenue PS	TF5585064520	Unknown Trib.	Pumping Station
D	Churchill Avenue Skegness	TF5682064490	Unnamed drain system Ingoldmel	Pumping Station
E	Fenside Road Sewage Pumping Station	TF6721036830	Heacham Parish Drain	Pumping Station
F	Fenside Road Sewage Pumping Station	TF9120043820	Unnamed Marsh Dyke North Sea	Storm Overflow/ Storm Tank
G	Folgate Rd TPS Heacham	TF6600040160	The Wash	Water Company Trade Effluent-Process Water
H	Freeman St	TF6662040020	The Wash	Water Company Trade Effluent-Process Water
I	Fring WTW	TF6100021570	Tributary of Tidal Great Ouse	Storm Overflow
J	Fring WTW	TF6097021620	Tidal River Great Ouse	Storm Overflow/ Storm Tank
K	Gaywood Outfall Pumped No. 1 Storm	TF6662040020	The Wash	Storm Overflow
L	Gaywood PS Outfall 2	TF6594040100	The Wash	Storm Overflow/ Storm Tank
M	Huns'ton Storm O'Flow 1	TF5971069000	North Sea	Storm Overflow/ Storm Tank
N	Ingoldmells (STW) PS	TF5712068390	The Haven	Storm Overflow/ Storm Tank
O	Ingoldmells STW	TF6054022220	Tidal River Great Ouse	Storm Overflow/ Storm Tank
P	King Lynn STW	TF6166019100	Tidal River Great Ouse	Storm Overflow

Q	King Lynn STW	TF3272043340	The Haven	Pumping Station
R	King's Lynn Tunnel PS	TF3272043340	The Haven	Storm Overflow/ Storm Tank
S	London Road Pumping Station	TF6154020030	Tidal River Great Ouse	Storm Overflow
T	London Road Pumping Station	TF5539061760	Croft Bank Drain	Storm Overflow
U	New East Side PS	TF5539061760	Croft Bank Drain	Storm Overflow/ Storm Tank
V	Norfolk Street SSO	TF6594040100	The Wash	Water Company Trade Effluent-Process Water
W	Purfleet Quay CSO	TF6100021600	Tidal River Ouse	Storm Overflow/ Storm Tank
X	Queen's Road CSO	TF6873042740	Tributary River Hun	Storm Overflow
Y	Richmond Rive TPS	TF3277043360	The Haven	Surface Water
Z	Richmond Rive TPS	TF5700068400	Trib to Ingoldmells Main Drain	Storm Overflow
AA	Ringstead WTW	TF5707068270	Unknown Trib. Ingoldmells Main	Pumping Station
BB	Sewers at Gaywood PS	TF4883023250	River Nene	Storm Overflow/ Storm Tank
CC	Sleaford Road SPS	TF3260044200	Witham Haven	Surface Water
DD	Sleaford Road SPS	TF9128044080	Tributary Wells Creek	Storm Overflow/ Storm Tank
EE	Smugglers Lane PS	TF7082043460	Tributary Marsh Dyke System	Pumping Station
FF	South Terrace SPS	TF3400042700	Witham Haven	Storm Overflow/ Storm Tank
GG	Southgate Ca. Ingoldmells	TF3323044440	Maud Foster Drain	Storm Overflow/ Storm Tank
HH	Southgate Camp PS	TF3314044590	Maud Foster Drain	Storm Overflow/ Storm Tank
II	Sutton Bridge STW	TF3145044510	North Forty Foot Drain	Storm Overflow
JJ	SWS	TF3145044510	North Forty Foot Drain	Storm Overflow/ Storm Tank
KK	Wells-next-the-Sea STW	TF3141043900	North Forty Foot Drain	Pumping Station
LL	Whitehall Farm SPS	TF3141043900	North Forty Foot Drain	Storm Overflow/ Storm Tank

Data from the Environment Agency

No recent spill records were available for any of these intermittent discharges and as such it is difficult to assess their potential impacts aside from noting their location and potential to spill untreated sewage. Some information was available on spill frequencies from the Kings Lynn sewerage catchment, although the period covered ended in 2004 (Metoc, 2004). This indicated that spills from most of these were relatively infrequent (active for <1% of the time), although four of these spilled for between 20 and 30% of the time. These were the two Gaywood PS outfalls in Table II.5 and two other outfalls whose name and location do not align with any of the consented outfalls listed in the database. All feed into the Ouse so their impacts will be felt via the Ouse outfall.

There are several clusters of intermittent discharges associated with the sewerage network at Skegness, Boston, King's Lynn and Hunstanton, with other intermittent discharges located at the larger sewage treatment works throughout the catchment. The impacts from these intermittent discharges associated with periods of elevated rainfall will reflect their location: in the north west corner of the Wash, the south west corner, the south east corner and in the north east corner.

Although the vast majority of the survey area is served by water company sewerage infrastructure, there are also a number of private discharges in the area. Where specified, these are generally treated by small treatment works such as package plants. The majority of these are small, serving one or two properties but there are several larger private discharges within 20km of the Wash coastline with flows of >50m^3/day, that may impact on the shellfisheries, details of which are presented in Table II.6 and illustrated in Figure II.1.

Table II.6 Details of private and trade discharges of over 50m^3/day within 20km of the Wash

	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A1	Albert Bartlett & Sons (Airedrie)	TF2586642426	Package Plant	50	New Hammond Beck
B1*	Calders & Grandige	TF3193041910	Activated Carbon	1000	Tributary Towns Drain
C1	Camping and Caravanning Club Site	TF6896026670	Package Plant	62	Trib of River Babingley
D1	Diglea Caravan Park	TF6572033230	Unspecified	50	Tributary River Ingol
E1*	Experimental Station at Sutton Bridge	TF4790020500	Unspecified	145	River Nene
F1	HM Prison	TF3920039700	Biodisc	100	Unnamed drain Witham Haven
G1	Holkham Estate	TF8944044040	Lagoon Settlement	94	Holkham Marsh Drainage Ditches
H1	Innisfree Mobile Home Park	TF6699020230	Package Plant	82	Trib Gaywood River
I1	Laburnam Farm	TF3980051470	Package	120	Unnamed trib of Hobhole Drain
J1*	Leziate Quarry	TF6750017750	Unspecified	950	Unnamed trib Middleton Stop D
K1*	Manor Farm	TF4044028770	Activated Carbon	320	Trib of the Fleet Haven Drain
L1*	Marham WTW	TF6031007020	Unspecified	832	Tidal Great Ouse
M1	Newgate Road	TF4239016150	Biological Filtration	93	Dyke north of Newgate Road
N1	RAF Marham	TF7155010850	Unspecified	1995	Polver Drain
O1*	Sluice Road	TF3470031700	Unspecified	1310	Holbeach River
P1*	Spalding Potatoes Ltd	TF2571021400	Biological Filtration	170	Trib of Wells Drain
Q1	Terrington St Clement	TF5438021500	Unspecified	76	Unknown Trib

*Probably has little or no sewage content.
Data from the Environment Agency

The largest private discharge is RAF Marham (N1) which has a consented maximum daily flow of 1995 m^3/day, the treatment level for which is unspecified (but it is very likely to be secondary), to Polver Drain about 22km from the edge of the shellfisheries. This discharge will contribute to microbiological loadings in water courses which discharge to the south eastern corner of the Wash. However, given the distance from the shellfisheries a certain amount of natural die-off is likely to reduce the microbiological loading associated with this effluent by the time it reaches the Wash. Although smaller, the discharge from HM Prison (F1), located near Boston, in the south west corner of the Wash, has a consented maximum daily flow of 100 m^3/day of secondary treated effluent discharging less than 1km to the edge of the nearest classification zone in the south western corner of the Wash and as such, will have an impact in that vicinity. Diglea Caravan Park (D1) has a consented DWF of 50m^3/day (DWF) of effluent discharging into a tributary of the River Ingol approximately 4.8km from the Wash. The treatment level is unspecified. This discharge will contribute to loadings in the watercourses leading to the east of the Wash. Laburnum Farm (I1) is located approximately 5.5km from the western coast of the Wash, has a consented maximum daily flow of 120 m^3/day of secondary treated combined trade and sewage effluent. The Camping and Caravanning Club (C1) has a consented maximum daily flow of 62 m^3/day of secondary treated effluent to a tributary of the River Babingley, approximately 7.75km from the south eastern corner of the Wash. Innisfree Mobile Home Park (H1) has a consented maximum daily flow of 82m^3/day of secondary treated effluent to a tributary of the Gaywood River approximately 10.5km from the edge of the south eastern corner of the Wash. The Newgate Road discharge (M1) has a consented maximum daily flow of 93 m^3/day of secondary treated effluent into a dyke north of Newgate Road, approximately 12km from the southern edge of the Wash. The discharge from Albert Bartlett and Sons (A1) has a consented maximum daily flow of 50 m^3/day of secondary treated effluent from food production, approximately 13km from the south western corner of the Wash. Holkham Estate discharge (G1) is unlikely to impact on the Wash shellfisheries given its distance >20km and the fact it discharges to Holkham Marshes which in turn will provide natural additional reduction in microbiological loading in addition to the lagoon settlement the effluent receives. All these discharges will contribute to microbiological loading to watercourses leading to the Wash.

There are other discharges in Table II.6 of varying sizes and composition that may contribute microbiological loading to their receiving waters. Many are unlikely to have a significant sewage content, comprising of trade effluent from properties such as vegetable processing units. These are clustered predominantly in the south west corner of the Wash (around the Boston area); at points along the southern coast of the Wash, and in watercourses leading to the south eastern corner of the Wash.

Table II.7 details private discharges >5 m^3/day (max daily flow) within 2km of the coast. Of these, HM Prison (discharge 3) is the largest and is described above, as is Diglea Caravan Park (discharge 2). Marsh Farm (discharge 4) has a consented maximum daily flow of discharges 36m^3/day of secondary treated effluent approximately 1.5km from the nearest edge of the Wash and will contribute to the impact on the west coast in that vicinity. All these private discharges and the other smaller private discharges will contribute to background levels of microbiological contamination in the various water sources impacting on the Wash. Within the wider catchment, most of the larger watercourses draining to the Wash also receive inputs from private discharges.

Table II.7: Private discharges >5m^3/day Max within 2 km of the Wash

	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
1	Beach Park Caravan Site	TF6531333322	Package Plant	11	Trib. Wolferton Creek
2	Diglea Caravan Park	TF6572033230	Unspecified	50	Trib. River Ingol
3	HM Prison	TF3920039700	Biodisc	100	Unnamed drain
4	Marsh Farm Caravan Site	TF4488250224	Package Plant	36	Trib Wrangle Drain
5	North Sea Camp	TF3870039600	Unspecified	5	Groundwater
6	Onslow Farm	TF4660028540	Biodisc	15	Trib. Lutton Leam
7	Summerville	TF6729236505	Package Plant	5	Land

Data from the Environment Agency.

In summary, there are no continuous water company sewage works which discharge directly to the Wash. Three of the four main rivers draining to The Wash receive significant sewage inputs from large secondary treated sewage works to their tidal reaches. The exception is the River Welland, although this does receive significant sewage inputs above its tidal limit, principally from Spalding STW. Multiple sewage works discharge to all four rivers further inland, although given their sluggish flows it is likely that the vast majority of bacteriological contamination from these dies off before it reaches The Wash. The Ingoldmells STW which discharges off Skegness may be an influence in the outer reaches on the Lincolnshire side. The drains in the Heacham and Gibraltar Point areas also receive some potentially significant sewage inputs. There are some intermittent discharges direct to The Wash in the Hunstanton area, but there is no information on their performance. The drains in some areas may be impacted to some extent by private discharges.

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

Agricultural land within the catchment is predominantly devoted to arable farming, particularly in the areas bordering The Wash where soils are very fertile and a large range of crops such as brassicas, potatoes and cereals are grown (Figure 1.2). Table III.1 and Figure III.1 to Figure III.4 present livestock numbers and densities for the sub-catchments draining to the Wash. These data were provided by Defra and are based on the 2010 census, as later censuses in 2011 and 2012 did not provide the same level of detail. Geographic assignment of animal counts in this dataset is based on the allocation of a single point to each farm, whereas in reality an individual farm may span the catchment boundary. Nevertheless, the data should give a good indication of the numbers and distribution of livestock within the catchment.

Table III.1: Summary statistics from 2010 livestock census for the Wash catchment

		Numbers				Densities (animals/km^2)			
No.	**Catchment area**	**Cattle**	**Sheep**	**Pigs**	**Poultry**	**Cattle**	**Sheep**	**Pigs**	**Poultry**
1	100ft and Old Bedford	1212	*	*	17550	9.7	*	*	140.7
2	Alconbury Brook	907	3618	*	43214	7.8	31.0	*	370.5
3	Alconbury Brook	*	0	0	0	*	0.0	0.0	0.0
4	Babingley	*	899	*	*	*	9.2	*	*
5	Bain	4104	8414	*	252796	19.4	39.9	*	1197.9
6	Barlings Eau	8094	11158	2189	1002332	21.9	30.1	5.9	2707.4
7	Bedford Ouse	2810	3498	46	260507	13.0	16.2	0.2	1204.9
8	Bourne Brook (Cambs)	292	431	*	262	3.3	4.8	*	2.9
9	Brant	2701	4207	10948	627139	18.6	28.9	75.3	4311.9
10	Broughton Brook	*	886	0	0	*	14.7	0.0	0.0
11	Cam (C033027)	1056	3259	241	24708	5.1	15.8	1.2	119.9
12	Cam (C033029)	*	*	*	0	*	*	*	0.0
13	Cam (C033033)	*	*	*	*	*	*	*	*
14	Cam (C033034)	1167	2485	*	1746	4.7	10.1	*	7.1
15	Campton Brook	1028	2724	*	6926	14.2	37.6	*	95.5
16	Carrs Dyke/Delphs	1009	4142	12530	1952303	2.9	11.7	35.5	5528.2
17	Chater	1420	23163	*	39595	15.1	246.3	*	421.1
18	Clipstone Brook	3274	6403	*	149	71.0	138.9	*	3.2
19	Counter Drain	1410	1975	3349	293625	12.9	18.0	30.6	2680.1
20	Cutoff and Renew Channel	945	1194	8673	406	6.6	8.3	60.1	2.8
21	East Glen	2656	4749	1021	93769	17.1	30.6	6.6	604.9
22	Ellington Brook	299	*	0	*	3.9	*	0.0	*
23	Ely Ouse	1957	*	*	*	13.0	*	*	*
24	Eye Brook	2335	9110	*	30239	43.5	169.7	*	563.4
25	Flit	1309	1228	*	25532	10.9	10.3	*	213.5
26	Fossdyke	2005	561	*	880894	18.5	5.2	*	8128.9
27	Gaywood River	630	0	*	*	9.9	0.0	*	*
28	Granta	500	*	*	11056	4.4	*	*	97.4
29	Great Drain	3564	6761	*	478639	25.9	49.1	*	3473.0
30	Great Ouse (Tidal)	751	719	766	50543	3.9	3.8	4.0	264.3

31	Gwash	2150	18764	*	54061	13.6	118.9	*	342.7
32	Harpers Brook	1118	2420	*	669	16.0	34.7	*	9.6
33	Heacham	1737	723	20490	*	14.9	6.2	175.6	*
34	Hiz	769	321	*	2010	6.9	2.9	*	18.1
35	Hobhole/Stonebridge	5545	8217	17764	2203947	11.5	17.0	36.8	4562.3
36	Hun and Coast	*	*	0	*	*	*	0.0	*
37	Ingel	*	*	*	*	*	*	*	*
38	Ise	7453	20362	63	413769	31.7	86.7	0.3	1762.2
39	Ivel (C033014)	433	1096	3448	258	5.3	13.5	42.4	3.2
40	Ivel (C033015)	*	*	0	*	*	*	0.0	*
41	Ivel (C033019)	200	181	86	199706	1.4	1.3	0.6	1438.3
42	Ivel Navigation	0	0	0	0	0.0	0.0	0.0	0.0
43	Jordan	1020	1196	*	*	46.2	54.2	*	*
44	Kennett	*	4770	*	835520	*	46.3	*	8107.4
45	Kym	932	1578	885	570807	6.8	11.6	6.5	4183.3
46	Langton Brook	3064	15117	*	10836	46.8	230.8	*	165.5
47	Lark (C033037)	1621	5994	50086	463246	4.5	16.7	139.4	1289.4
48	Lark (C033039)	1625	*	5871	418878	11.5	*	41.4	2951.5
49	Little Ouse (C033042)	1023	437	21267	816593	8.1	3.4	167.5	6431.4
50	Little Ouse (C033043)	*	*	*	*	*	*	*	*
51	Little Ouse (C033045)	343	*	*	*	3.8	*	*	*
52	Little Ouse (C033046)	1721	*	3631	*	12.9	*	27.2	*
53	Lymn - Steeping	7624	6546	3944	54084	38.2	32.8	19.8	270.8
54	Medbourne Brook	1510	4471	*	*	41.6	123.2	*	*
55	Middle Level	2693	7658	4618	346191	3.8	10.9	6.6	493.2
56	Middleton Stop Drain	758	*	0	*	18.8	*	0.0	*
57	Nar	1812	3587	25238	979624	8.0	15.8	111.4	4323.8
58	Nene - Wansford	8478	26566	1965	90847	17.9	56.0	4.1	191.6
59	Nene blw Orton Lock	5351	5096	7010	356476	7.3	7.0	9.6	488.3
60	Nene,Brampton Bridge	3601	22568	157	898	14.7	92.4	0.6	3.7
61	Nene,Kis'bry Bridge	3886	25917	2352	28514	32.9	219.5	19.9	241.5
62	Nene,Orton	1060	469	*	40316	9.3	4.1	*	352.6
63	Nene,Whilton Bridge	5276	18643	2593	50184	47.9	169.4	23.6	456.1
64	Nene,Wl'boro	478	2544	*	*	5.8	30.8	*	*
65	Old West	3176	2525	1941	106585	16.7	13.3	10.2	559.7
66	Ouse (Beds) (C033001)	6366	30585	466	852729	40.9	196.5	3.0	5478.5
67	Ouse (Beds) (C033003)	4682	13509	3025	249272	40.0	115.4	25.8	2129.2
68	Ouse (Beds) (C033005)	1417	5122	*	299	16.5	59.7	*	3.5
69	Ouse (Beds) (C033011)	3907	14706	10903	5244	13.4	50.3	37.3	17.9
70	Ouse (Beds) (C033012)	1465	9756	*	8592	7.3	48.6	*	42.8
71	Ouse (Beds) (C033020)	2493	2063	1566	31698	14.2	11.7	8.9	180.5
72	Ouse (Beds) (C033022)	399	*	*	*	4.0	*	*	*
73	Ouzel (C033006)	2808	10656	2868	955512	23.5	89.3	24.0	8011.5
74	Ouzel (C033008)	1953	5683	*	772	17.6	51.3	*	7.0
75	Ouzel (C033010)	*	*	0	0	*	*	0.0	0.0
76	Rhee	963	5824	2896	96849	3.1	19.0	9.5	316.8
77	Sapiston	643	450	21222	643456	3.2	2.3	106.2	3219.7
78	Slea - Kyme Eau	837	5817	*	1102894	5.6	39.3	*	7442.0
79	South Forty Foot	8223	12546	10850	745855	12.8	19.5	16.9	1158.4
80	Stanton Brook	*	3132	0	38	*	69.7	0.0	0.8
81	Stringside Drain	884	881	*	161991	9.1	9.1	*	1667.6

82	Ten Mile (C033040)	0	0	0	0	0.0	0.0	0.0	0.0
83	Ten Mile (C033047)	*	*	0	*	*	*	0.0	*
84	Ten Mile (C033051)	634	178	28722	176570	10.7	3.0	486.9	2993.4
85	Terrington	*	0	*	*	*	0.0	*	*
86	Thet	5011	5498	103887	2798319	16.6	18.2	343.8	9259.4
87	Till (Lincs)	3748	704	7609	4988	29.9	5.6	60.7	39.8
88	Tove	8835	43681	46	277170	41.6	205.7	0.2	1305.1
89	Twin	10965	34184	6449	421840	47.2	147.2	27.8	1816.1
90	Welland	2977	9983	*	71	66.0	221.5	*	1.6
91	Welland - Peakirk	743	4507	7565	*	7.0	42.4	71.2	*
92	Welland - Rockingham	3426	14332	*	429	39.7	166.1	*	5.0
93	Welland - Stamford	2319	22470	*	218	23.0	222.4	*	2.2
94	Welland and Glen	1461	3021	*	610216	3.3	6.8	*	1365.2
95	West Glen	3496	7285	232	124361	18.5	38.5	1.2	656.4
96	Willow Brook	1305	2712	*	*	14.5	30.0	*	*
97	Wissey (C033048)	2628	21490	61190	512883	7.4	60.7	172.9	1449.2
98	Wissey (C033050)	*	*	0	*	*	*	0.0	*
99	Witham Bargate (Upper)	2018	3125	4804	225698	16.0	24.8	38.2	1792.6
100	Witham Claypole (Upper)	2761	3428	4825	28293	14.7	18.2	25.6	150.2
101	Witham Saltesford (Upper)	2233	12309	*	38273	19.0	104.8	*	325.8
102	Wooton Brook,Kis'bry	3106	10369	*	486281	34.1	113.8	*	5336.7
	TOTAL (>)	218600	629349	492296	24698757	13.7	39.5	30.9	1551.6

*Data suppressed to prevent disclosure of information about individual holdings

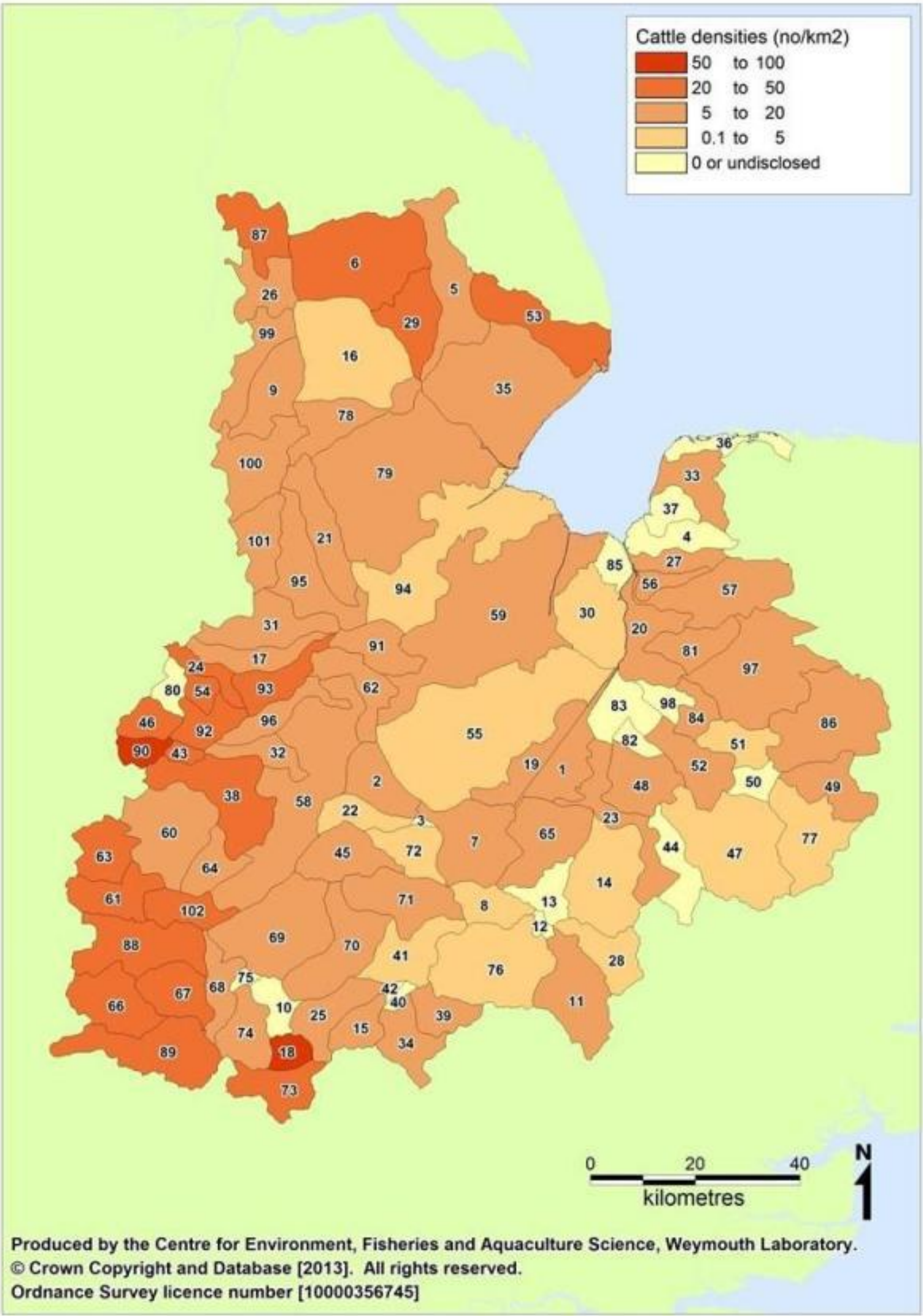


Figure III.1: Cattle densities within the Wash catchment.

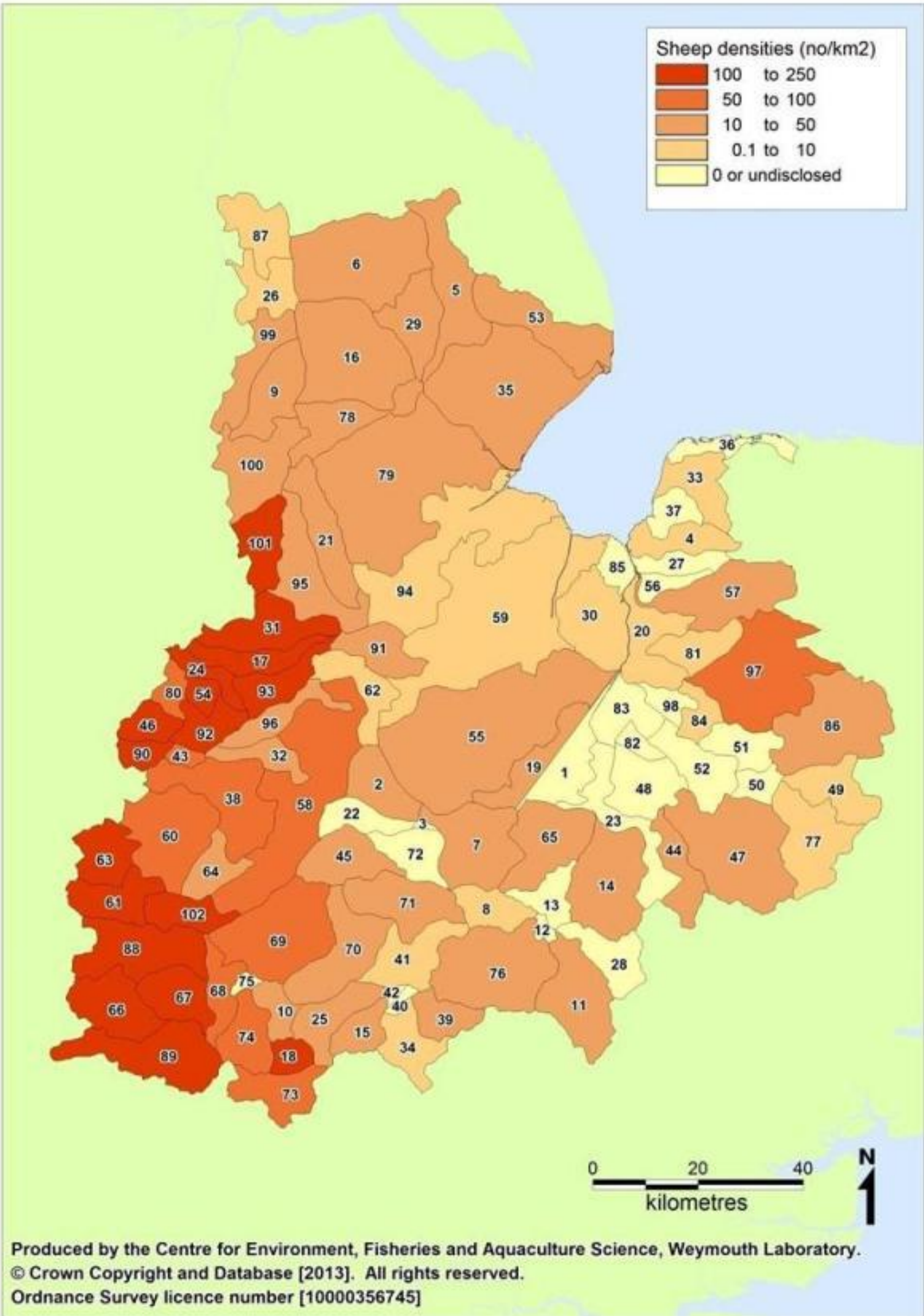


Figure III.2: Sheep densities within the Wash catchment.

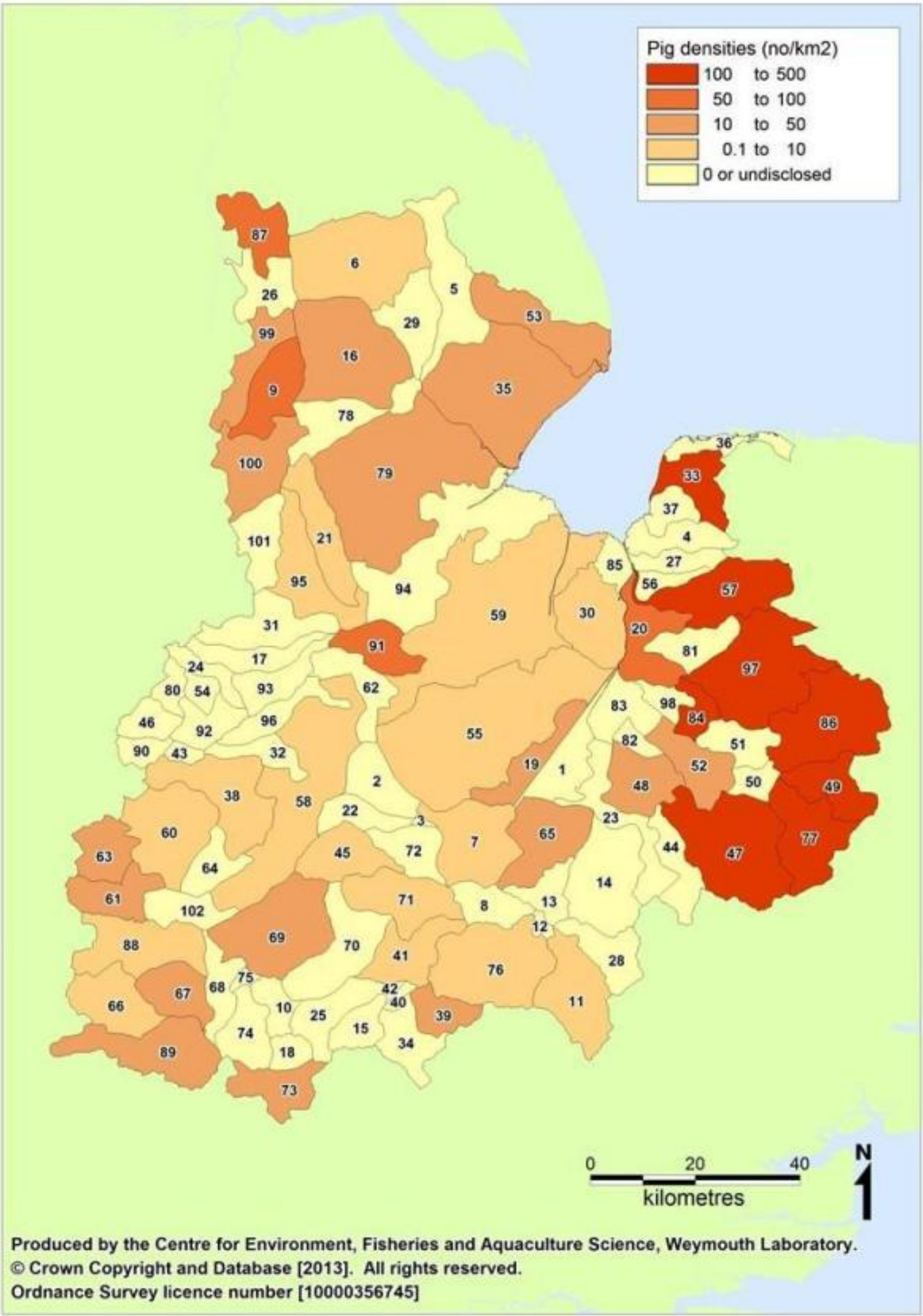


Figure III.3: Pig densities within the Wash catchment.

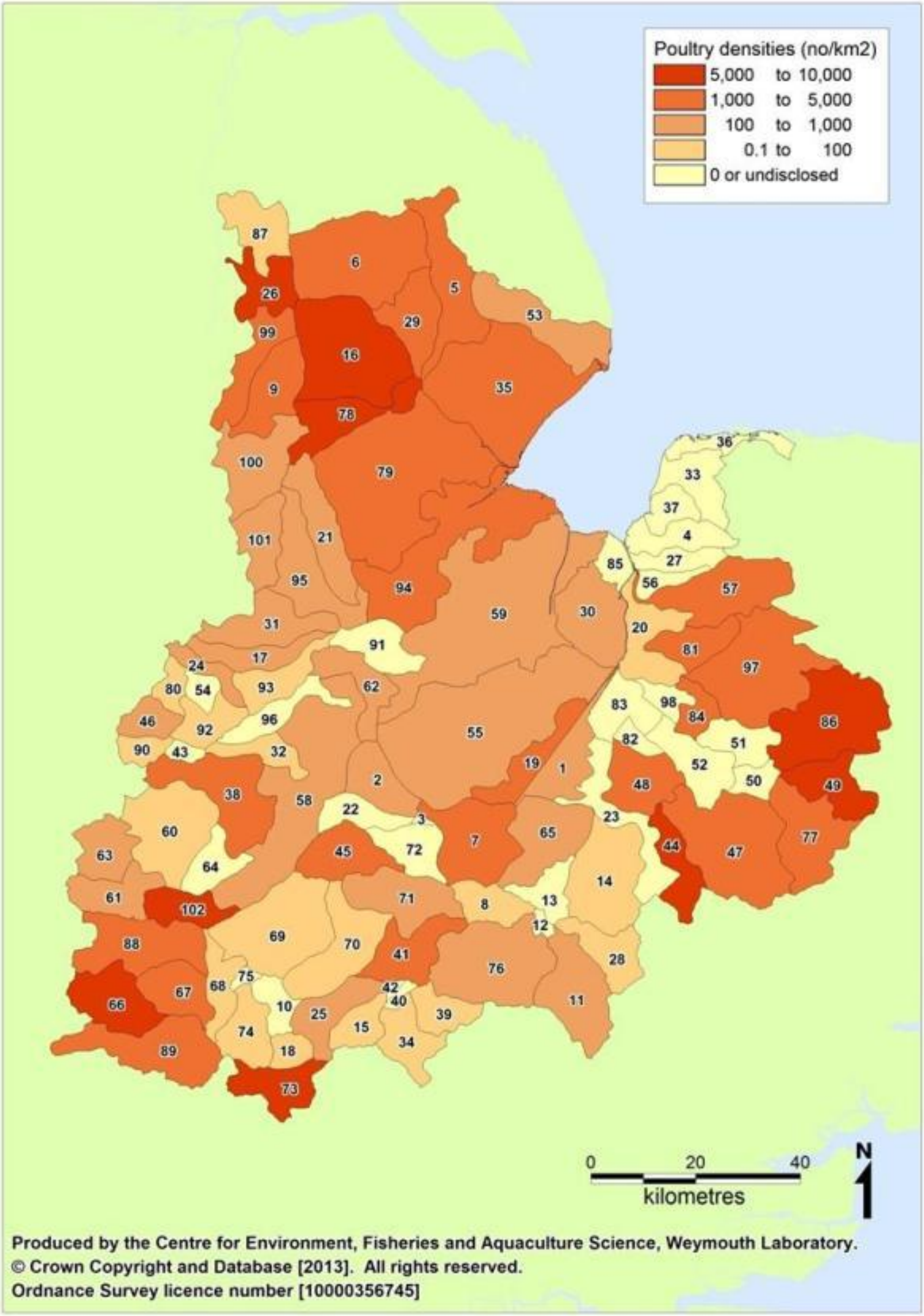


Figure III.4: Poultry densities within the Wash catchment.

The concentration of faecal coliforms excreted in the faeces of animal and human and corresponding loads per day are summarised in Table III.2.

Table III.2: Levels of faecal coliforms and corresponding loads excreted in *the faeces of warm-blooded animals.*

Farm Animal	Faecal coliforms (No. g^{-1} wet weight)	Excretion rate (g day^{-1} wet weight)	Faecal coliform load (No. day^{-1})
Chicken	1,300,000	182	2.3×10^{8}
Pig	3,300,000	2,700	8.9×10^{8}
Human	13,000,000	150	1.9×10^{9}
Cow	230,000	23,600	5.4×10^{9}
Sheep	16,000,000	1,130	1.8×10^{10}

Data from Geldreich (1978) and Ashbolt et al. (2001).

There are large numbers of grazing animals within the catchment with over 200,000 cattle and 600,000 sheep although the overall density of grazers is not particularly high. They are widespread throughout the catchment, although there are generally lower numbers in subcatchments bordering the south eastern shore of The Wash. Diffuse inputs associated with grazing livestock are therefore anticipated from most areas via direct deposition on pastures. Slurry is also collected from livestock sheds when cattle are housed indoors and subsequently applied to fields as fertilizer. Large numbers of poultry and pigs are also raised within the catchment. Highest pig densities are found in the eastern most parts of the catchment. Poultry are generally widespread although there are few in subcatchments bordering the south eastern shore. Manure from pig and poultry operations is typically collected, stored and spread on nearby farm land (Defra, 2009). Sewage sludge may also be used as fertilizer, but no information on local practices was available at the time of writing.

The primary mechanism for mobilisation of faecal matter deposited or spread on farmland to coastal waters is via land runoff, so fluxes of livestock related contamination into the Wash will be highly rainfall dependent. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the 'first flush'). Most, if not all significant watercourses will be impacted to some extent by agriculture. Runoff from the majority of the catchment area enters the Wash via the four main rivers, so highest impacts are anticipated in the vicinity of their outfalls. There are other surface water outfalls feeding in at various points around the shore, which will also carry some agricultural contamination. The main rivers draining into the Wash are long, highly regulated lowland rivers. The lengthy transit time will mean the vast majority of bacterial contamination of more distant origin will die off before reaching the area. Agricultural practices in the areas immediately bordering the Wash will therefore be of greatest influence.

Shoreline survey observations indicate that most of the land immediately adjacent to the shore is used for growing crops such as brassicas and potatoes, although there were some relatively small areas in use as pasture. Of most significance was the presence of cattle on the sea banks and on the saltmarsh between the sea banks and the sand/mudflats. These animals will defecate on the saltmarsh, and this will be washed directly into the Wash via tidal inundation on the larger spring tides. An Environment Agency study conducted in the Ribble estuary found a significant increase in levels of faecal coliforms within saltmarsh creeks in grazed areas as the tide started to ebb following tidal inundation (Dunhill, 2003) so this is a recognised phenomenon. Cattle or cattle prints and dung were commonly seen during the shoreline survey on sea banks and adjacent saltmarsh on most areas where the foreshore was of this type. It is quite likely that other areas are similarly affected, but the presence of cattle did not coincide with the survey. Creeks draining these areas will be subject to contamination from cattle. An exception was the area used for military exercises between the Nene and the Welland. Some fenced fields behind the sea wall were also in use for grazing, but the vast majority of adjacent fields were arable. The stretch from the mouth of the Ouse to the Ingol was not surveyed so its use for grazing could not be confirmed.

There is likely to be seasonality in levels of contamination originating from livestock. Numbers of sheep and cattle will increase significantly in the spring, with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. During winter cattle may be transferred from pastures to indoor sheds, and at these times slurry will be collected and stored for later application to fields. Timing of these applications is uncertain, although farms without large storage capacities are likely to spread during the winter and spring. Poultry/pig manure and sewage sludge may be spread at any time of the year. Therefore peak levels of contamination from sheep and cattle may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised basis if wet weather follows a slurry application which is more likely in winter or spring. Their seasonal pattern of impacts from adjacent reclaimed farmland will also be influenced by the seasonal patterns by which water is pumped from the drains out into the Wash.

Appendix IV. Sources and Variation of Microbiological Pollution: Boats

The discharge of sewage from boats is potentially a source of bacterial contamination of shellfisheries within the Wash. There is significant boat traffic within the Wash, and most of this is associated with the four commercial ports. Recreational boat traffic (e.g. yachts and cabin cruisers) is relatively light. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources.

Figure IV.1: Boating activity within The Wash

The Wash hosts four commercial ports; Boston, Sutton Bridge, Wisbech and Kings Lynn (Figure IV.1). Collectively, they handle around 1,600 ships from Western Europe, the Baltic, Mediterranean and West Africa per year (Hartwell, 2011) and dry cargo, in particular steel, timber and agricultural products (Ports and Harbours,2013) . Merchant shipping vessels are not permitted to make overboard discharges within 3 nautical miles of land[1]. Cargo ships may therefore potentially empty their tanks in the central outer reaches of The Wash, but not over the cockle or mussel beds which are closer inshore.

There is a sizable commercial fishing fleet operating from and within The Wash, the majority of which are based at King's Lynn (Eastern-IFCA, 2013). There are two marinas within the rivers that lead into The Wash which offer around 100 berths some of which are drying berths (Figure IV.1). There are no significant mooring areas within the Wash itself, although there are several moorings located on the River Glen and up river of the Port of Boston. There is no sewage pump out facilities available at either marina. There were 23 yachts in a tidal creek at Gibraltar Point at the time of shoreline survey and three yachts moored or anchored off Heacham. The Greater Wash area has been described as a 'somewhat unfriendly area for recreational sailors' and recreational traffic within it has been categorised as light (RYA, 2004).

There are several sailing and watersports centres surrounding the Wash which offer a range of watersports including dinghy sailing, motor boating, kite surfing, windsurfing and kayaking. The smaller recreational boats are not large enough to contain onboard toilet facilities and therefore are unlikely to make overboard discharges.

Private vessels such as yachts, motor cruisers and fishing vessels of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the relative calm of the river estuaries. However, most moorings and marinas are located a significant distance up the estuaries and therefore it is likely that any microbiological pollution derived from boats moored will be diluted by the time it reaches the shellfish beds in the Wash. Therefore, the areas at highest risk from microbiological pollution are river estuaries, and the main navigation routes through the Wash. The Wainfleet Haven may be affected to some extent by the yachts moored in it. Peak pleasure craft activity is anticipated during the summer, so associated impacts may be higher during the summer. Merchant and fishing vessels will operate all year round.

Overall, the impacts are anticipated to be minor and largely confined to the river estuaries, or in the case of shipping, the outer central areas of the Wash. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

[1] The Merchant Shipping (Prevention of Pollution by Sewage and Garbage from Ships) Regulations 2008

Appendix V. Sources and Variation of Microbiological Pollution: Wildlife

The Wash encompasses vast areas of intertidal mudflats, sand flats and saltmarsh. In fact 10% of England's saltmarsh is located within The Wash (Natural England, 2013). It also comprises of areas of saline lagoons, shingle banks and sand dunes. These features attract a large variety of wildlife including the largest aggregations of overwintering wildfowl and the largest colony of common seal in the UK. Consequently the whole of The Wash has several international, national and local conservation titles designations. The Wash and North Norfolk Coast European Marine Site encompasses the marine elements of the overlapping SPAs and SACs, including: The Wash SPA; Gibraltar Point SPA; North Norfolk Coast SPA; North Norfolk Coast SAC; The Wash and North Norfolk Coast SAC.

The most significant wildlife aggregation in terms of shellfish hygiene is likely to be overwintering waterbirds (waders and wildfowl). Studies in the UK have found significant concentrations of microbiological contaminants (thermophilic Campylobacter, salmonellae, faecal coliforms and faecal streptococci) from intertidal sediment samples supporting large communities of birds (Obiri-Danso and Jones, 2000). The Wash supports the largest overwintering aggregation of wildfowl and waders in the UK. An average total count of 379,164 waterbirds (wildfowl and waders) /year was reported over five winters up to 2010/11 for The Wash (Holt *et al*, 2012). Internationally important species include dark-bellied brent geese, knot, dunlin, oystercatcher, pink footed goose, shelduck, pintail, plover species, lapwing, sanderling, black tailed godwit.

Geese and ducks will mainly frequent the grassland and saltmarsh, where their faeces will be carried into coastal waters via runoff or through tidal inundation. Therefore RMPs within or near to the drainage channels from saltmarsh areas will be best located to capture contamination from this source. Waders, such as dunlin and oystercatchers will forage (and defecate) directly on any shellfish beds on the intertidal. They may tend to aggregate in certain areas holding the highest densities of bivalves of their preferred size and species, but this will probably vary from year to year. Contamination via direct deposition may be patchy, with some shellfish containing high levels of *E. coli* while others a short distance away are unaffected. At high tide waders are likely to frequent the saltmarsh around the perimeter of the Wash. Due to the diffuse and spatially unpredictable nature of contamination from wading birds it is difficult to select specific RMP locations to best capture this, although they may well be a significant influence during the winter months.

Birds such as gulls and terns and relatively small numbers of waders remain in the area to breed in the summer, but the majority migrate elsewhere outside of the winter months. Bird numbers and potential impacts on the hygiene status of the fisheries are therefore much lower during the summer. The JNCC Seabird 2000 census recorded a total of 6,686 pairs of terns and gulls along the perimeter of the Wash (Mitchell *et al*, 2004). The largest aggregation, 4,200 pairs of the Sandwich Tern was recorded on the North Norfolk Coast on the eastern edge of the mouth of the Wash. In the inner reaches, in closer proximity to the shellfish beds, a total of around 2,100 pairs of seabirds were recorded, predominantly the black-headed gull and also the common tern and lesser black-headed gull. Seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. Their faeces will be carried into coastal waters via runoff from their nesting sites or via direct deposition to the adjacent intertidal.

The largest breeding colony of common/harbour seals in the UK is located in the Wash, with 2,894 recorded in 2011 (SCOS, 2012). There are also significant seal colonies at Donna Nook, just south of the Humber estuary, and at Blakeney, on the North Norfolk coast. They haul out on the sandbanks at low tide, and it is at these locations where their impacts will be the highest. When hauled out, the animals are gregarious, occupying a small area at high densities. The haulout sites they use are widely distributed throughout the Wash, but are most concentrated in the inner eastern corner, with fewer in the outer reaches, particularly on the eastern side (Eastern IFCA, 2012). Their haulout sites may coincide with the location of some cockle beds, particularly those along the inner (south) shore and also along the west shore to a lesser extent. However, as their spatial use varies from year to year, as do the exact locations of the highest density cockle beds, it is difficult to predict exactly where the two will coincide. Where they do haul out on cockle beds they are likely to have a significant but localised impact on shellfish hygiene. During the moulting and pupping season, which occurs during the summer they tend to spend more time on haulout sites so their impacts are likely to be more acute during this period. When foraging they range widely and so their impacts at these times may be considered diffuse. One of the Eastern IFCAs management policies is '*Cockle/mussel beds, or parts thereof, will not be opened to fishing if there is deemed to be risk of disturbing known seal haulouts*' (Eastern Sea Fisheries Joint Committee, 2008). This will presumably prevent the gathering of shellfish at the more regularly and heavily used haulout sites.

Appendix VI. Meteorological Data: Rainfall

The Heacham weather station, received an average of 597mm per year and the Robin Hood's Walk weather station at Boston received an average of 620mm per year between 2003 and 2012. Figure VI.1 presents a boxplot of daily rainfall records by month at Heacham and Figure VI.2 presents a boxplot of daily rainfall records by month at Robin Hood's Walk.

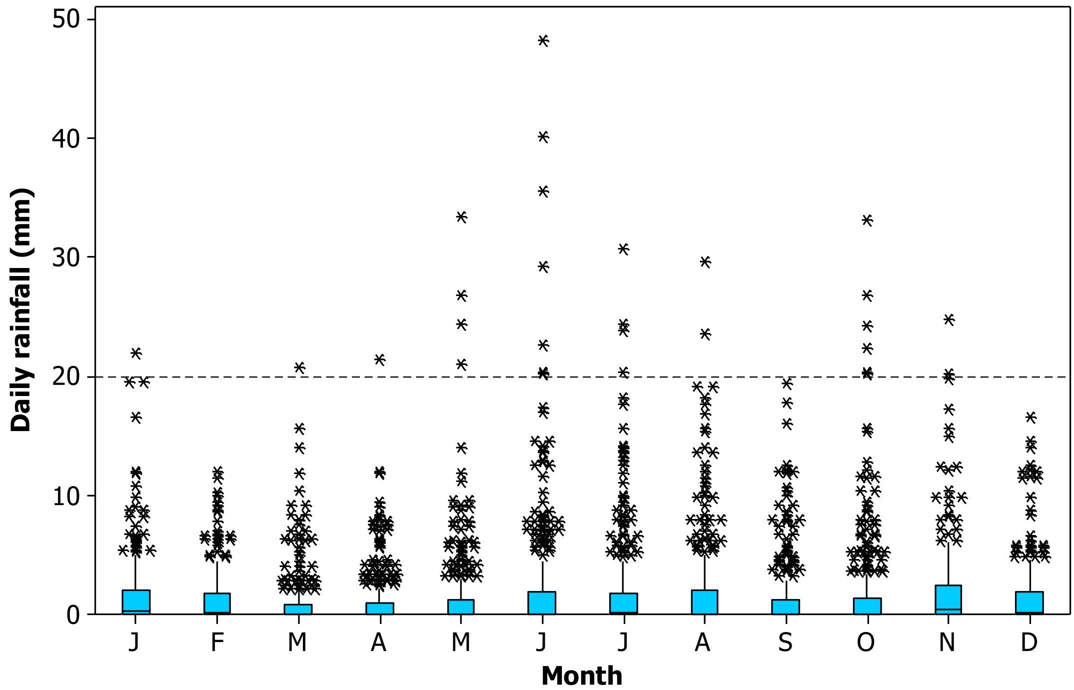


Figure VI.1: Boxplot of daily rainfall totals at Heacham, January 2003 to December 2012.
Data from the Environment Agency

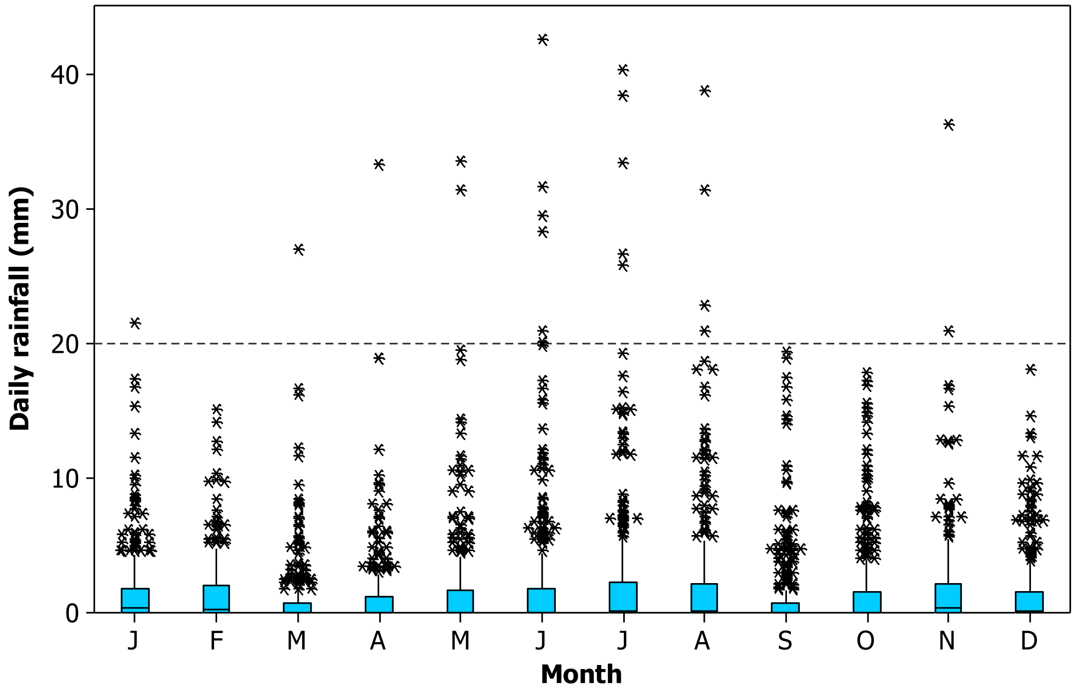


Figure VI.2: Boxplot of daily rainfall totals at Robin Hood's Walk, January 2003 to December 2012.
Data from the Environment Agency

Rainfall records from Heacham and Robin Hood's Walk, which are representative of conditions in the vicinity of the shellfish beds in the south and the north of the Wash respectively, indicate relatively minor seasonal variation in average rainfall with slightly more rainfall in the summer and winter than the spring and autumn. At Heacham, rainfall was lowest on average in March and highest on average in June, while at Robin Hood's Walk, the highest rainfall was in July. Daily totals of over 20mm were recorded on 0.8% and 0.6% of days at Heacham and Robin Hood's Walk respectively and 53% and 49% of days were dry at Heacham and Robin Hood's Walk respectively. High rainfall events (>20 mm) occurred in most months at both sites, but were more common and of a higher intensity from May to August.

Rainfall may lead to the discharge of raw or partially treated sewage from combined sewer overflows (CSO) and other intermittent discharges as well as runoff from faecally contaminated land (Younger *et al*., 2003). Representative monitoring points located in parts of shellfish beds closest to rainfall dependent discharges and freshwater inputs will reflect the combined effect of rainfall on the contribution of individual pollution sources. Relationships between levels of *E. coli* and faecal coliforms in shellfish and water samples and recent rainfall are investigated in detail in Appendices XI and XII.

Appendix VII. Meteorological Data: Wind

Eastern England is one of the more sheltered parts of the UK, since the windiest areas are to the north and west, closer to the track of Atlantic storms (Met Office, 2012). The strongest winds are associated with the passage of deep depressions across or close to the UK. The frequency of depressions is greatest during the winter months so this is when the strongest winds normally occur.

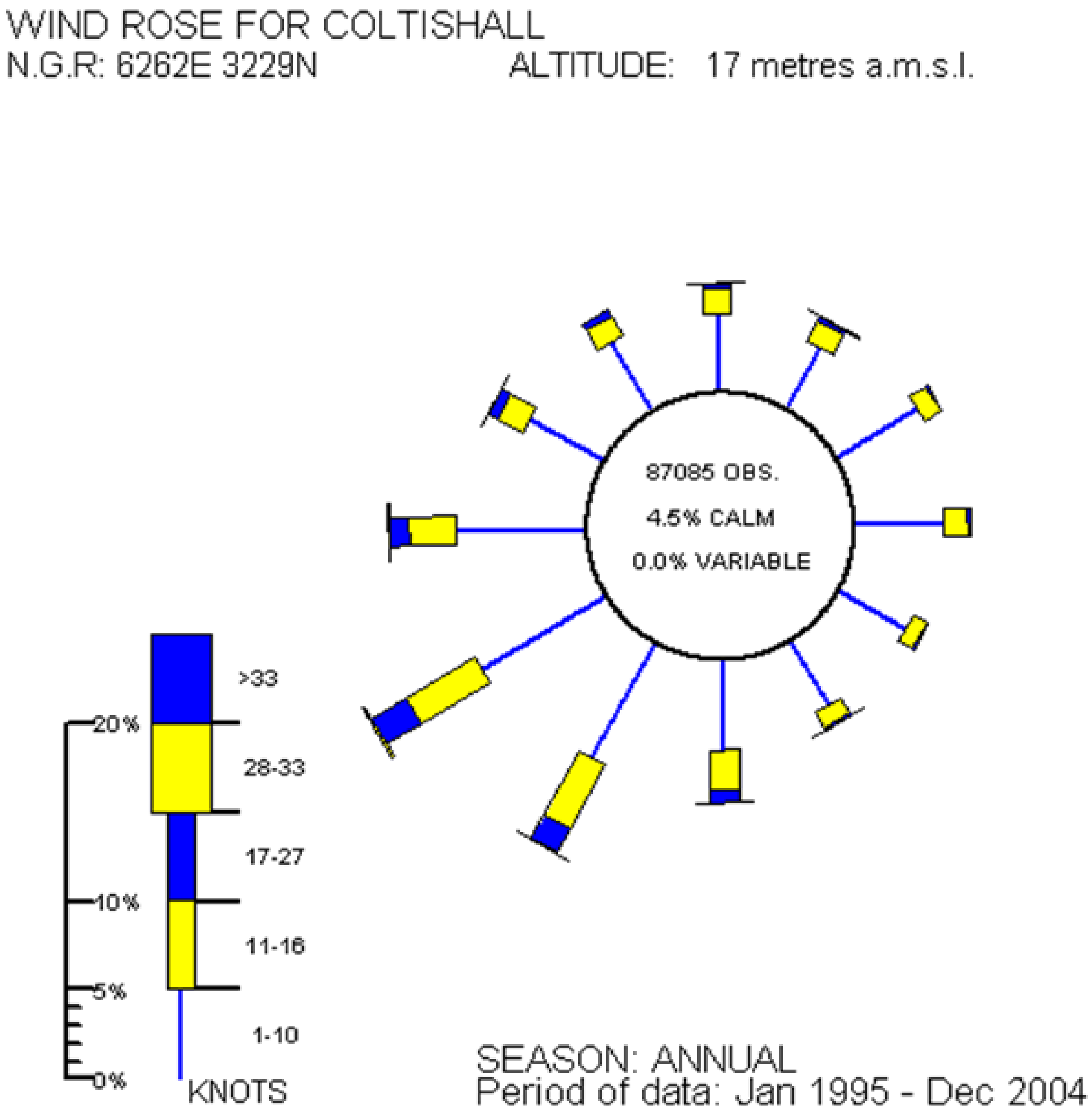


Figure VII.1

Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The wind rose for Coltishall, typical of open, level locations across the region. There is a prevailing south-westerly wind direction throughout the year. During spring there is a higher frequency of north-easterly winds due to a build up of high pressure over Scandinavia (Met Office, 2012). Periods of very light or calm winds are more prevalent inland, with coastal areas having similar wind directions to inland locations but higher wind speeds. The Wash is a wide embayment with a south west to north east orientation. A large proportion of the surrounding land is low lying, and will offer little shelter from the prevailing winds. Due to the large size of the embayment, strong winds from any direction will blow across a considerable distance of water, and so nowhere in the Wash is sheltered from an onshore wind. The area is particularly exposed from north easterly winds blowing in off the North Sea.

Appendix VIII. Hydrometric Data: Freshwater Inputs

The Wash has a large catchment area which covers 12% of the land area of England. There are four main freshwater inputs which discharge into the Wash; the Rivers Witham, Welland, Nene and Great Ouse. Their location is illustrated in Figure VIII.1 and information about their sub catchments in Table VIII.1.

Figure VIII.1 Freshwater Inputs into The Wash

The largest freshwater input into the Wash is from the River Great Ouse, which has the largest catchment (8,596km²) and longest length (230 km), but all four are significant.

Table VIII.1 Sub catchments and freshwater inputs within The Wash

River	Catchment area (km²)	River length (Km)	Population	Watercourses within the sub catchment
River Witham	3,000	132	375,000	River Brant, River Till, Fossdyke Canal, Barlings Eau, River Bain
River Welland	1,680	105	250,000	West Glen, East Glen Rivers, Eye Brook, River Chater and River Gwash
River Nene	2,270	161	750,000	Kislingbury Branch, Brampton Branch, Wootton Brook
River Great Ouse	8,596	230	1.7 million	Tove, Ouzel, Cam, Ivel, Lark, Little Ouse and Wissey

Data from the Environment Agency (EA, 2009 a,b,c and EA, 2011)

The underlying geology of the catchment comprises of a mixture of bedrock, predominantly mudstones to the west between King's Lynn and Milton Keynes. Horizontal bands of clay, limestone and sandstone exist in the central to eastern catchment. Bands of chalk exist in the north and south of the catchment. Areas of clay and mudstones have low permeability and therefore rainfall will be washed into waterways as runoff whereas in areas of limestone and sandstone which are more permeable, rainfall will percolate through the bedrock and will reach the watercourses as groundwater (EA, 2009 a,b,c and EA, 2011). The majority of the land surrounding the Wash comprises of low permeability mudstones and clay bedrock and therefore there will be relatively high rainfall runoff rates that flow directly into the watercourses.

All four rivers predominantly flow through rural land although there are many significant areas of urbanised land within their catchments. They will receive microbiological pollution from point and diffuse sources such as sewage works and urban and agricultural runoff. They are therefore a significant pathway of microbiological contamination to the shellfisheries in the Wash. They are lowland rivers and have been heavily engineered for flood defence and land drainage purposes, particularly in their lower reaches (EA, 2010a). Weirs and locks throughout reduce flow rates. The lower reaches are embanked and elevated above the surrounding reclaimed land, which is generally around or below sea level. A series of pumping stations pump water from the land drains up into the rivers. Their estuaries extend a significant distance inland, and consist of canalised trapezoidal channels.

An Environment Agency initiative collated and analysed the results of dye tracer studies in England (Guymer, 2002), and found that solute travel velocities in a selection of watercourses averaged about 24km d^{-1} and ranged from 1.7 to 91 km d^{-1}. The lowland rivers draining into the Wash are likely to fall towards the slower extreme under normal conditions. Therefore hydraulic transit times from sources in the upper areas of larger catchments are in the order of weeks under normal conditions. Most reported dieoff rates for *E. coli* in freshwater under various conditions range from a T_{90} of about 1 day to 1 week[2] (Jewell *et al*, 2004), so the vast majority are likely to die off before reaching the Wash. Samples taken from their tidal reaches during the shoreline survey whilst the tide was ebbing contained relatively low levels of *E. coli* (60-190 cfu/100 ml).

Summary statistics for flow gauging records at the farthest downstream gauging stations on these rivers are presented in Table VIII.2, covering the period from 2003 to 2013 unless otherwise stated. Futurecoast (2002) estimated the mean and maximum combined freshwater inputs to the Wash 44.05 m^3s^{-1} and 406.1 m^3s^{-1} respectively. This is considerably higher than the sum of the totals in Table VIII.2.

Table VIII.2 Summary flow statistics for flow gauging stations draining into The Wash (2003 -2013)

Watercourse	Station name	Catchment Area (Km²)	Mean annual rainfall 1961-1990 (mm)	Mean Flow (m³/s)	Q95[1] (m³/s)	Q10[2] (m³/s)
Heacham	Heacham	59.0	688	0.20	0.07	0.35
Ely Ouse	Denver Sluice	3430.0	587	6.23	1.07	14.40
Nene	Orton	1634.3	616	2.60	0.96	3.94
Welland	Tallington	717.4	634	2.23	0.08	0.17
Witham	Claypole Mill	297.9	614	2.06	0.54	4.02

1Q95 is the flow that is exceeded 95% of the time (i.e. low flow). 2Q10 is the flow that is exceeded 10% of the time (i.e. high flow).
Data from NERC (2012) and Environment Agency

The highest mean flow rate, 6.23 m³/s was recorded at Denver sluice gauging station on the Ely Ouse watercourse. This is significantly higher than the other principal watercourses flowing into the Wash, which have a mean flow rate of between 2 and 2.6 m³/s, although these gauging stations are a considerable distance from the Wash and so only represent a proportion of the river discharge. The Heacham, which has a considerably smaller catchment, had the lowest mean flow rate of 0.20 m³/s. Denver Sluice is situated where several drainage channels meet the tidal river, and water may be diverted down other (flood relief) channels rather than passing through the sluice. As such the data should be treated with caution as they do not consistently represent the total discharge into the tidal river. Considerably higher Q10s were reported at gauging stations on the Great Ouse farther inland. The other three main river gauging stations are all affected to varying extents by abstraction to Rutland water (NERC, 2012).

Boxplots showing mean daily flow records by month for individual gauging stations are presented in Figure VIII.2 to Figure VIII.6.

[2] T_{90} is the time taken for 90% of the organisms to die off.

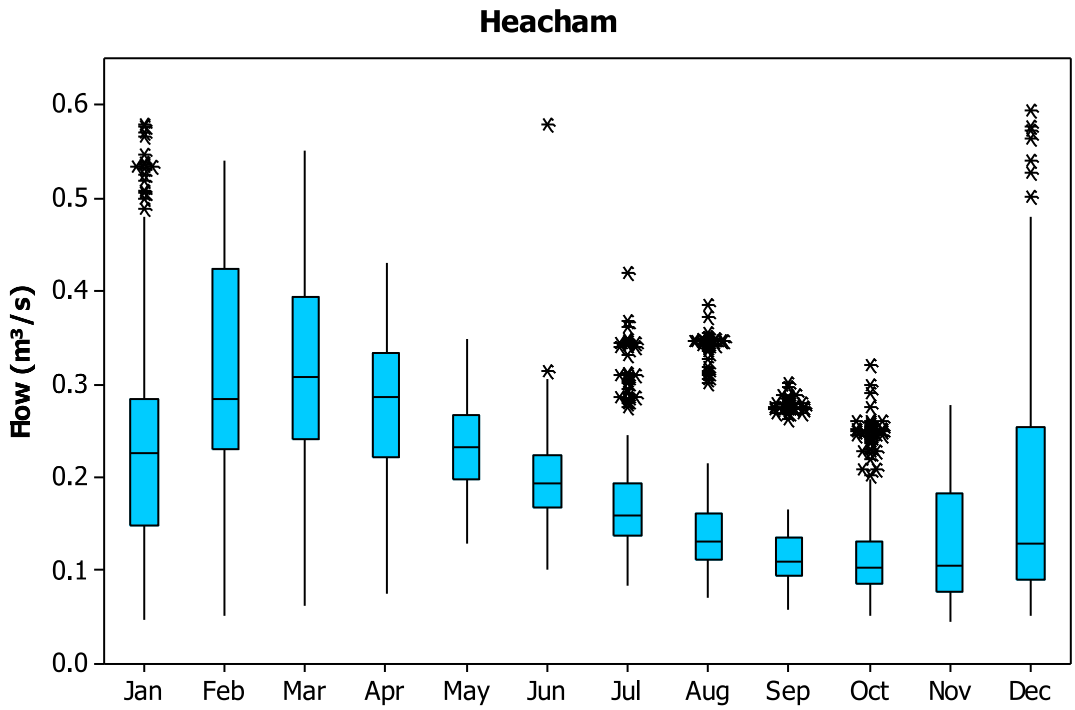


Figure VIII.2 Boxplots of the mean daily flow records from the Heacham gauging station on the Heacham watercourse (2003-2013)

Data from the Environment Agency

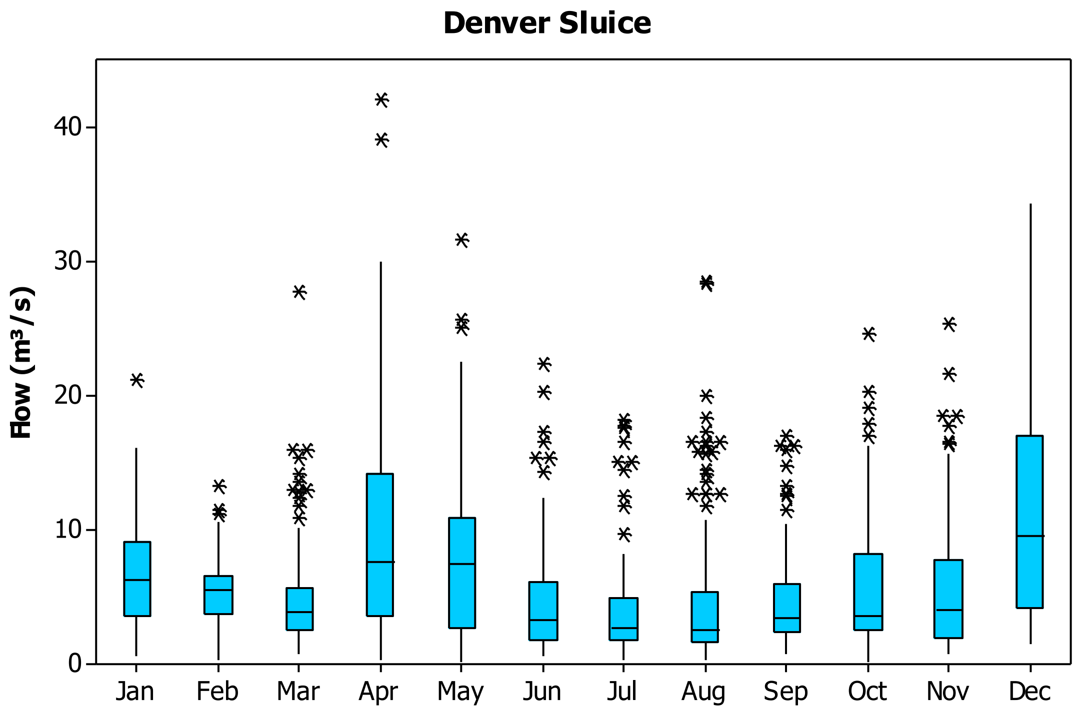


Figure VIII.3 Boxplots of the mean daily flow records from the Denver Sluice gauging station on the Ely Ouse watercourse (2003-2013)

Data from the Environment Agency

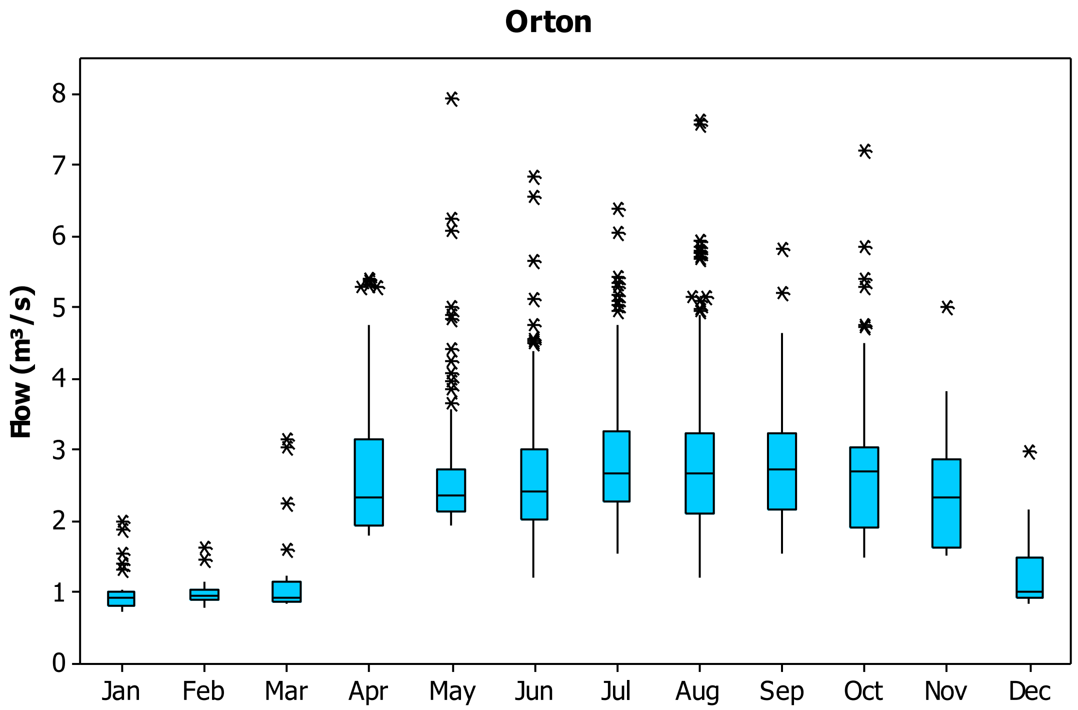


Figure VIII.4 Boxplots of the mean daily flow records from the Orton gauging station on the Nene watercourse (2003-2013)
Data from the Environment Agency

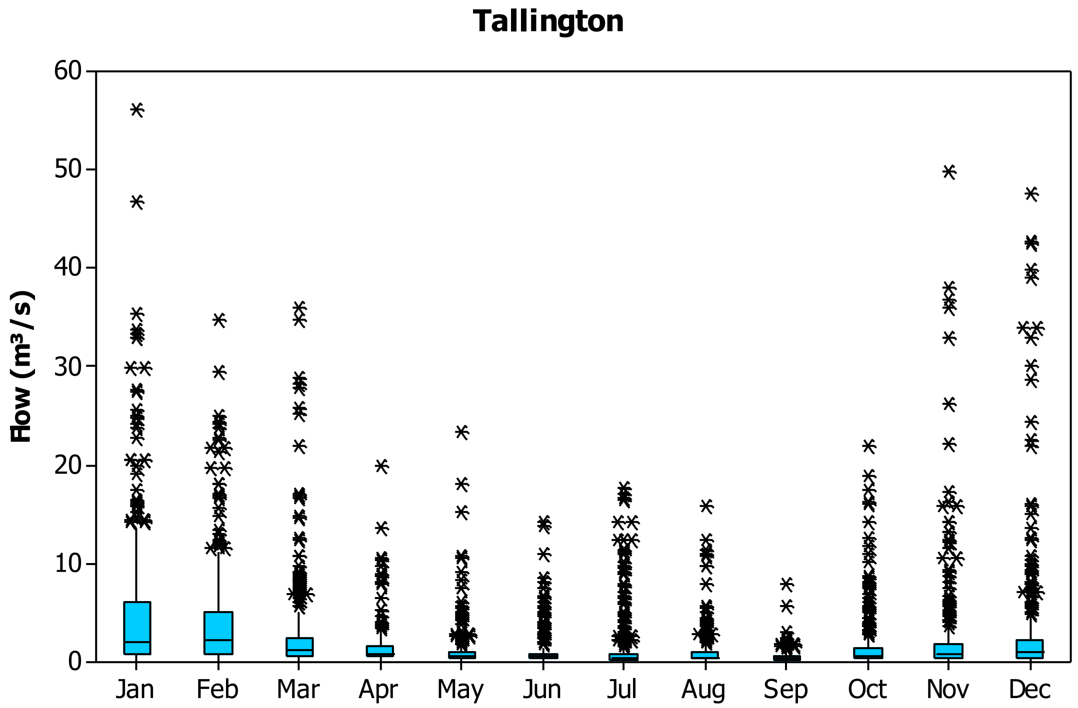


Figure VIII.5 Boxplots of the mean daily flow records from the Tallington gauging station on the Welland watercourse (2003-2013)
Data from the Environment Agency

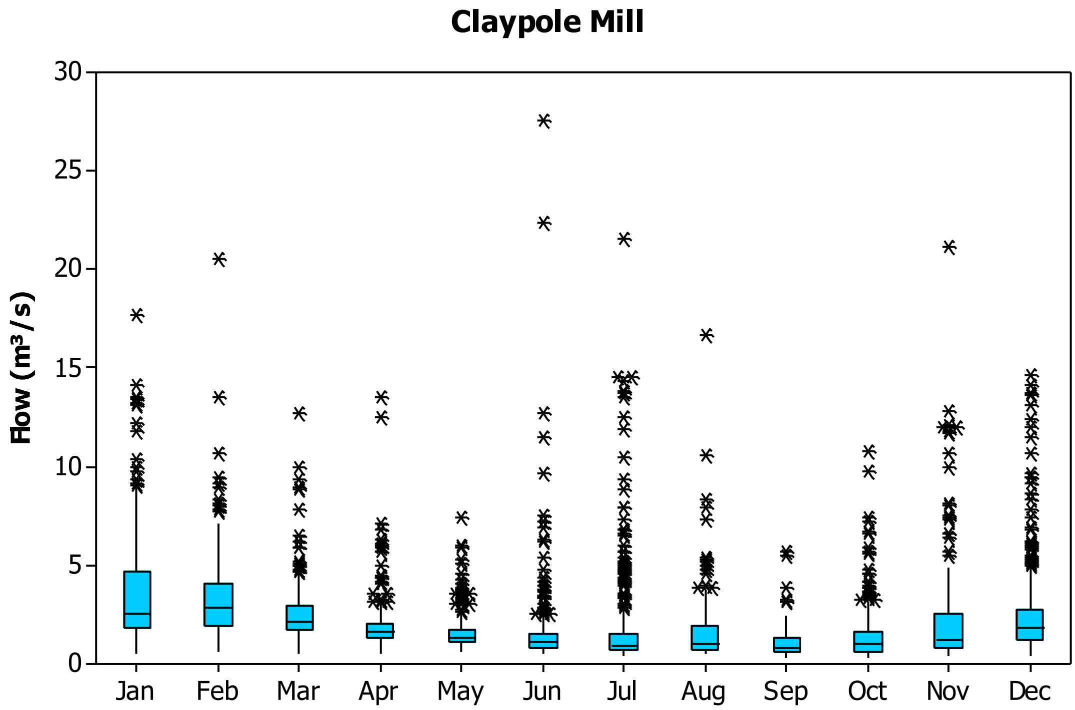


Figure VIII.6 Boxplots of the mean daily flow records from the Claypole Mill gauging station on the Witham watercourse (2003-2013)
Data from the Environment Agency

Figure VII.2, Figure VIII.5 and Figure VIII.6 show that flows were highest in the colder months at these locations. However at Denver Sluice (Figure VIII.3) highest daily mean flow rates were recorded between April and December, with lower flows from January to March, possibly representing seasonal differences in the management of flows down the various channels. At Orton (Figure VIII.4) highest mean daily flow rates were recorded between April and November (2 - 3 m^3/s). Unusually low flow rates of around 1 m^3/s at Orton were recorded during the winter months, possibly as a result of the abstraction of water from Wansford upstream to Rutland Water.

The lower temperatures and decreased solar radiation during the colder months of the year will reduce dieoff rates. Also, transit times will decrease in general within watercourses at these times due to decreased evaporation, transpiration, and a higher water table. Increased turbidity will generally be associated with increased flows, further reducing dieoff rates by preventing UV penetration. As such, there may be marked seasonal variation in the loadings of faecal coliforms that these rivers deliver.

As well as the four main rivers, there are a number of watercourses draining the adjacent land at various points around the Wash. These are generally field drains which discharge via engineered outfalls and most require pumping stations as the surrounding land is largely below the high tide level. Figure VIII.7 shows the location of the surface water outfalls draining to the shoreline of the Wash.

Figure VIII.7: Pumping stations and minor watercourses discharging to the shoreline.

Water samples were taken from the drains behind the pumping stations during the shoreline survey, and these contained low to moderate concentrations of *E. coli* (0 to 5000 cfu/100ml). None were operating at the time. They mainly drain arable fields, with occasional areas of pasture. Their pumping capacities range from 0.4 to 4.71 m^3/sec. Solomon and Wright (2012) report that pumping stations in the Lindsey Marsh drainage board, in the Wainfleet area, are run intermittently at a rate equivalent to about 5% of the total installed capacity on average.

Table VIII.3: Details of freshwater outfalls to the shoreline

Name	NGR of outfall	Pump capacity (m^3/sec)	***E.coli*** **(cfu/100ml)**
Wolferton PS	TF 65320 30240	3.75	1400
Burgh Sluice PS	TF 55253 58628	4.71	730
Gibraltar Point PS	TF 55330 58127	1.136	1900
Wainfleet Sea Lane PS	TF 52596 56570	0.4	90
Fleet Haven PS	TF 43817 32914	1.76	100
Lawyers PS	TF 40796 34541	4.2	0
Dawsmere PS	TF 46132 30949	1.08	80
Kirton and Frampton PS	TF 35608 36467	0.71	Not sampled
Wrangle PS	TF 46812 50923	2.63	40
Benington PS	TF 41807 44466	1.41	373
Leverton PS	TF 43461 47310	1.41	5000
Unnamed gravity outfall	TF 57448 25592	Small gravity sluice	60
Heacham River	TF 66235 36868	Gravity outfall via flap valve	2100

Pump capacities from Solomon & Wright, 2012.

It is likely that during the warmer months of the year most water from these drains is used for irrigation, and evaporation rates will be high so little is pumped out. During the winter they are likely to pump out considerably more water. Discharges from these outfalls will follow drainage channels running across the intertidal. Shellfish lying within or immediately adjacent to these are likely to carry elevated levels of contamination, particularly for the more heavily contaminated and larger outfalls.

Appendix IX. Hydrography

IX.1. Bathymetry

The Wash is a large shallow water embayment of the North Sea, with an area of about 667km^2, of which 298km^2 are intertidal (Futurecoast, 2002). It is characterised by a series of mobile sandbanks separated by parallel subtidal channels. These channels join in the outer reaches to form two main subtidal channels, the Boston Deeps and the Lynn Deeps. Intertidal areas are smaller and subtidal areas are deeper in its outer reaches, with a maximum depth is just over 30m relative to chart datum in the Lynn Deeps. Intertidal sediments are generally sandy in the outer reaches, with muddy sand in the inner reaches. Sand predominates in the subtidal, with mud and shells also present in the channel bottoms. The seabed in the deepest parts is of coarser materials (Dare *et al*, 2004).

The Wash receives freshwater inputs from four significant lowland rivers via canalised estuaries (Witham, Welland, Nene and Great Ouse) and so displays some estuarine characteristics. The impounded tidal sections of these rivers extend significant distances inland, up to about 26km in the case of the Ouse. They follow trained channels across the intertidal areas in the inner reaches of the Wash, and where the trained reaches end, tidal deltas have formed. The Witham and Welland join to share a trained channel before entering the Boston Deeps. Maintenance dredging is undertaken in these channels (Futurecoast, 2002). There are also many smaller, natural drainage channels cutting across the intertidal flats, some of which carry the smaller freshwater inputs.

The land surrounding the Wash has been subject to significant reclamation over the centuries. Most of its shoreline is fringed by a strip of saltmarsh, backed by flood defence dykes. The exception is the eastern shore, which is backed by a shingle ridge from Wolferton Creek to Hunstanton, and by cliffs at Hunstanton. Also, on the west shore, the very outer reaches, from Gibraltar Point, are flanked by dunes.

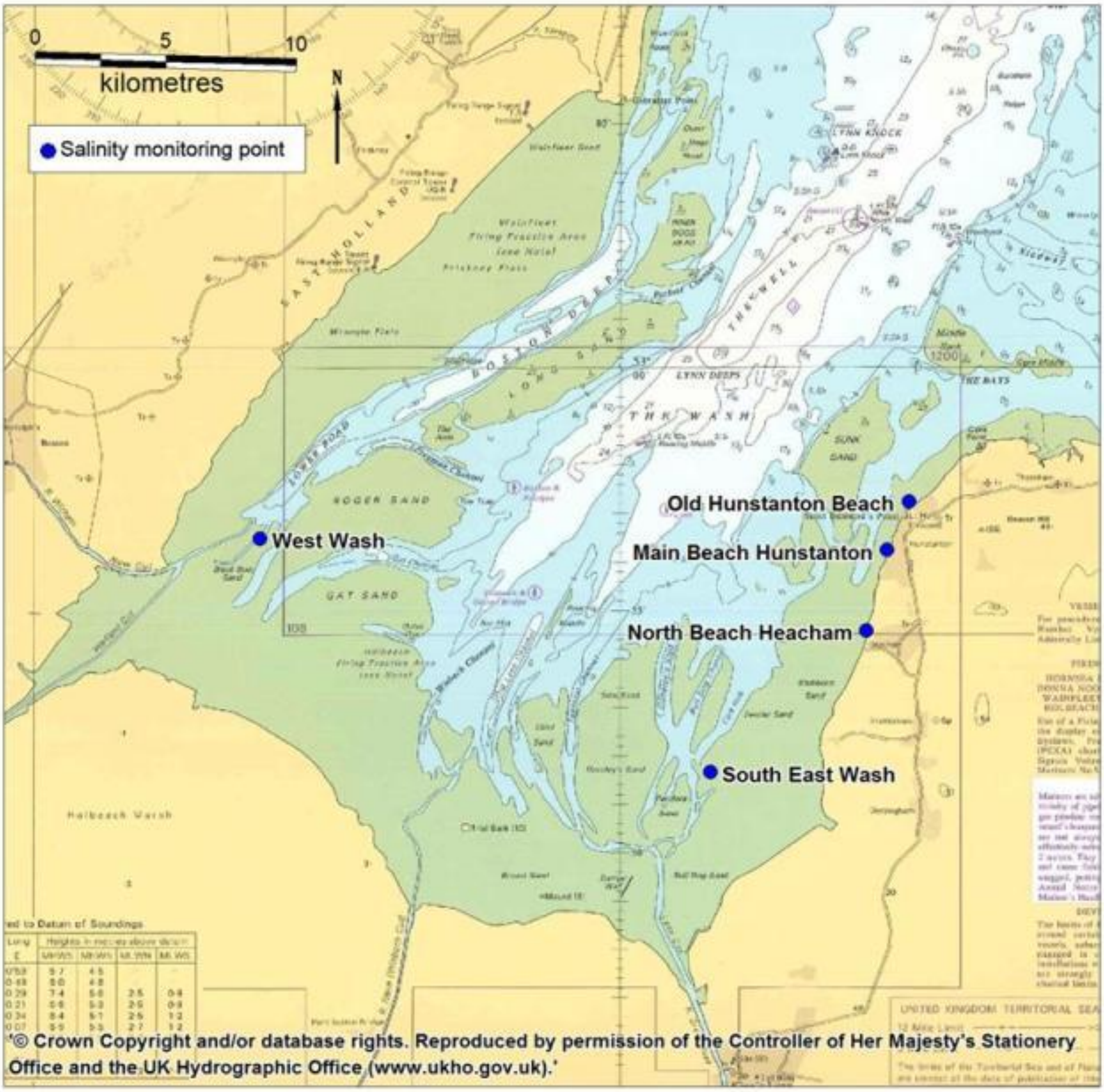


Figure IX.1: Bathymetry of The Wash

IX.2. Tides and Currents

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The Wash is macro-tidal and expresses a semi diurnal cycle with an average tidal range on spring tides of up to 6.36m at Tabs Head. The large tidal range indicates that tides will be the dominant force driving water circulation within the Wash. Futurecoast (2002) indicates that tidal asymmetry is ebb dominant, though there is likely to be considerable horizontal variation. Tidal curves indicate that tides are flood dominant within the impounded river estuaries, to the extent that a bore forms on the tidal Ouse on the very largest tides.

Table IX.1: Tide Levels and ranges for selected ports within the Wash

Port	Height above chart datum (m)				Range (m)	
	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Hunstanton	6.85	5.31	2.29	0.74	6.11	3.02
Tabs Head	7.00	5.41	2.23	0.64	6.36	3.18
West Stones	7.00	5.40	2.30	1.10	5.90	3.10
West Lighthouse	6.28	4.87	1.82	0.41	5.87	3.05
King's Lynn (Ouse)	6.80	5.00	1.80	1.00	5.80	3.20
Fosdyke Bridge (Welland)	5.69	4.38	1.58	0.27	5.42	2.80
Boston (Witham)	6.80	4.80	1.70	0.40	6.40	3.10

Data from the Proudman Oceanographic Laboratory

Table IX.1 and Table IX.2 present the direction and rate of tidal streams at various stations within the Wash at hourly intervals before and after high water. Figure IX.1 shows the locations of these stations, and the direction and relative strength of the spring flood (3 hours before high water) and ebb (3 hours after high water) streams.

Tides arrive from the North Sea from both the north and the east, and move up the main channels. The flood flow enters the Wash predominantly through the Lynn Deeps and progresses further into the area following the main channels in a south-westward direction. The ebb flow leaves the area predominantly along the margins in a north-eastward direction. During the earlier stages of the flood water spreads across the tidal flats perpendicular to the coast, but later during the tide once there is a sufficient depth of water over the flats, the water moves parallel to the shore (Evans, 1965). Current speeds in the main channels peak at 1.0-1.2m/s and 0.5-0.7m/s over the intertidal flats (Ke and Collins, 2000). Current velocities on neap tides are just under half those on spring tides. Tidal diamonds suggest a tidal excursion through the channels in the approximate order of 10-20km on spring tides and 5-10km on neap tides. Therefore, contamination discharged to the inner reaches of the Wash, such as that from the four main rivers, will not be carried out into the North Sea before tides reverse, even on large spring tides.

Whether contamination from sources such as sewage works discharging to the tidal rivers reaches shellfish beds in The Wash during the course of an ebb tide, before the tide reverses, will influence the extent of their impacts. There are no tidal diamonds within any of these tidal rivers however. Current measurements taken during the course of an ebb tide on the Nene at Sutton Bridge (Metoc, 2004) suggest an approximate tidal excursion within this estuary of about 14km on spring tides. It was not possible to get a similar estimate from measurements taken near the King's Lynn STW outfall as intervals between measurements were longer, but peak ebb current speeds were about 50% higher and the ebb duration was similar, so the ebb tide excursion through the tidal Ouse may exceed 20km on the larger tides. Tidal excursions on neap tides will be about half that experienced on spring tides. No information on current velocities or tidal excursion could be found for the Welland or Witham estuaries.

Table IX.2: Tidal Stream predictions for the Wash

Time before /after Highwater	Station A			Station B			Station C			Station D		
	Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)	
		Spring	Neap		Spring	Neap		Spring	Neap		Spring	Neap
HW-6	350	0.6	0.3	053	0.5	0.2	057	0.2	0.1	025	0.2	0.1
HW-5	347	0.2	0.1	321	0.1	0.0	138	0.1	0.0	211	0.4	0.2
HW-4	176	0.4	0.2	235	0.5	0.3	215	0.2	0.1	208	0.9	0.5
HW-3	175	0.9	0.5	233	0.9	0.5	221	0.5	0.3	208	1.2	0.6
HW-2	175	1.2	0.6	233	1.0	0.5	222	0.9	0.5	208	1.2	0.6
HW-1	175	1.0	0.5	233	0.9	0.5	237	0.6	0.3	208	0.9	0.4
HW	175	0.6	0.3	235	0.5	0.3	240	0.3	0.1	213	0.3	0.1
HW+1	162	0.1	0.1	321	0.1	0.0	048	0.2	0.1	027	0.4	0.2
HW+2	357	0.4	0.2	053	0.5	0.3	048	0.4	0.2	029	0.8	0.4
HW+3	356	0.8	0.4	055	0.8	0.4	048	0.5	0.3	030	1.1	0.5
HW+4	355	1.0	0.5	056	1.0	0.5	048	0.5	0.3	030	1.1	0.6
HW+5	354	1.0	0.5	055	0.9	0.4	041	0.4	0.2	030	0.9	0.5
HW+6	352	0.7	0.4	054	0.6	0.3	048	0.3	0.1	030	0.5	0.2
Excursion (flood)		15.1	7.9		14.0	7.6		9.4	4.7		17.6	8.6
Excursion (ebb)		16.9	8.6		15.8	7.6		9.0	4.3		18.0	9.0

Time before /after Highwater	Station E			Station F			Station G			Station H		
	Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)	
		Spring	Neap		Spring	Neap		Spring	Neap		Spring	Neap
HW-6	358	0.2	0.1	211	0.3	0.1	025	0.3	0.2	000	0.2	0.1
HW-5	203	0.1	0.1	206	0.4	0.2	330	0.1	0.1	220	0.2	0.1
HW-4	195	0.3	0.2	200	0.6	0.3	223	0.3	0.2	209	0.5	0.3
HW-3	192	0.6	0.3	197	0.7	0.4	213	0.8	0.4	206	0.9	0.5
HW-2	192	0.9	0.5	195	0.8	0.4	212	1.1	0.6	205	1.0	0.5
HW-1	192	0.8	0.4	203	0.5	0.3	212	1.0	0.5	205	0.8	0.4
HW	188	0.3	0.2	013	0.2	0.1	212	0.5	0.3	198	0.3	0.2
HW+1	021	0.2	0.1	025	0.7	0.4	182	0.1	0.1	036	0.4	0.2
HW+2	016	0.6	0.3	022	1.0	0.5	032	0.4	0.2	029	0.7	0.4
HW+3	014	0.8	0.4	020	0.9	0.4	035	0.9	0.5	029	0.9	0.5
HW+4	010	0.8	0.4	017	0.5	0.3	038	1.0	0.5	025	0.9	0.5
HW+5	007	0.5	0.3	007	0.2	0.1	037	0.8	0.4	020	0.6	0.3
HW+6	003	0.3	0.2	225	0.1	0.1	031	0.4	0.2	015	0.3	0.2
Excursion (flood)		10.8	6.1		12.2	6.5		13.7	7.6		13.3	7.2
Excursion (ebb)		12.2	6.5		12.6	6.5		14.0	7.6		14.4	7.9

Time before /after Highwater	Station I			Station J			Station K		
	Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)		Direction (°)	Rate (m/s)	
		Spring	Neap		Spring	Neap		Spring	Neap
HW-6	313	0.2	0.1	013	0.3	0.1	302	0.8	0.4
HW-5	230	0.5	0.3		0.0	0.0	302	0.7	0.3
HW-4	216	1.0	0.5	200	0.4	0.2	283	0.4	0.2
HW-3	213	1.2	0.6	205	0.7	0.4	225	0.3	0.2
HW-2	213	1.2	0.6	211	1.2	0.6	182	0.4	0.2
HW-1	214	0.9	0.5	210	1.1	0.6	155	0.4	0.2
HW	249	0.2	0.1	203	0.6	0.3	128	0.5	0.3
HW+1	035	0.5	0.3	064	0.2	0.1	108	0.7	0.3
HW+2	047	1.1	0.6	034	0.7	0.4	096	0.6	0.3
HW+3	049	1.3	0.7	031	1.0	0.5	077	0.4	0.2
HW+4	042	1.1	0.6	026	1.0	0.5	018	0.3	0.1
HW+5	032	0.8	0.4	018	0.7	0.4	322	0.4	0.2
HW+6	000	0.3	0.2	015	0.4	0.2	306	0.7	0.3
Excursion (flood)		18.0	9.4		14.4	7.6		11.9	6.1
Excursion (ebb)		19.1	10.4		15.5	7.6		11.9	5.4

Data from Admiralty Totaltide

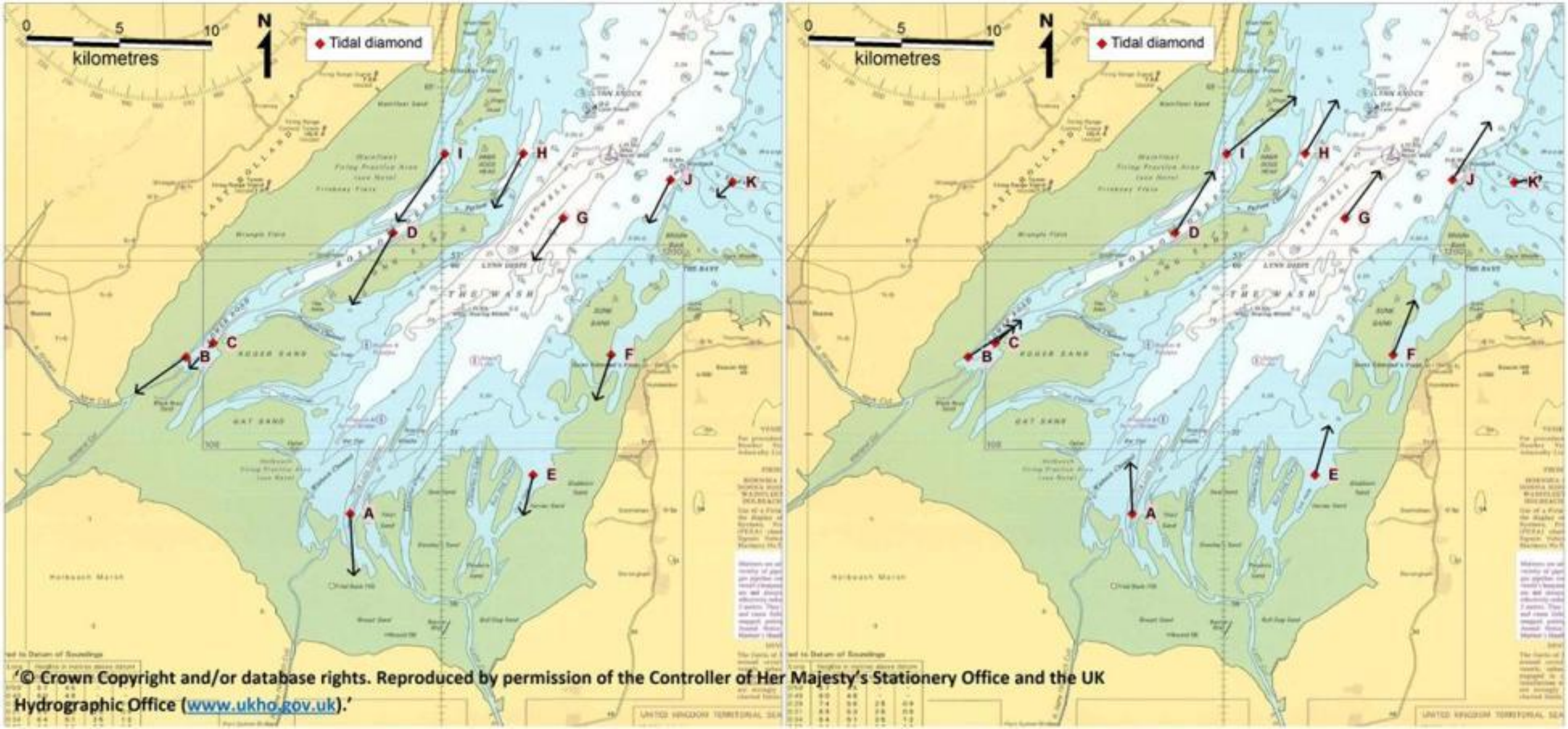


Figure IX.2: Location of tidal diamonds, and direction and relative strength of tidal streams mid flood (left) and mid ebb (right). The length of the arrows indicate the distance a particle would travel in an hour, assuming it carried on at the speed and direction indicated by the diamond.

Superimposed on tidally driven currents are the effects of freshwater inputs and wind. The flow ratio (freshwater input:tidal exchange) is low for the Wash as a whole (mean of 0.001 and maximum 0.006) indicating little possibility of density driven circulation (Futurecoast, 2002). Such effects may arise within the canalised tidal rivers, where there will also be a net (residual) seaward movement due to the riverine inputs. Average salinity exceeds 31ppt apart from in the immediate vicinity of the river outfalls, where it drops to below 20ppt (Dare *et al*, 2004). These areas of decreased average salinity are likely to represent areas of increased microbiological contamination. Figure IX.3 presents boxplots of near surface salinity readings taken at various monitoring points within the Wash, the locations of which are shown in Figure IX.1.

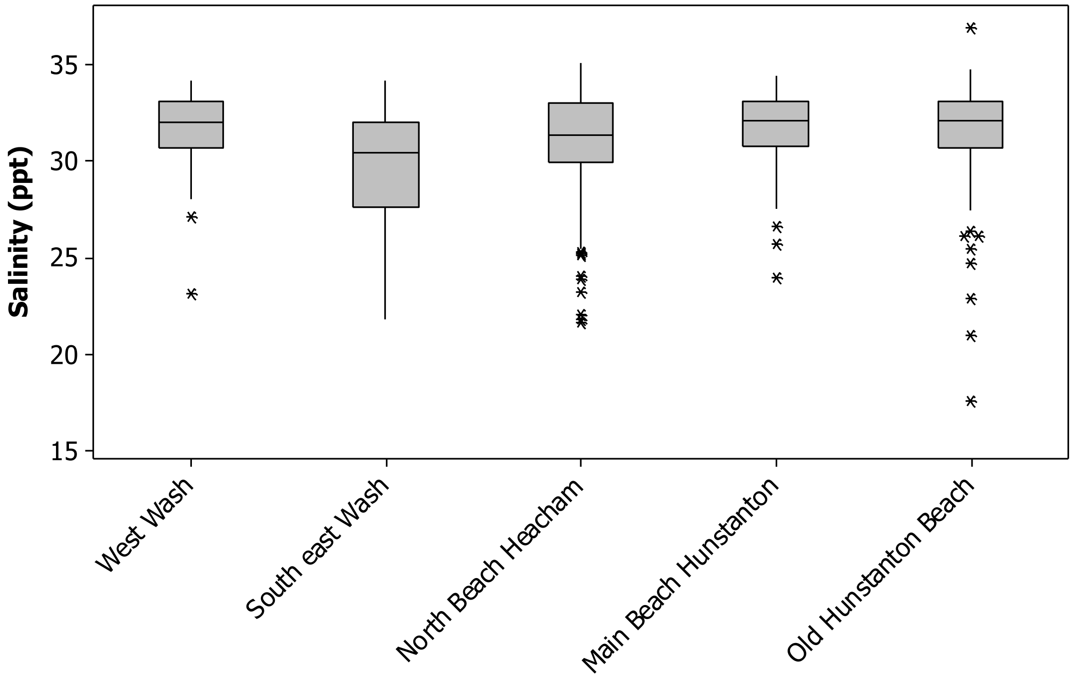


Figure IX.3: Boxplot of salinity readings at five points in The Wash
Data from the Environment Agency

Table IX.3: Summary statistics for salinity readings

Sampling Point	No.	Mean	Minimum	Maximum
West Wash	47	31.6	23.1	34.2
South east Wash	40	30.0	21.8	34.2
North Beach Heacham	200	31.0	21.7	35.1
Main Beach Hunstanton	203	31.8	24.0	34.4
Old Hunstanton Beach	307	31.7	17.6	36.9

Data from the Environment Agency

Across the five sampling points salinity was similar, and generally approaching that of full strength seawater throughout, with occasional lower readings at times of higher freshwater input. The lowest average result was recorded at South East Wash, suggesting that a minor influence of the river outfall extends as far as this point. West Wash had a similar salinity profile to the sites in the outer Wash, suggesting the influence of the river outfalls does not generally extend this far.

Strong winds will modify surface currents. Winds typically drive surface water at about 3% of the wind speed (Brown, 1991) so gale force wind (34 knots or 17.2 m/s) would drive a current of about 0.5 m/s. These surface currents drive return currents which may travel lower in the water column or along sheltered margins. The Wash is most exposed to the north and east, whereas the prevailing wind is from the south west. A large proportion of the surrounding land is low lying, and will offer little shelter from the prevailing winds. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action, and where these waves break contamination held in intertidal sediments may be resuspended. Due to the large size of the embayment, strong winds from any direction will blow across a considerable distance of water, and so nowhere in the Wash is particularly sheltered from an onshore wind. The area is most exposed from north easterly winds blowing in off the North Sea, and under these conditions much larger swells from the open sea will travel into the Wash. The Brancaster/Heacham area is likely to be most exposed to such swells.

Appendix X. Microbiological Data: Seawater

X.1. Shellfish Waters

Summary statistics and geographical variation

There are three shellfish waters sites designated under Directive 2006/113/EC (European Communities, 2006) in the Wash. One of these shellfish waters (North East Wash) is monitored for bacteriological data at the Old Hunstanton Beach point used for bathing waters monitoring. The other two waters are monitored from independent points and are analysed in this section. Figure X.1 shows the location of the two sites. Table X.1 presents summary statistics for bacteriological monitoring results and Figure X.2 presents a boxplot of faecal coliform levels from the monitoring points.

Figure X.1: Location of shellfish waters sampling points in the Wash
Data from the Environment Agency

Table X.1: Summary statistics for shellfish waters faecal coliform results, 2003 to 2013 (cfu/100ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
West Wash	47	13/01/2003	10/04/2013	3.9	<2	2520	6.4	2.1
South east Wash	42	22/01/2003	08/04/2013	14.2	<2	1364	19.0	2.4

Data from the Environment Agency

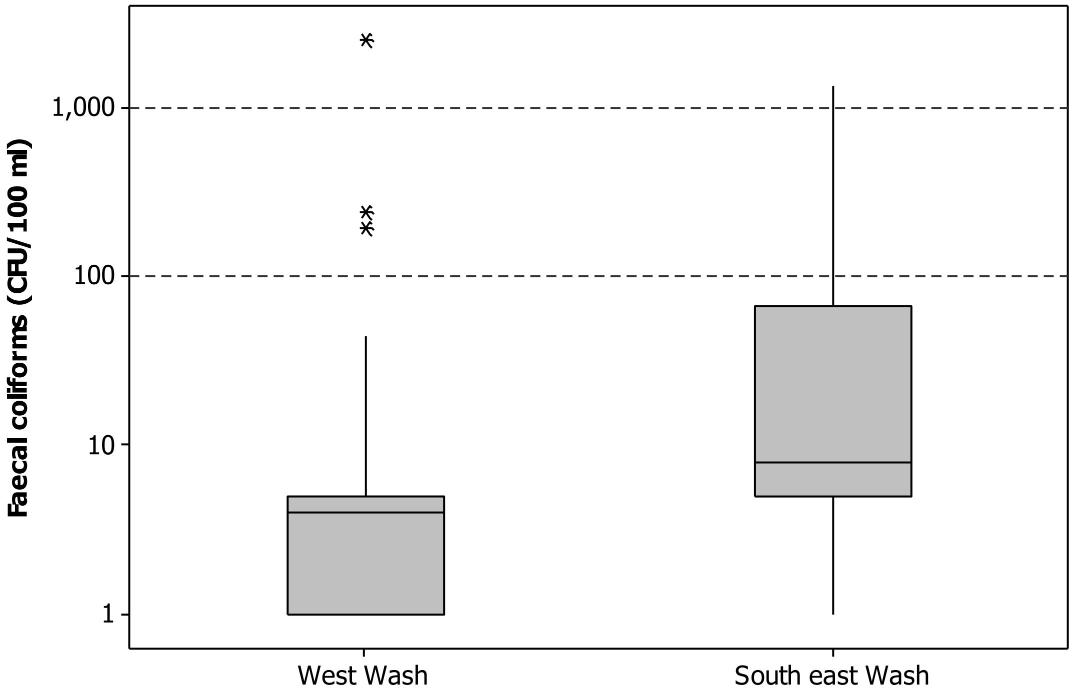


Figure X.2: Box-and-whisker plots of all faecal coliforms results
Data from the Environment Agency

A two sample T test revealed that faecal coliforms were significantly higher at South East Wash than West Wash ($p = 0.001$).

Overall temporal pattern in results

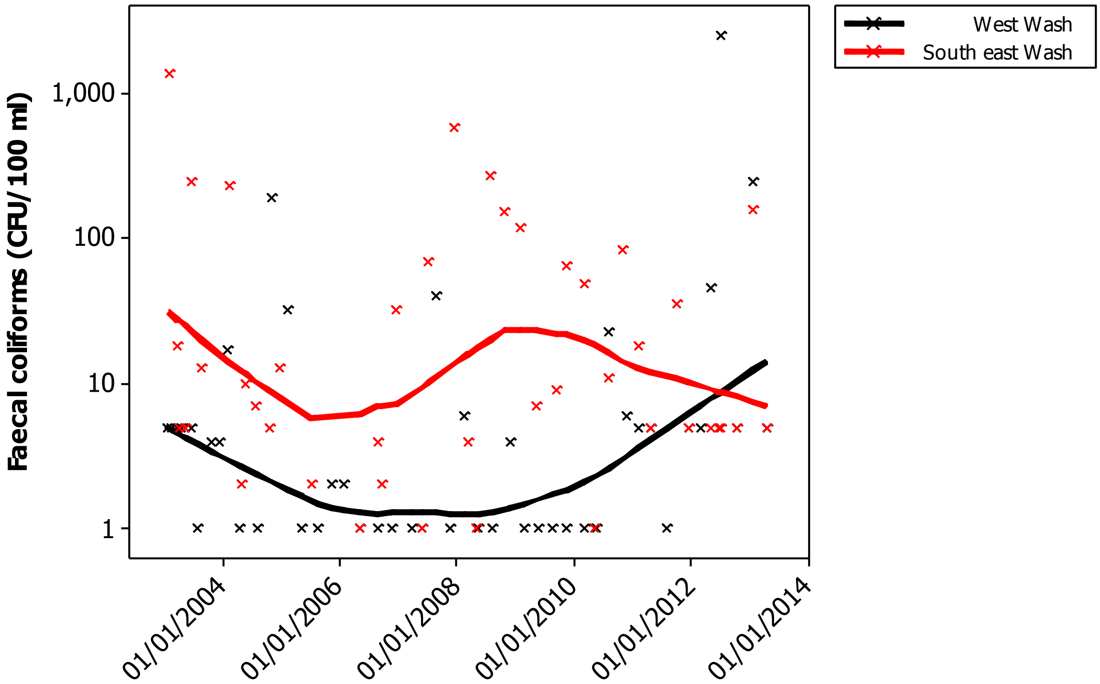


Figure X.3: Scatterplot of faecal coliform results by date, overlaid with loess lines
Data from the Environment Agency

Figure X.3 shows that faecal coliform levels at West Wash have been increasing since 2009. At South East Wash, faecal coliform levels have fluctuated since 2003 and appear to have been decreasing since 2009.

Seasonal patterns of results

Figure X.4 shows the variations in faecal coliform levels at shellfish waters sites across the seasons.

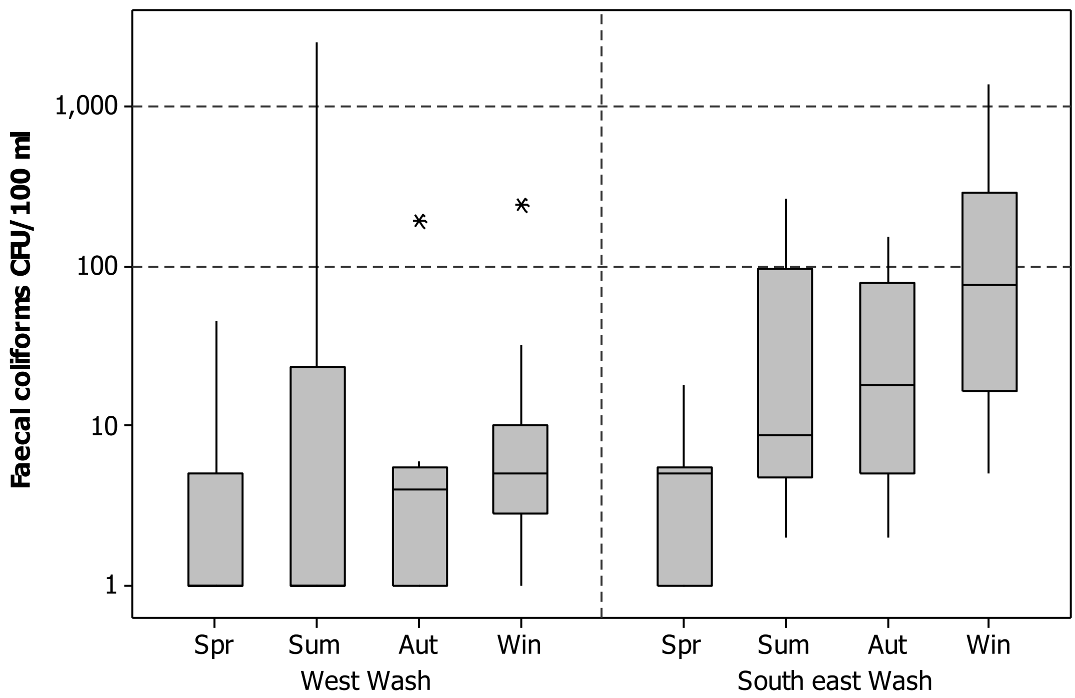


Figure X.4: Boxplot of faecal coliform results by site and season
Data from the Environment Agency

There is a similar seasonal pattern at the two, but much less variation at West Wash. Comparisons (One-way ANOVA) of faecal coliform levels revealed that there was a significant difference between seasons at South East Wash ($p < 0.001$) but not at West Wash ($p=0.531$). Post ANOVA Tukey tests showed that faecal coliforms were significantly higher in the winter than in the spring at South East Wash.

Influence of tide

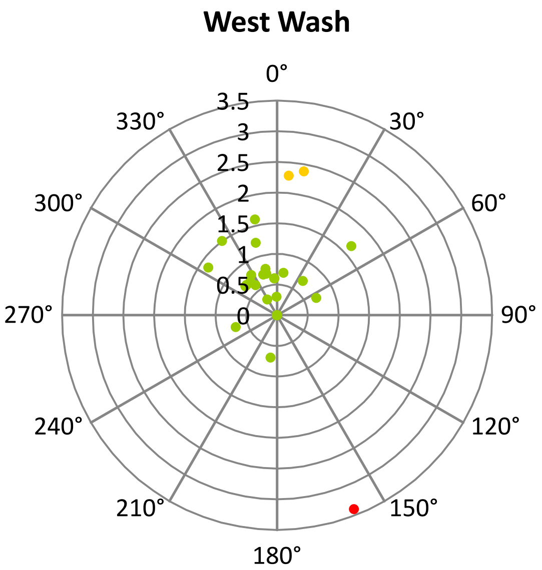
To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against the high/low and spring/neap tidal cycles. The results of these correlations are summarised in Table X.2, and significant correlations are highlighted in yellow.

Table X.2: Circular linear correlation coefficients (r) and associated p values for faecal coliform results against the high/low and spring/neap tidal cycles

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
West Wash	0.404	0.001	0.334	0.007
South East Wash	0.413	0.001	0.393	0.002

Data from the Environment Agency

Figure X.5 presents polar plots of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at King's Lynn is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.



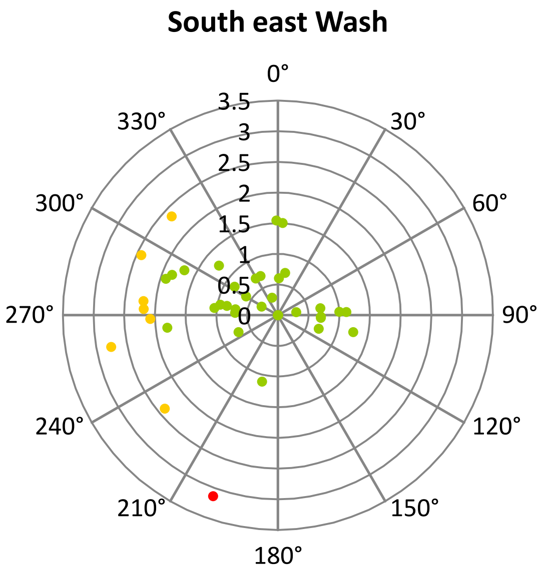


Figure X.5: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the high/low tidal cycle for shellfish waters monitoring points with significant correlations
Data from the Environment Agency

At South East Wash there appears to be a tendency for higher results to arise as the tide floods. No strong pattern was apparent for West Wash.

Figure X.6 presents polar plots of faecal coliform results against the lunar spring/neap cycle, where a statistically significant correlation was found. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1,000 are plotted in yellow, and those exceeding 1,000 are plotted in red.

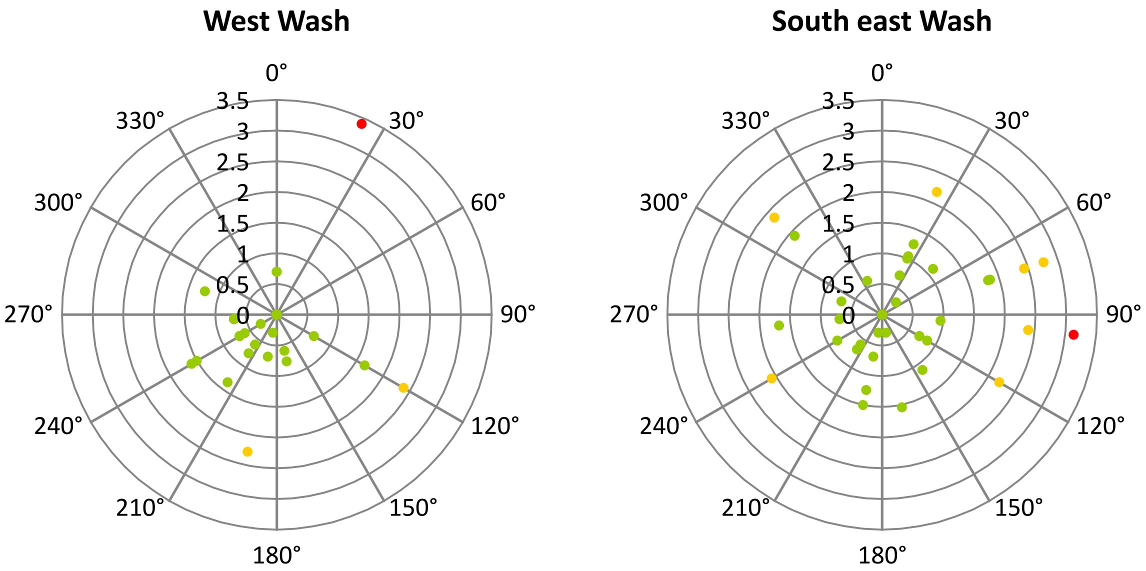


Figure X.6: Polar plots of log_{10} faecal coliforms against tidal state on the spring/neap tidal cycle for shellfish waters monitoring points with significant correlations
Data from the Environment Agency

Although significant correlations were detected at both monitoring points, no strong patterns are evident in Figure X.6.

Influence of rainfall

To investigate the effects of rainfall on levels of contamination at the water quality monitoring sites Spearman's rank correlations were carried out between rainfall recorded at the Heacham weather station (Appendix II for details) over various periods running up to sample collection and faecal coliform results. These are presented in Table X.3 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.3: Spearmans Rank correlation coefficients for faecal coliform results against recent rainfall

	Site	West Wash	South East Wash
	n	45	40
24 hour periods prior to sampling	1 day	0.127	-0.182
	2 days	0.512	0.027
	3 days	-0.040	0.094
	4 days	0.172	0.296
	5 days	-0.074	0.488
	6 days	-0.040	0.120
	7 days	-0.035	-0.014
Total prior to sampling over	2 days	0.300	-0.084
	3 days	0.183	-0.023
	4 days	0.150	0.045
	5 days	0.121	0.159
	6 days	0.133	0.108
	7 days	0.146	0.101

Data from the Environment Agency

Rainfall had some limited effect on faecal coliform levels at the shellfish waters sites. The effect was more rapid at West Wash.

Influence of salinity

Pearson's correlations were run to determine the effect of salinity on faecal coliforms at shellfish waters sites. Figure X.7 shows a scatterplot of faecal coliforms against salinity and the results of Pearson's correlations between the two.

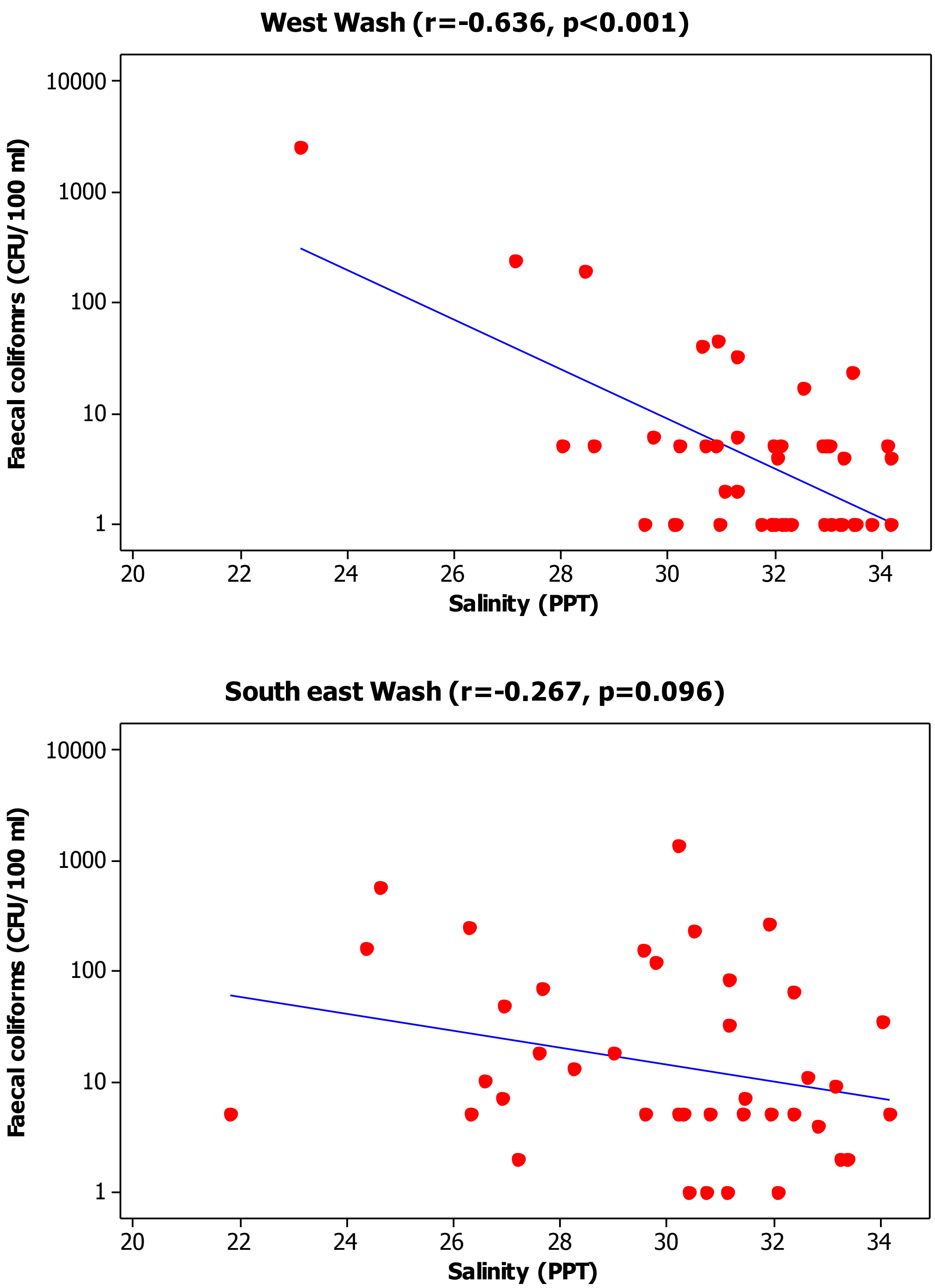


Figure X.7: Scatterplot of salinity against faecal coliform results
Data from the Environment Agency

A strong negative correlation between salinity and faecal coliform levels was observed at West Wash, while no significant correlation was found between faecal coliform levels and salinity at South East Wash.

X.2. Bathing Waters

There are 3 bathing waters in the Wash and 1 just outside the Wash designated under the Directive 76/160/EEC (Council of the European Communities, 1975). Due to changes in the analyses of bathing water quality by the Environment Agency from 2012, only data produced up to the end of 2011 were used in these analyses for three of the sites.

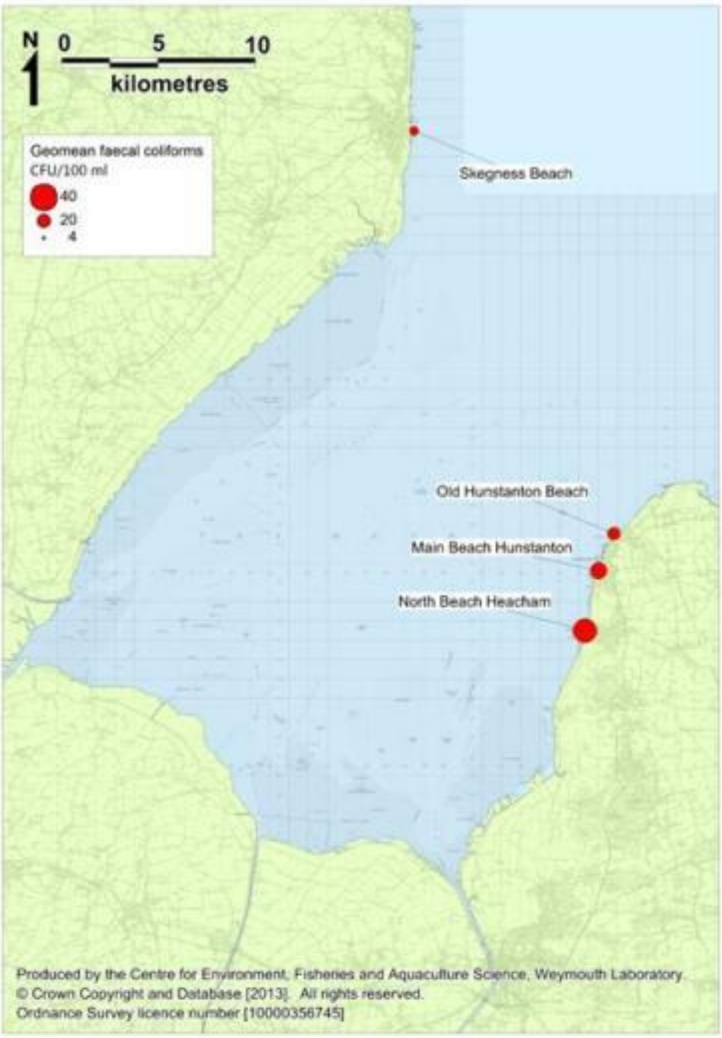


Figure X.8: Location of designated bathing waters monitoring points in the Wash
Data from the Environment Agency

Around twenty water samples were taken from each of the bathing waters sites during each bathing season, which runs from the 15th May to the 30th September. Faecal coliforms were enumerated in all of these samples. Summary statistics of all results by bathing water are presented in Table X.4, and Figure X.9 presents box plots of these data.

Table X.4: Summary statistics for bathing waters faecal coliforms results, 2003-2013 (cfu/100 ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Skegness Beach	184	01/05/2003	20/09/2011	13.6	<2	1944	7.1	1.1
Old Hunstanton Beach	229	17/01/2003	14/03/2013	19.1	<2	3400	17.0	1.3
Main Beach Hunstanton	206	06/05/2003	19/09/2011	24.2	<2	1280	18.4	0.5
North Beach Heacham	184	06/05/2003	19/09/2011	35.5	<2	1480	19.0	1.1

Data from the Environment Agency

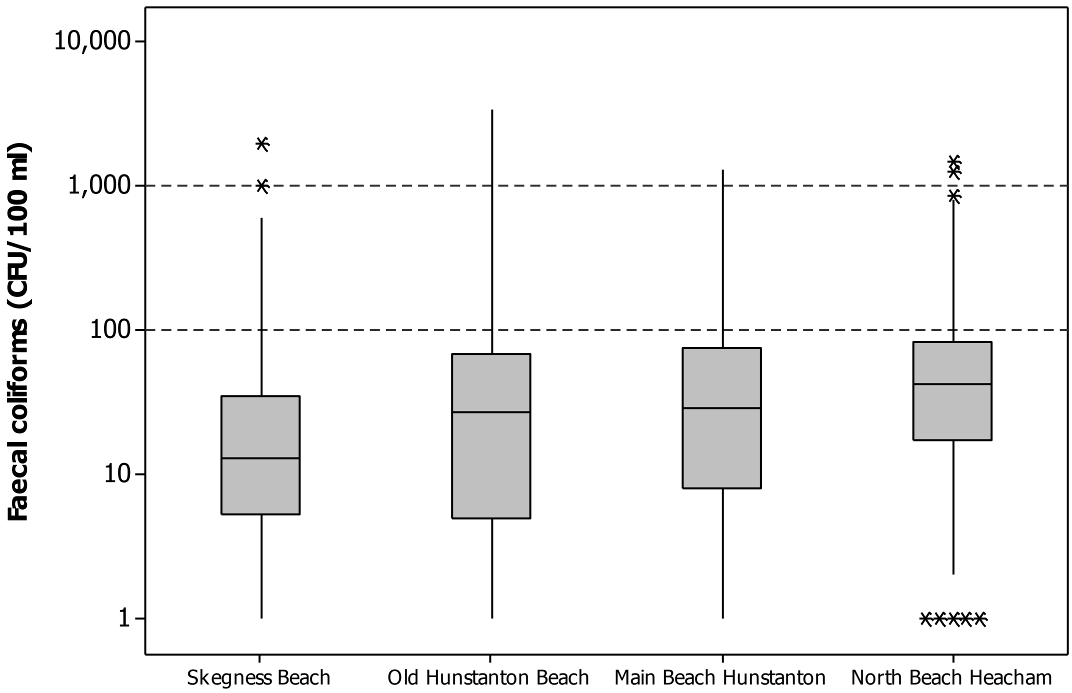


Figure X.9: Box-and-whisker plots of all faecal coliforms results by site
Data from the Environment Agency

All sites had results exceeding 1,000 faecal coliforms/100 ml. One-way ANOVA testing showed there to be a significant difference in faecal coliform levels between sites ($p < 0.001$). Post ANOVA tests (Tukey) revealed that Skegness Beach had significantly lower faecal coliform results than Main Beach Hunstanton and North Beach Heacham; and Old Hunstanton Beach had significantly lower faecal coliform levels than North Beach Heacham. This suggests that levels of faecal coliform levels decline at beaches closer to the North Sea.

More robust comparisons of sites were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared sampling dates, and therefore environmental conditions, on at least 20 occasions. Skegness Beach did not have and significant correlations with any of the other bathing waters, and all other bathing waters were significantly correlated with each other. This indicates that Old Hunstanton Beach, Main Beach Hunstanton, North Beach Heacham probably share contamination sources, but Skegness Beach is influenced by different factors.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at bathing water sites is shown in Figure X.10.

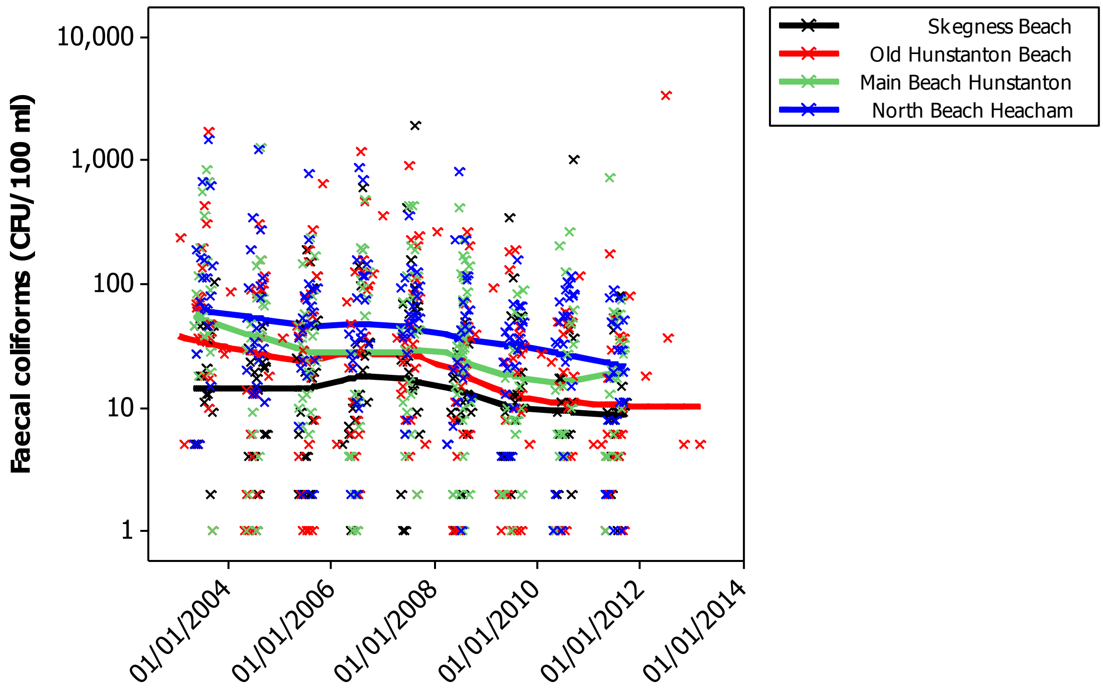


Figure X.10: Scatterplot of faecal coliform results for bathing waters in the Wash overlaid with loess lines.
Data from the Environment Agency

The level of faecal coliforms declined slightly at all sites since 2003. At Old Hunstanton Beach, which is the only site that has been sampled since 2011, faecal coliform levels have remained stable since 2011.

Influence of tides

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of these bathing waters sampling points. Correlation coefficients are presented in Table X.5, with statistically significant correlations highlighted in yellow.

Table X.5: Circular linear correlation coefficients (r) and associated p values for faecal coliform results against the high low and spring/neap tidal cycles

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Skegness Beach	0.110	0.114	0.217	<0.001
Old Hunstanton Beach	0.258	<0.001	0.306	<0.001
Main Beach Hunstanton	0.233	<0.001	0.263	<0.001
North Beach Heacham	0.070	0.412	0.044	0.707

Data from the Environment Agency

Figure X.11 presents polar plots of log_{10} faecal coliform results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at King's Lynn is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1,000 are plotted in yellow, and those exceeding 1,000 are plotted in red.

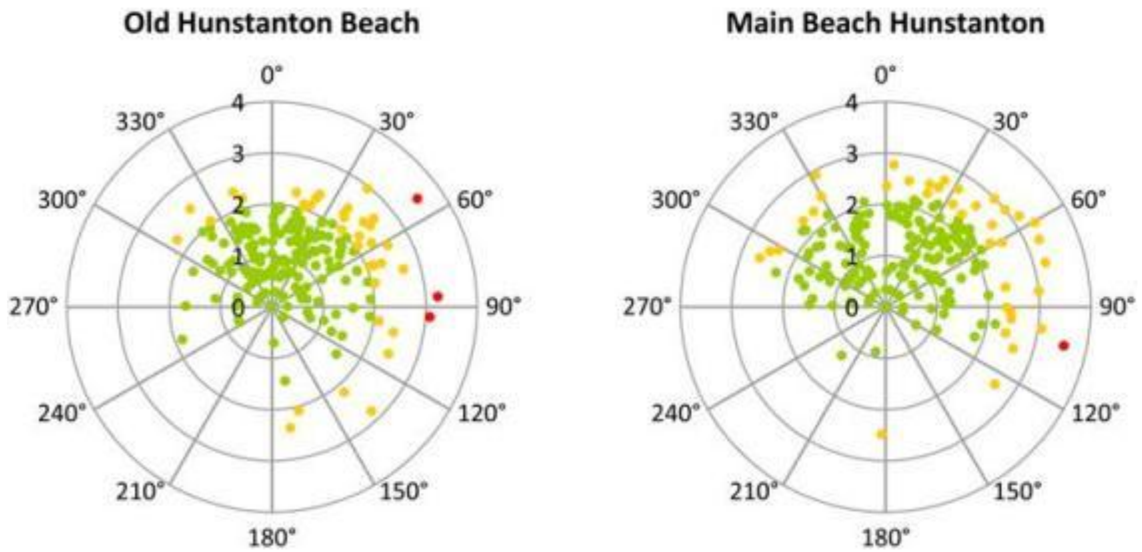


Figure X.11: Polar plots of log_{10} faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations

Data from the Environment Agency

The majority of samples were taken around high water to the middle of the ebb tide. Higher results at Old Hunstanton Beach and Main Beach Hunstanton tended to occur during the ebb tide.

Figure X.12 presents polar plots of faecal coliform results against the lunar spring/neap cycle, where a statistically significant correlation was found. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1,000 are plotted in yellow, and those exceeding 1,000 are plotted in red.

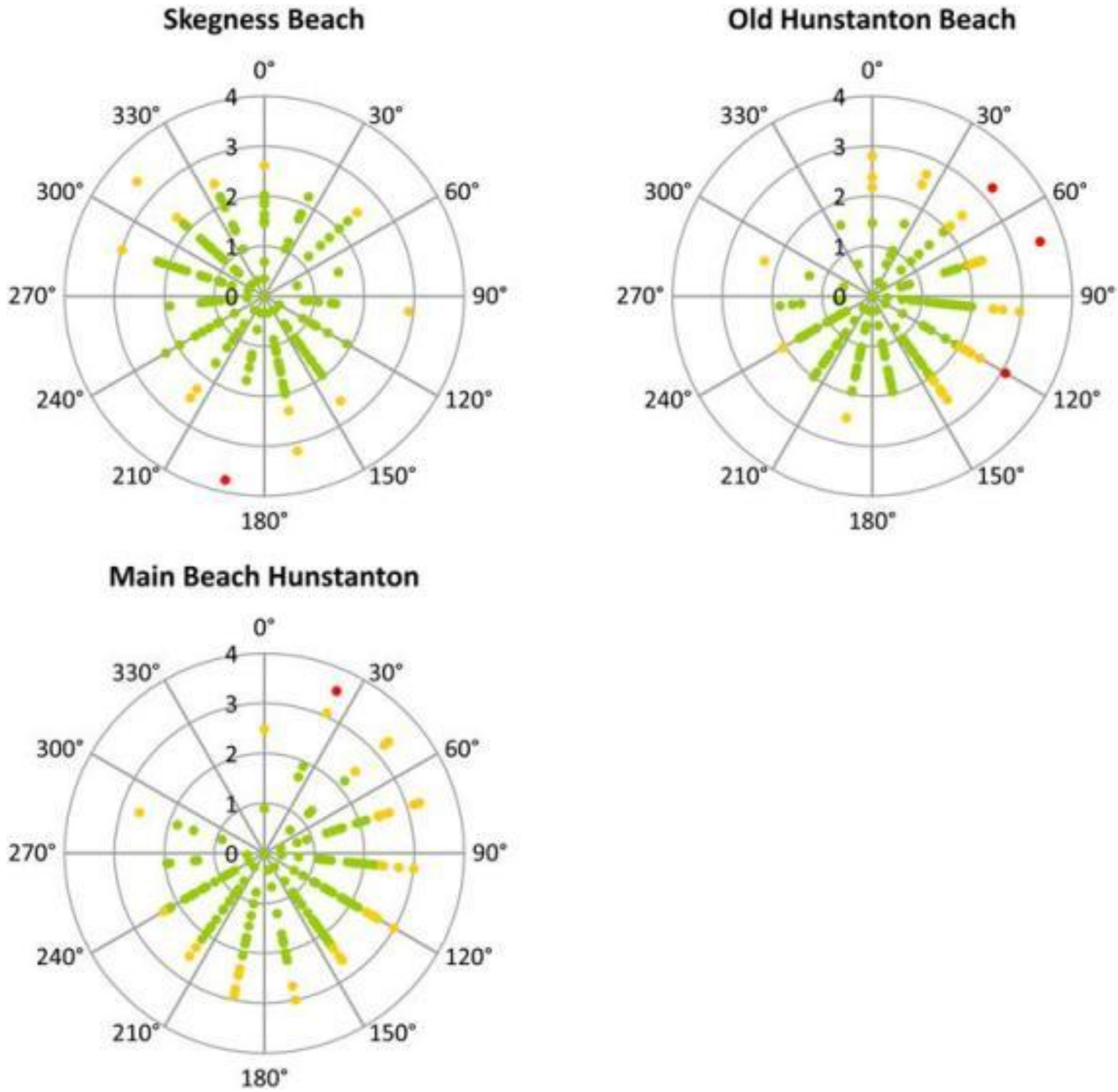


Figure X.12:Polar plots of $\log_{10}$ faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

At Skegness Beach, higher results tended to occur during neap tides. At Old Hunstanton Beach, higher results tended to occur around and just after spring tides. The same was true of Main Beach Hunstanton, but higher results tended to continue to occur as tide size declined towards neap tides.

Influence of Rainfall

To investigate the effects of rainfall on levels of contamination at the bathing waters sites Spearman’s rank correlations were carried out between rainfall recorded at the Heacham weather station (Appendix II for details) over various periods running up to sample collection and faecal coliforms results. These are presented in Table X.6 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.6: Spearmans Rank correlation coefficients for faecal coliforms results against recent rainfall

	Site	Skegness Beach	Old Hunstanton Beach	Main Beach Hunstanton	North Beach Heacham
	n	184	219	182	182
24 hour periods prior to sampling	1 day	0.048	0.215	0.226	0.094
	2 days	0.077	0.336	0.338	0.115
	3 days	0.038	0.169	0.294	0.130
	4 days	0.183	-0.002	0.010	-0.088
	5 days	0.015	0.104	0.158	0.030
	6 days	0.085	0.039	0.150	-0.009
	7 days	0.112	0.012	0.126	0.085
Total prior to sampling over	2 days	0.070	0.332	0.333	0.131
	3 days	0.059	0.325	0.383	0.149
	4 days	0.154	0.250	0.297	0.059
	5 days	0.144	0.266	0.323	0.070
	6 days	0.158	0.244	0.345	0.068
	7 days	0.186	0.221	0.341	0.082

Data from the Environment Agency

At Old Hunstanton Beach and Main Beach Hunstanton, rainfall events appeared to rapidly increase the level of faecal coliforms and continue to do so for several days. At Skegness Beach, rainfall had less of an immediate impact on faecal coliform levels. Little effect of rainfall was seen at North Beach Heacham.

Appendix XI. Microbiological Data: Shellfish Flesh

XI.1. Summary statistics and geographical variation

There are two production areas in the Wash, Boston in the west and King's Lynn in the east. Each of these production areas has 15 RMPs which have been sampled between 2003 and 2013, to give a total of 30 RMPs. Ten RMPs are for cockles, 17 are for mussels, one is for Pacific oysters and two are for razor clams. The geometric mean results of shellfish flesh monitoring from 2003 to 2013 at these RMPs are presented in Figure XI.1. Summary statistics are presented in Table XI.1. Neither razor clams or Pacific oysters were sampled on 10 or more occasions at each site and so will not be subject to detailed analyses. Boxplots of *E. coli* results for cockle and mussel RMPs sampled on more than 20 occasions are shown in Figure XI.2 and Figure XI.3.

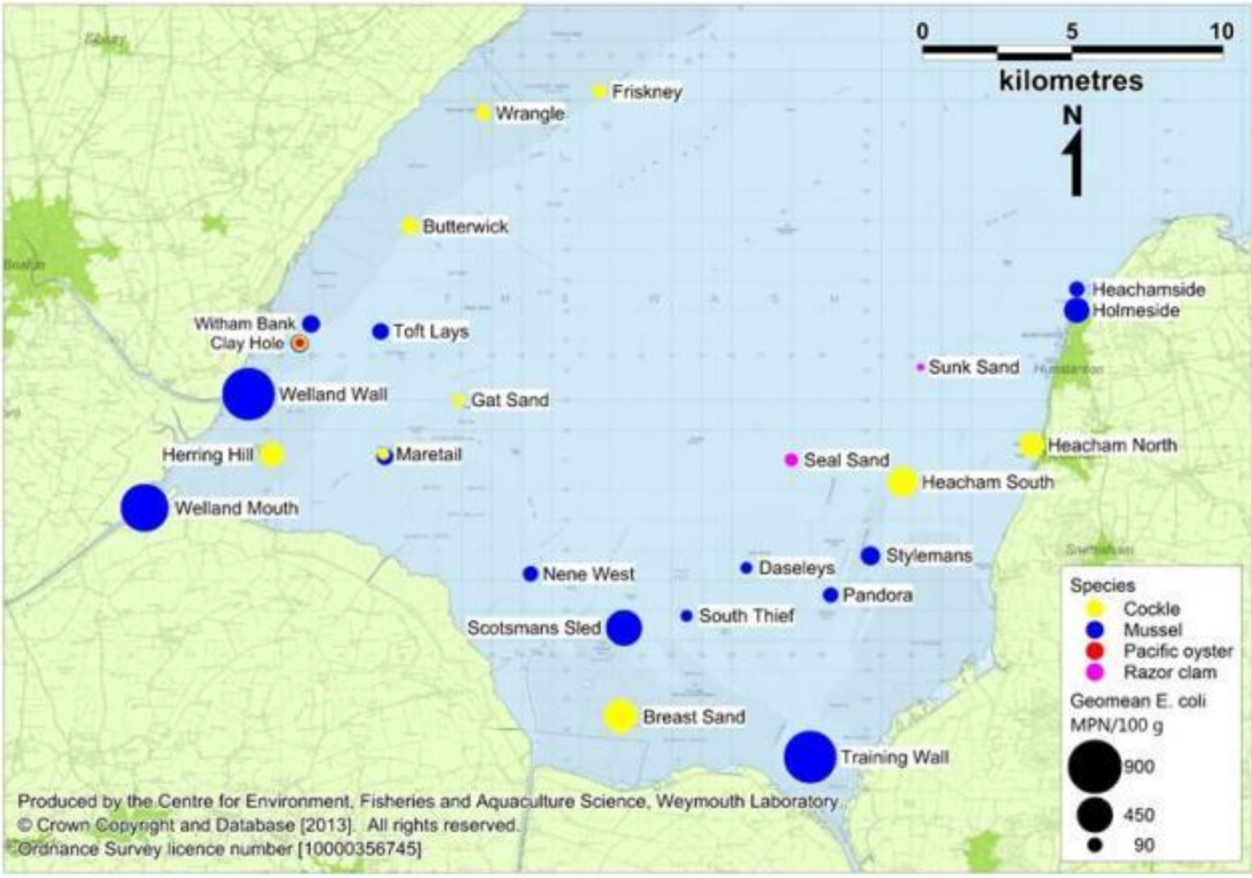


Figure XI.1: Bivalve RMPs active since 2003

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) sampled from 2003 onwards

RMP	Production area	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4600
Herring Hill	Boston	Cockle	12	26/03/2007	21/07/2008	209.8	50	1300	41.7	0.0
Witham Bank	Boston	Cockle	10	07/07/2005	13/02/2006	99.0	20	310	20.0	0.0
Maretail	Boston	Cockle	13	07/07/2005	15/09/2008	65.0	40	310	7.7	0.0
Butterwick	Boston	Cockle	17	15/04/2003	18/08/2008	105.6	20	1100	23.5	0.0
Gat Sand	Boston	Cockle	27	23/08/2005	18/08/2008	61.4	<20	1300	11.1	0.0
Wrangle	Boston	Cockle	68	05/01/2003	11/06/2013	99.3	<20	7000	23.5	2.9
Friskney	Boston	Cockle	22	05/01/2003	01/03/2010	76.7	<20	2400	18.2	0.0
Breast Sand	King’s Lynn	Cockle	96	21/06/2004	10/06/2013	283.0	20	>18000	53.1	5.2
Heacham South	King’s Lynn	Cockle	126	21/01/2003	04/06/2013	317.3	<20	16000	64.3	4.0
Heacham North	King’s Lynn	Cockle	69	21/01/2003	11/11/2008	223.2	20	>18000	40.6	1.4
Welland Mouth	Boston	Mussel	1	18/06/2003	18/06/2003	750.0	750	750	100.0	0.0
Welland Wall	Boston	Mussel	112	18/02/2003	11/06/2013	858.5	40	170000	79.5	13.4
Clay Hole	Boston	Mussel	5	18/02/2003	26/03/2003	136.7	20	500	40.0	0.0
Witham Bank	Boston	Mussel	106	15/04/2003	11/06/2013	130.7	<20	9100	31.1	2.8
Toft Lays	Boston	Mussel	57	05/01/2003	23/06/2008	120.5	<20	5400	22.8	1.8
Maretail	Boston	Mussel	107	05/01/2003	11/06/2013	106.2	<20	9100	24.3	0.9
Gat Sand	Boston	Mussel	59	05/01/2003	18/08/2008	41.4	<20	1100	11.9	0.0
Breast Sand	King’s Lynn	Mussel	108	15/04/2003	10/06/2013	478.1	<20	16000	72.2	1.9
Nene West	King’s Lynn	Mussel	52	17/02/2003	18/08/2008	101.2	<20	2200	23.1	0.0
Scotsmans Sled	King’s Lynn	Mussel	4	17/02/2003	11/11/2003	453.3	160	2400	50.0	0.0
South Thief	King’s Lynn	Mussel	53	16/02/2003	22/07/2008	62.5	<20	2400	13.2	0.0
Daseleys	King’s Lynn	Mussel	56	16/02/2003	22/07/2008	63.7	<20	1300	19.6	0.0
Training Wall	King’s Lynn	Mussel	81	15/07/2003	10/06/2013	844.7	110	9200	87.7	6.2
Pandora	King’s Lynn	Mussel	1	14/04/2003	14/04/2003	90.0	90	90	0.0	0.0
Stylemans	King’s Lynn	Mussel	108	16/02/2003	10/06/2013	146.1	<20	3500	33.3	0.0
Holmeside	King’s Lynn	Mussel	125	20/01/2003	04/06/2013	235.9	<20	>18000	45.6	0.8
Heachamside	King’s Lynn	Mussel	1	13/10/2003	13/10/2003	90.0	90	90	0.0	0.0
Clay Hole	Boston	Pacific oyster	7	28/01/2003	10/03/2004	43.6	<20	310	14.3	0.0
Seal Sand	King’s Lynn	Razor clam	9	13/12/2005	11/10/2006	74.0	<20	500	22.2	0.0
Sunk Sand	King’s Lynn	Razor clam	9	13/12/2005	18/10/2006	31.6	<20	110	0.0	0.0

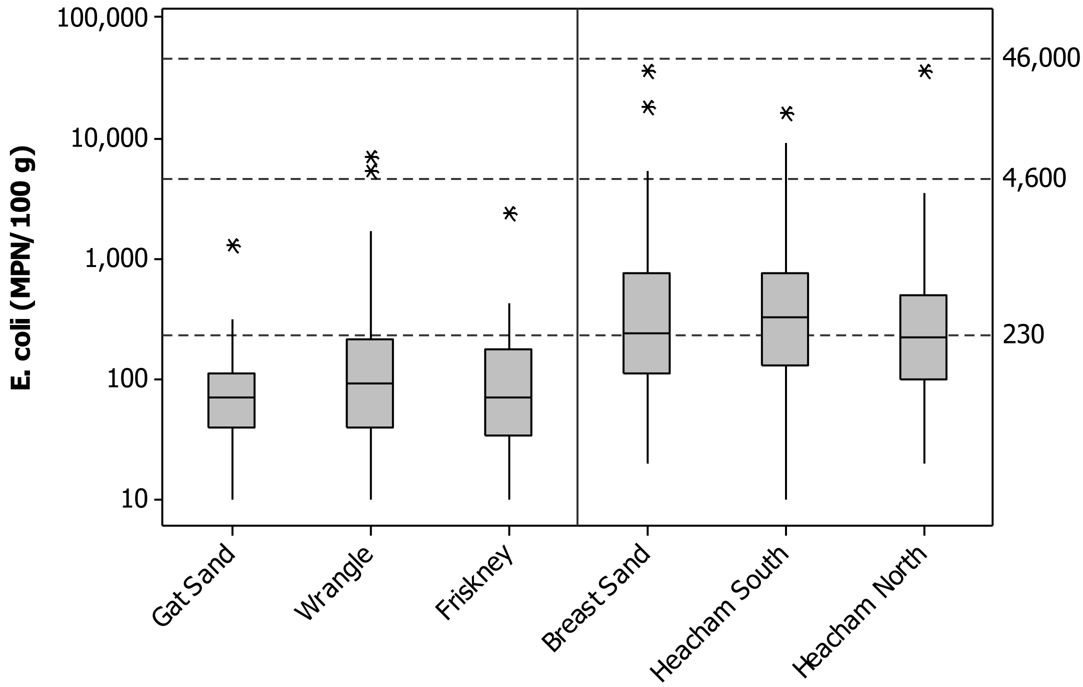


Figure XI.2: Boxplots of *E. coli* results from cockle RMPs from 2003 onwards.

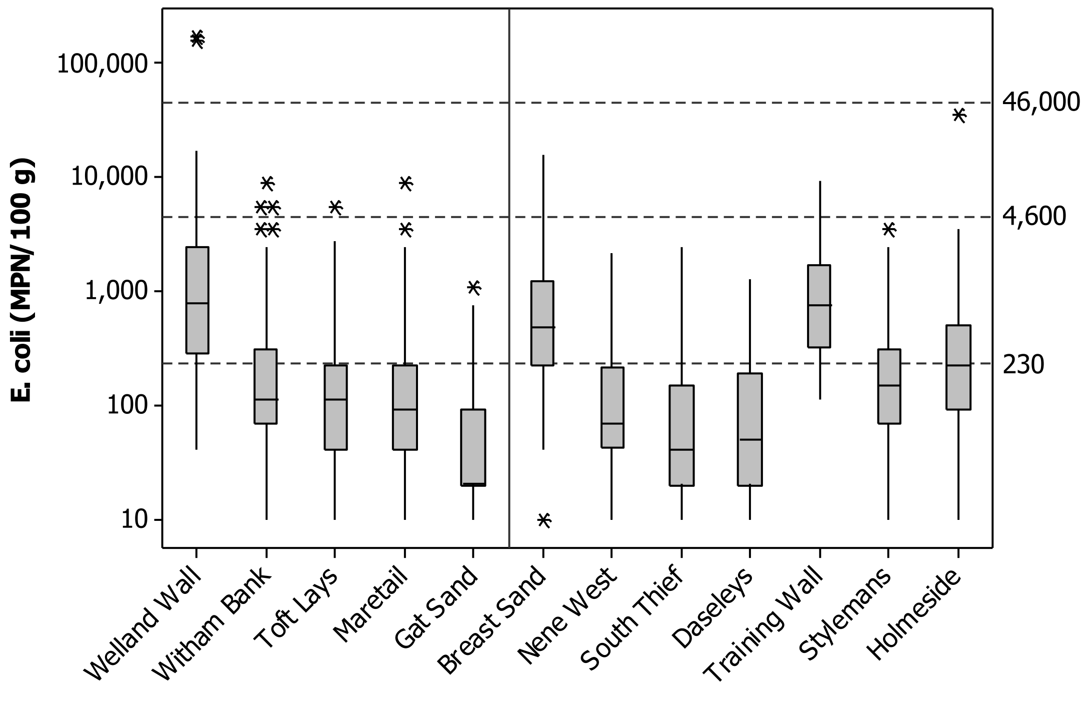


Figure XI.3: Boxplots of *E. coli* results from mussel RMPs from 2003 onwards.

Only one RMP (Welland Wall, mussels) exceeded 4,600 *E. coli* MPN/100 g in more than 10% of samples. Samples with greater than 46,000 *E. coli* MPN/100 g were only recorded for Welland Wall (mussels).

Statistical comparisons of cockle RMPs (one-way ANOVA) revealed that there were significant differences between them ($p < 0.001$). Post ANOVA tests (Tukey) showed that all of these differences occurred between the King's Lynn sites and the Boston sites. The King's Lynn RMPs Breast Sand, Heacham South and Heacham North had significantly higher results than the Boston RMPs Gat Sand, Wrangle and Friskney.

Statistical comparisons of mussel RMPs (one-way ANOVA) revealed that there were significant differences between RMPs ($p < 0.001$). Table XI.2 shows the results of post-ANOVA (Tukey) tests. Grey boxes indicate no significant difference between sites; green boxes indicate that the site listed at the top of the matrix has significantly higher *E. coli* levels than the site listed along the side of the matrix; red boxes indicate that the site listed at the side of the matrix has significantly higher *E. coli* levels than the site listed along the top of the matrix. Welland Wall and Training Wall are both located close to river outfalls and this is reflected by their *E. coli* levels being significantly higher than at most other sites. Breast Sand, which also has significantly greater *E. coli* than all other RMPs except Welland Wall and Training Wall, is also located in relative close proximity to a river outfall.

Table XI.2: Post-ANOVA Tukey test results for *E. coli* levels at mussel RMPs in The Wash

		1	2	3	4	5	6	7	8	9	10	11	12
1	Welland Wall												
2	Witham Bank												
3	Toft Lays												
4	Maretail												
5	Gat Sand												
6	Breast Sand												
7	Nene West												
8	South Thief												
9	Daseleys												
10	Training Wall												
11	Stylemans												
12	Holmeside												

To explore geographical variation in *E. coli* levels, Pearson's correlations were run to compare *E. coli* levels between individual pairs of sites which were sampled on the same day and therefore under similar environmental conditions on 20 or more occasions. For cockles, only two comparisons were possible, and it was found that Heacham South and Heacham North were significantly correlated, suggesting that they share similar environmental influences. Breast Sand and Heacham South were not significantly correlated, suggesting that they did not share similar environmental influences.

Similar correlation analyses were carried out for mussel RMPs, and the results for these tests are shown in Table XI.3. Numbers in the boxes are the correlation coefficients, grey boxes indicate that no correlation was possible (sites shared less than 20 sampling days), and yellow boxes indicate a significant correlation.

Table XI.3: Correlations between *E. coli* levels at mussel RMPs

		1	2	3	4	5	6	7	8	9	10	11	12
1	Welland Wall												
2	Witham Bank	0.38											
3	Toft Lays		0.52										
4	Maretail	0.40	0.39	0.24									
5	Gat Sand		0.38	0.60	0.37								
6	Breast Sand	0.12	0.02		-0.18								
7	Nene West		0.26	0.44	-0.24	0.14	0.36						
8	South Thief						0.31	0.32					
9	Daseleys						0.21	0.35	0.48				
10	Training Wall	0.14					0.08		-0.31	0.14			
11	Stylemans	0.33					0.35	0.56	0.40	0.29	0.10		
12	Holmeside		0.41		0.33		0.09					0.20	

These tests indicate that Welland Wall, Witham Bank, Toft Lays and Gat Sand were largely influenced by similar sources; as were Breast Sand, Nene Wash, South Thief, Daseleys, and Stylemans. However, given the large area over which these samples were taken, it is likely that changes in environmental conditions such as rainfall, which may rapidly affect inshore sites, may not affect sites further offshore until several hours or days later. Therefore these tests may not pick up existing relationships. Further tests to control for this are beyond the scope of this report.

XI.2. Overall temporal pattern in results

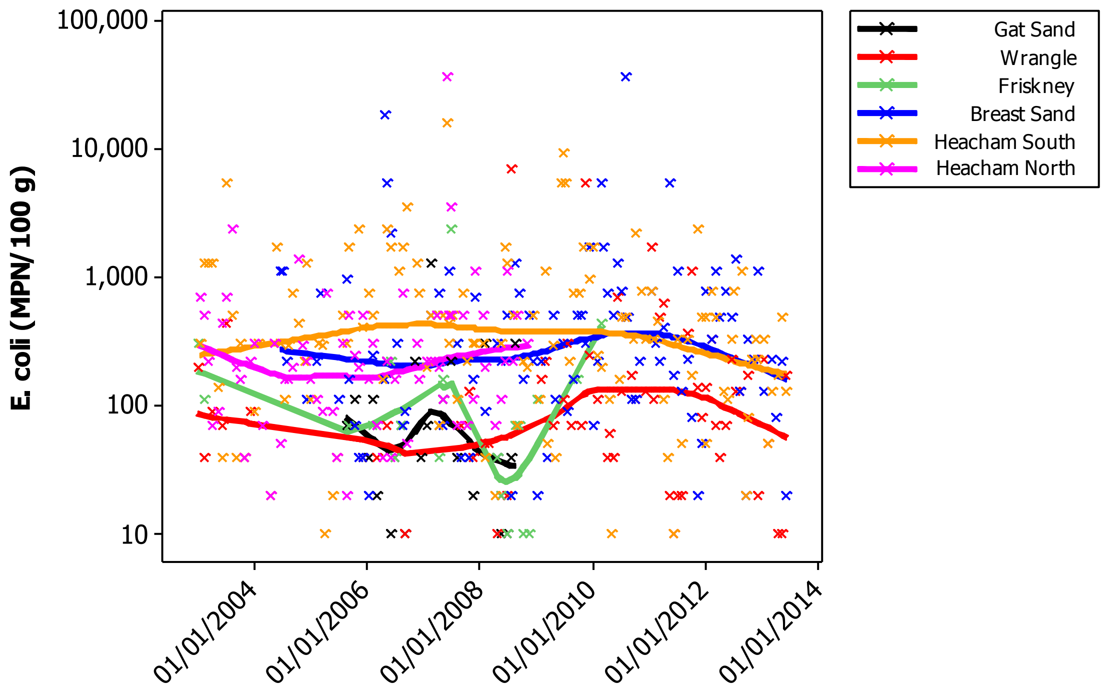


Figure XI.4: Scatterplot of *E. coli* results in cockles by RMP and date, overlaid with loess lines

Figure XI.4 shows that overall, levels of *E. coli* in cockles remained about the same from 2003 to 2013. However, there were fluctuations in *E. coli* levels at Friskney and there has been a slight reduction in *E. coli* levels at Heacham South, Breast Sand and Wrangle from late 2011 to present.

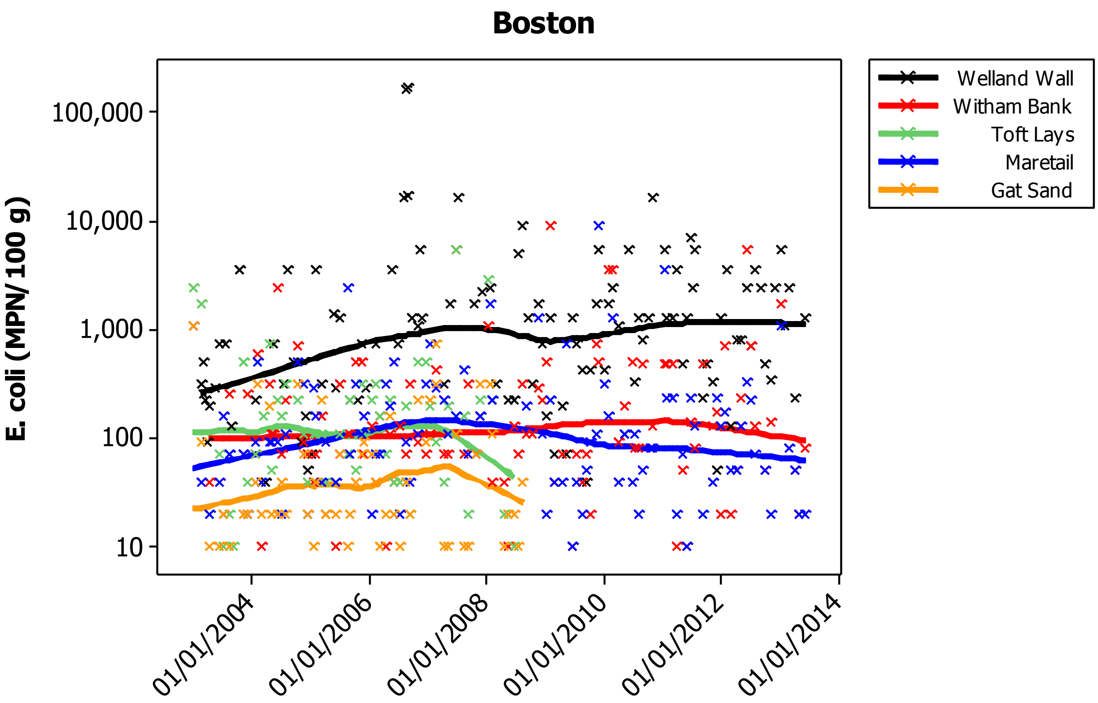


Figure XI.5: Scatterplot of *E. coli* results in mussels in the Boston production area of the Wash by RMP and date, overlaid with loess lines

Figure XI.5 shows that *E. coli* levels in mussels have remained fairly constant since 2003 at Witham Bank and Maretail, but increased between 2003 and 2008 at Welland Wall.

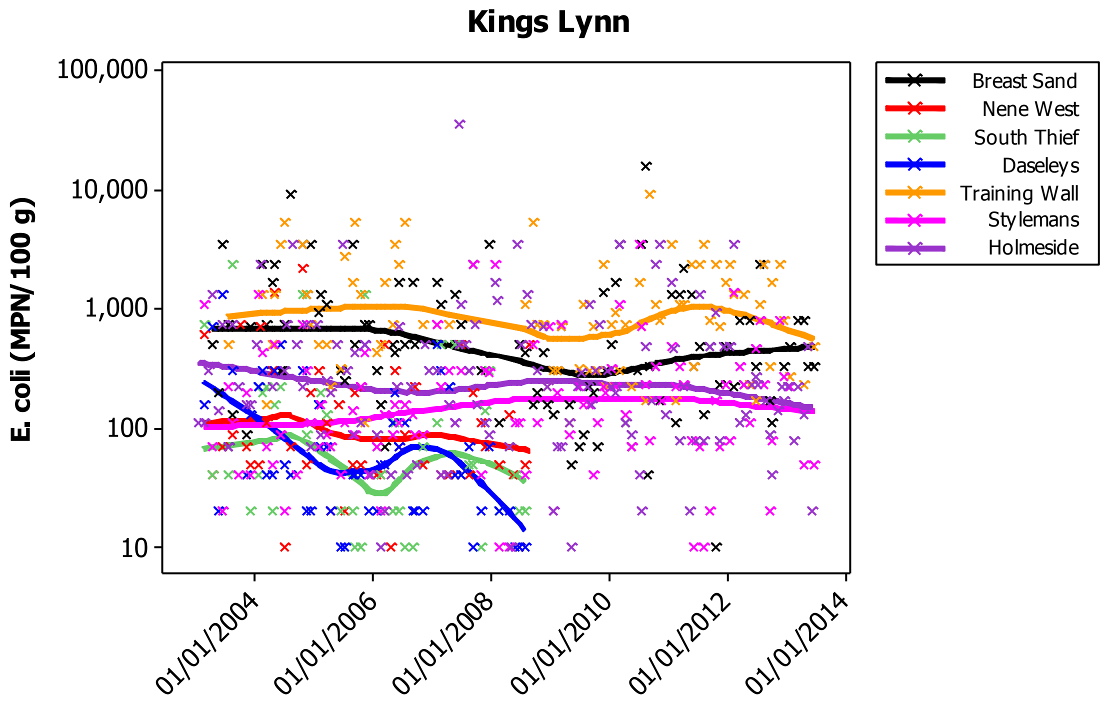


Figure XI.6: Scatterplot of *E. coli* results in mussels in the King's Lynn production area of the Wash by RMP and date, overlaid with loess lines

Figure XI.6 shows that *E. coli* levels in mussels have remained constant at all sites sampled from 2003 to present. At King's Lynn, *E. coli* levels in mussels have remained fairly consistent from 2003 onwards. However, levels at Daseleys dropped between 2003 and the discontinuation of the RMP in 2008.

XI.3. Seasonal patterns of results

The seasonal patterns of results from 2003 onwards were investigated by RMP.

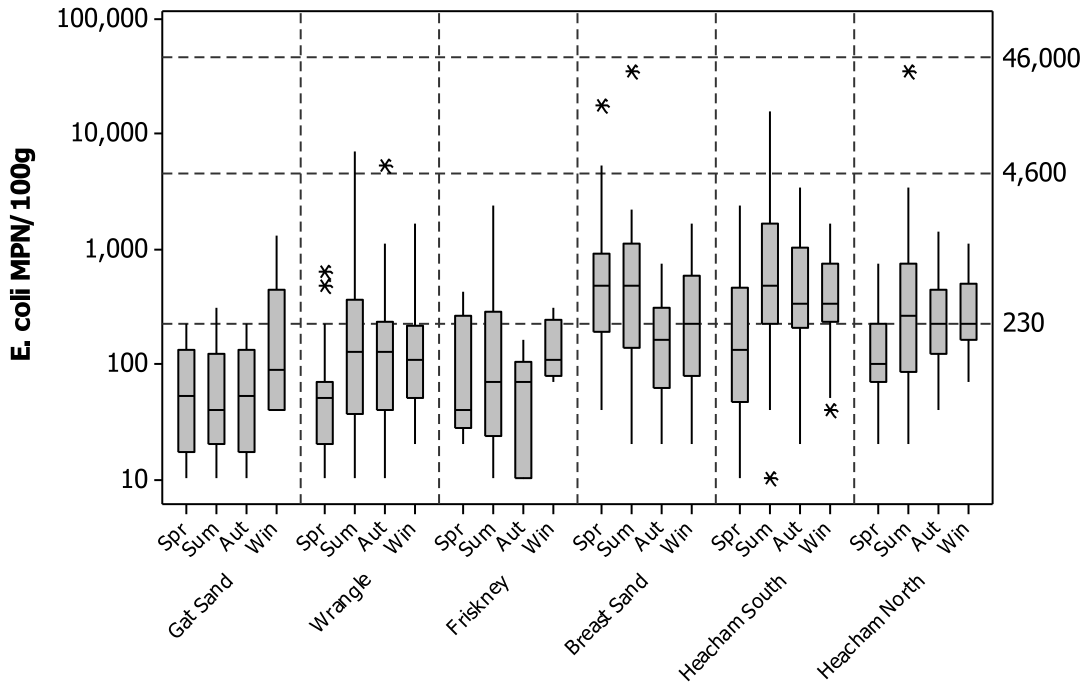


Figure XI.7: Boxplot of *E. coli* results in cockles by RMP and season

One-way ANOVA tests showed that there was significant seasonal variation at Breast Sand (p = 0.005) and Heacham South (p = 0.002) cockle RMPs, but no other cockle RMPS. At Breast Sand, spring and summer had significantly higher levels of *E. coli* than the autumn. At Heacham South, spring had significantly lower *E. coli* levels than the other seasons.

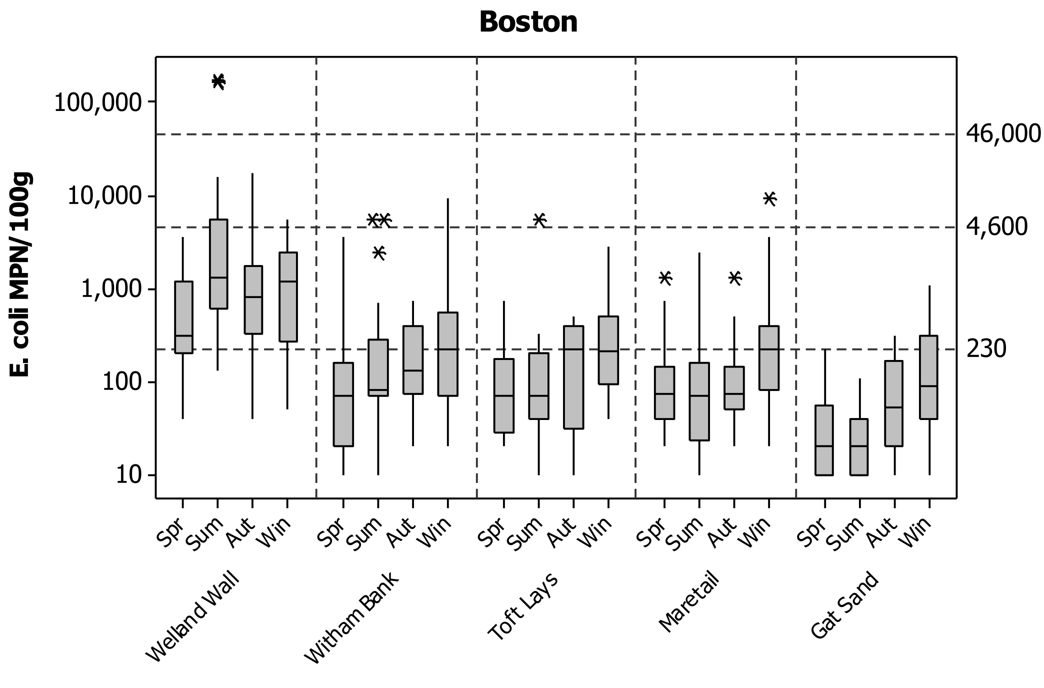


Figure XI.8: Boxplot of *E. coli* results in mussels within the Boston production area by RMP and season

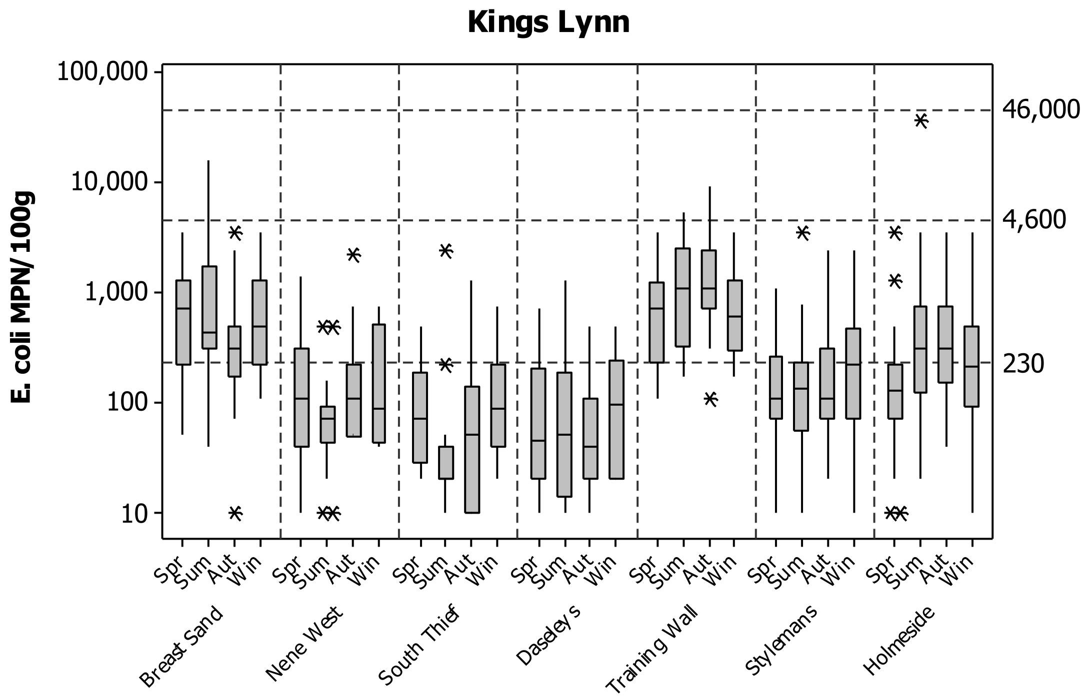


Figure XI.9: Boxplot of *E. coli* results in mussels within the King's Lynn production area by RMP and season

Significant variations in *E .coli* levels in mussels between seasons (Figure XI.8 and Figure XI.9) were found at Welland Wall (p = 0.002), Witham Bank (p = 0.013), Maretail (p = 0.020), Gat Sand (p = 0.001) and Holmeside (p = 0.014). At Witham Bank, winter levels were higher than spring levels. At Maretail winter levels were higher than summer levels. At Gat Sand winter levels were higher than both spring and summer levels. At Holmeside summer and autumn levels were higher than spring levels.

XI.4. Influence of tide

To investigate the effects of tidal state on *E. coli* results, circular-linear correlations were carried out against the high/low and spring/neap tidal cycles for each RMP with 30 or more samples. The results of these correlations are summarised in Table XI.4 and Table XI.5, with significant results highlighted in yellow.

Figure XI.10, Figure XI.11 and Figure XI.14 present polar plots of $\log_{10}$ *E. coli* results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Boston or King's Lynn is at 0° and low water is at 180°. Results of 230 *E. coli* MPN/100g or less are plotted in green, those from 231 to 4,600 are plotted in yellow, and those exceeding 4,600 are plotted in red.

Figure XI.12, Figure XI.13 and Figure XI.15 present polar plots of $\log_{10}$ *E. coli* results against the spring/neap tidal cycle for those RMPs that showed a significant correlation. Full/new moons occur at 0º, and half moons occur at 180º, and the largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 230 *E. coli* MPN/100g less are plotted in green, those from 231 to 4,600 are plotted in yellow, and those exceeding 4600 are plotted in red.

Boston

Table XI.4: Circular linear correlation coefficients (r) and associated p values for *E. coli* results from RMPs in the Boston production area against the high/low and spring/neap tidal cycles at Boston

		High/low tides		Spring/neap tides	
Site Name	**Species**	**r**	**p**	**r**	**p**
Wrangle	Cockle	0.215	0.049	0.29	0.004
Welland Wall	Mussel	0.208	0.009	0.037	0.864
Witham Bank	Mussel	0.104	0.326	0.011	0.989
Toft Lays	Mussel	0.208	0.097	0.167	0.222
Gat Sand	Mussel	0.084	0.673	0.364	<0.001
Maretail	Mussel	0.092	0.417	0.176	0.04

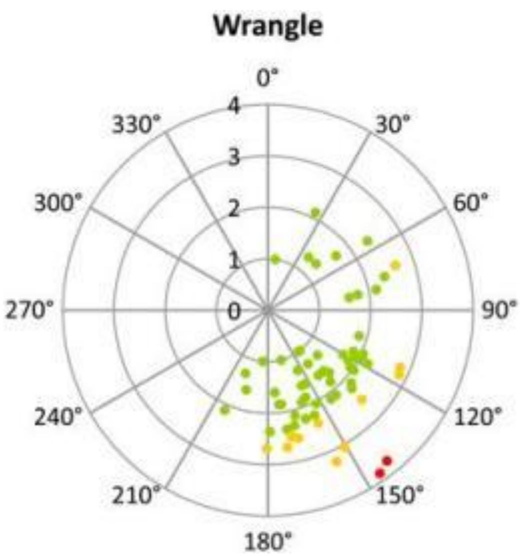


Figure XI.10: Polar plots of $\log_{10}$ *E. coli* results (MPN/100g) against tidal state on the high/low tidal cycle for cockle sampling points with significant correlations

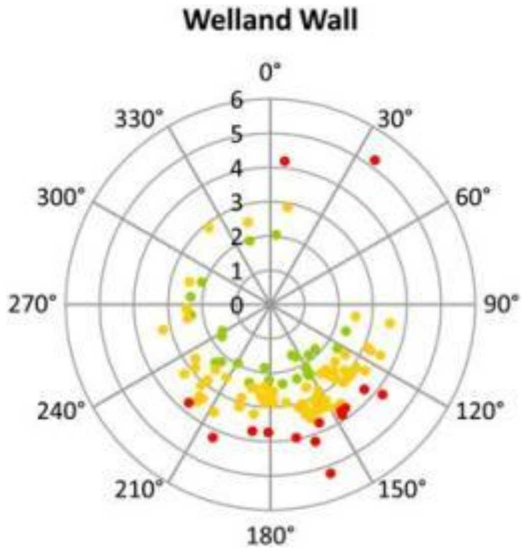


Figure XI.11: Polar plots of log_{10} *E. coli* results (MPN/100g) against tidal state on the high/low tidal cycle for mussel sampling points with significant correlations

E. coli levels at the Wrangle cockle RMP and Welland Wall mussel RMP tended to be higher just before low tide.

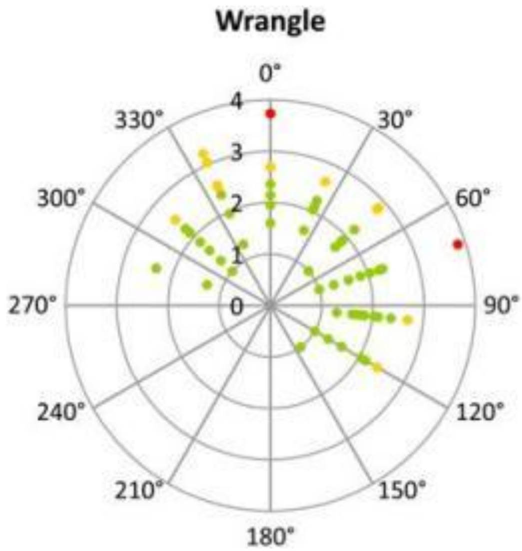


Figure XI.12: Polar plot of log_{10} *E. coli* results (MPN/100g) against tidal state on the spring/neap tidal cycle for the cockle sampling point with a significant correlation

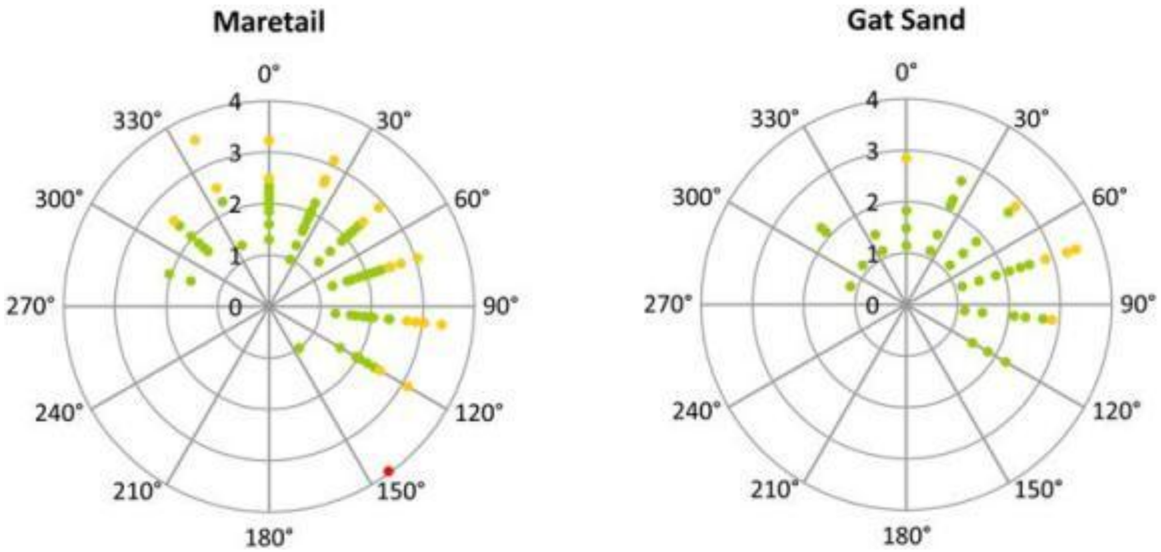


Figure XI.13: Polar plots of $\log_{10}$ *E. coli* results (MPN/100g) against tidal state on the spring/neap tidal cycle for mussel sampling points with significant correlations

All of the samples at both the cockle and mussel RMPs were taken around the spring tide. Despite the significant correlations, no pattern in *E. coli* levels is obvious from the polar plots.

King's Lynn

Table XI.5: Circular linear correlation coefficients (r) and associated p values for *E. coli* results from RMPs in the King's Lynn production area against the high/low and spring/neap tidal cycles at King's Lynn

		High/low tides		Spring/neap tides	
Site Name	**Species**	**r**	**p**	**r**	**p**
Breast Sand	Cockle	0.086	0.5	0.095	0.431
Heacham South	Cockle	0.011	0.984	0.153	0.056
Heacham North	Cockle	0.123	0.368	0.138	0.286
Breast Sand	Mussel	0.057	0.711	0.049	0.779
Nene West	Mussel	0.234	0.069	0.102	0.603
South Thief	Mussel	0.129	0.435	0.167	0.248
Daseleys	Mussel	0.27	0.021	0.153	0.288
Training Wall	Mussel	0.076	0.637	0.142	0.206
Stylemans	Mussel	0.068	0.615	0.178	0.036
Holmeside	Mussel	0.091	0.366	0.125	0.149

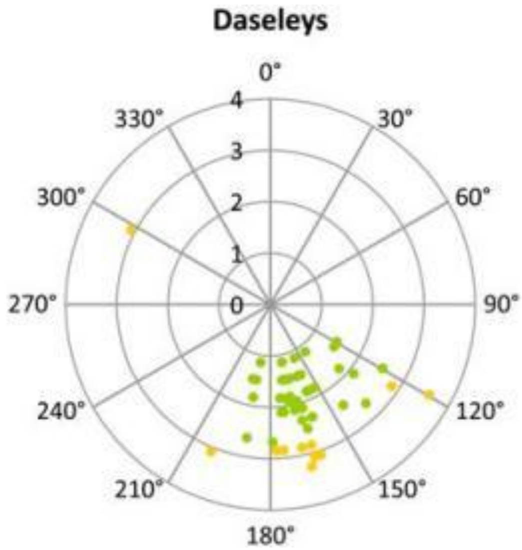


Figure XI.14: Polar plots of $\log_{10}$ *E. coli* results (MPN/100g) against tidal state on the high/low tidal cycle for mussel sampling points with significant correlations

At Daseleys, sampling was strongly targeted towards low water and no patterns are apparent in the polar plot.

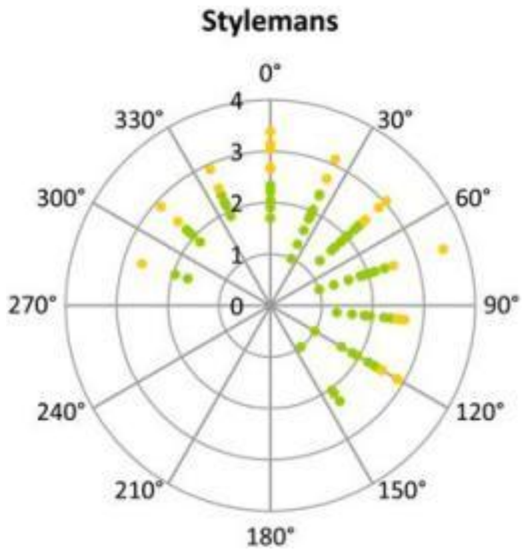


Figure XI.15: Polar plots of $\log_{10}$ *E. coli* results (MPN/100g) against tidal state on the spring/neap tidal cycle for mussel sampling points with significant correlations

Sampling was targeted towards spring tides, and no patterns are apparent in the polar plot.

XI.5. Influence of rainfall

To investigate the effects of rainfall on levels of contamination within shellfish samples, Spearman's rank correlations were carried out between *E. coli* results and rainfall recorded at the Robin Hoods Walk (Boston) and Heacham (King's Lynn) weather stations (Appendix II for details) over various periods running up to sample collection. These are presented in Table XI.6 and Table XI.7, and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table XI.6: Spearman's Rank correlations between rainfall recorded at Robin Hoods Walk and shellfish hygiene results at the Boston production area

			24 hour periods prior to sampling							Total prior to sampling over					
Site	**Species**	**n**	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**
Gat Sand	Cockle	27	0.012	0.355	0.193	0.036	0.405	0.134	0.372	0.162	0.172	0.141	0.183	0.225	0.290
Wrangle	Cockle	62	-0.100	0.258	0.241	0.231	0.269	0.228	0.216	0.147	0.236	0.277	0.301	0.282	0.313
Friskney	Cockle	22	0.183	0.513	0.028	0.315	0.276	0.162	0.090	0.386	0.260	0.372	0.349	0.172	0.148
Welland Wall	Mussel	106	0.050	0.131	0.173	0.242	0.191	0.145	0.200	0.093	0.151	0.229	0.260	0.274	0.323
Witham Bank	Mussel	101	0.087	0.201	0.139	0.162	0.331	0.197	0.131	0.209	0.276	0.264	0.327	0.329	0.309
Toft Lays	Mussel	56	0.063	0.280	0.260	0.334	0.323	-0.048	0.157	0.179	0.290	0.363	0.393	0.281	0.277
Gat Sand	Mussel	58	0.005	0.045	0.127	0.338	0.170	0.033	0.154	0.049	0.154	0.225	0.219	0.137	0.165
Maretail	Mussel	100	0.044	0.039	0.114	0.162	0.370	0.283	0.089	0.049	0.102	0.137	0.186	0.180	0.194

Table XI.7: Spearman's Rank correlations between rainfall recorded at Heacham and shellfish hygiene results at the King's Lynn production area

			24 hour periods prior to sampling							Total prior to sampling over					
Site	**Species**	**n**	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**
Breast Sand	Cockle	91	-0.105	-0.032	0.093	0.233	0.034	0.107	0.033	-0.093	-0.045	0.018	0.022	0.027	0.045
Heacham South	Cockle	120	0.055	0.099	0.091	0.198	-0.005	-0.027	-0.004	0.086	0.101	0.169	0.161	0.169	0.167
Heacham North	Cockle	69	-0.137	0.082	0.202	0.122	0.061	0.209	0.234	-0.040	0.070	0.105	0.109	0.119	0.178
Breast Sand	Mussel	103	0.083	0.072	0.203	0.197	-0.037	0.117	0.095	0.137	0.163	0.172	0.109	0.142	0.131
Nene West	Mussel	52	0.114	-0.005	0.195	0.214	-0.049	-0.005	0.168	0.088	0.032	0.186	0.148	0.084	0.159
South Thief	Mussel	53	-0.082	-0.111	0.061	0.037	0.062	0.139	0.120	-0.160	-0.102	-0.144	-0.017	0.044	-0.016
Daseleys	Mussel	56	-0.057	0.091	0.072	0.073	0.133	0.114	-0.049	-0.045	-0.052	-0.074	0.050	0.042	0.022
Training Wall	Mussel	78	0.149	0.019	-0.103	0.089	0.087	0.246	-0.096	0.150	0.023	0.108	0.143	0.162	0.131
Stylemans	Mussel	105	0.043	0.189	0.176	0.246	0.157	0.318	0.037	0.126	0.127	0.130	0.184	0.222	0.200
Holmeside	Mussel	119	0.088	0.076	0.103	0.224	0.156	0.064	0.157	0.104	0.123	0.225	0.212	0.171	0.171

Rainfall did not have a significant effect on *E. coli* levels at any site until at least 2 days after a rainfall event. There appeared to be a greater influence of rainfall at Boston than King's Lynn.

Appendix XII. Shoreline Survey Report

Date (time): 09/09/2013 (08:30-13:30)
10/09/2013 (08:30-15:00)
11/09/2013 (08:30-13:00)
12/09/2013 (08:30-13:30)
16/09/2013 (09:00-16:30)
17/09/2013 (09:00-15:00)

Cefas Officer: Alastair Cook

Local Enforcement Authority Officers: Ruth Moore (King's Lynn Council)
Trevor Darnes (Boston Council)
Sarah Johnson (East Lindsey Council)
Steven Bass (Fenland Council)

Area surveyed: Most of the perimeter of the Wash was surveyed (~85 km walked in total). The significant exception to this was the marshes around North Wootton where access to the shore is via long walks through private land owned by unknown parties. This omission was not considered critical as maps indicate the stretch has no major freshwater inputs and there are no settlements anywhere near this shore.

Weather: 09/09/2013 – Sunny/cloudy/drizzle, wind W 3km/h, 15C
10/09/2013 – Patchy rain, wind NW 20km/h, 13C
11/09/2013 – Overcast, wind N 11km/h, 13C
12/09/2013 – Sunny, wind W 5km/h, 15C
16/09/2013 – Occasional showers, wind W 20km/h, 13C
17/09/2013 – Overcast, wind SW 16km/h, 14C.

Tides:

Admiralty TotalTide tidal predictions for West Stones (52°50'N 0°21'E). All times in this report are BST.

09/09/2013	10/09/2013	11/09/2013
High 08:01 7.6 m High 20:28 7.1 m Low 03:28 1.3 m Low 16:00 1.2 m	High 08:40 7.4 m High 21:06 6.9 m Low 03:58 1.4 m Low 16:25 1.4 m	High 09:24 7.0 m High 21:52 6.6 m Low 04:23 1.5 m Low 16:46 1.6 m
12/09/2013	**16/09/2013**	**17/09/2013**
High 10:18 6.5 m High 22:49 6.2 m Low 04:56 1.7 m Low 17:18 1.8 m	High 03:56 6.2m High 16:47 6.3m Low 11:07 1.6m Low 23:30 1.8m	High 04:58 6.7m High 17:42 6.8m Low 12:28 1.1m

Appendix XIII. Shoreline Survey

XIII.1. Objectives

The shoreline survey aims to obtain samples of freshwater inputs to the area for bacteriological testing, confirm the location of previously identified sources of potential contamination; locate other potential sources of contamination that were previously unknown. A full list of recorded observations is presented in Table XIII.1 and the locations of these observations are mapped in Figure XIII.1. Photographs are presented in Figure XIII.3 to Figure XIII.15.

XIII.2. Description of Fishery

No significant additional information on the fishery was obtained during the visit. Some fishing boats were observed heading out, waiting for the tide to drop, and beached on intertidal sandbanks harvesting shellfish. One aggregation of 8 boats was observed waiting to beach off the mouth of the Welland, and two were seen beached off the mouth of the Nene.

XIII.3. Sources of contamination

Sewage discharges

Very few sewage discharges were seen. The location of the North Sea Camp Prison discharge, to a drain behind the sea bank was confirmed (observation 34). Two possible small sewage discharges associated with military buildings were seen (observations 47 and 50) but no outfalls were visible so it is likely that they if they are sewage discharges, the effluent goes to soakaway.

Freshwater inputs

The four main freshwater inputs are the Ouse, Nene, Welland and Witham/Haven, the estuaries of which are canalised and extend a significant distance inland. Samples were taken from each of these estuaries whilst the tide was ebbing, and none carried high concentrations of *E. coli*.

Aside from these rivers, and a small gravity sluice on the seawall between the Ouse and the Nene (observation 2) all surface water drainage direct to the foreshore of the Wash was via pumping stations due to the low lying nature of the land. None was running at the time of visit, but water samples were taken from the drains immediately behind them. Levels of *E. coli* within them varied markedly, from 0 to 5000 cfu/100ml.

Livestock

Of most significance were cattle observed grazing on the sea banks and saltmarshes. Although they were not present in all areas where the foreshore is sea banks fronted by saltmarsh, signs of cattle were widespread. There were no signs of cattle on the area used for military exercises between the Nene and the Welland. Some of the fields behind the seawalls (which were fenced) contained cattle or sheep.

Wildlife

A significant aggregation of birds was seen on wetlands behind the seawall on the Frampton Marshes, and several flocks were seen in flight over the saltmarshes. However, the main aggregations of birds arrive in the area later in the year than when the survey took place.

Boats and shipping

A total of 23 yachts were recorded in a tidal creek near Gibraltar Point, and three yachts were recorded moored off Snettisham. Apart from this, some boat traffic was observed moving in and out of the Ouse, including several fishing vessels, and some fishing vessels were observed beached on the sands.

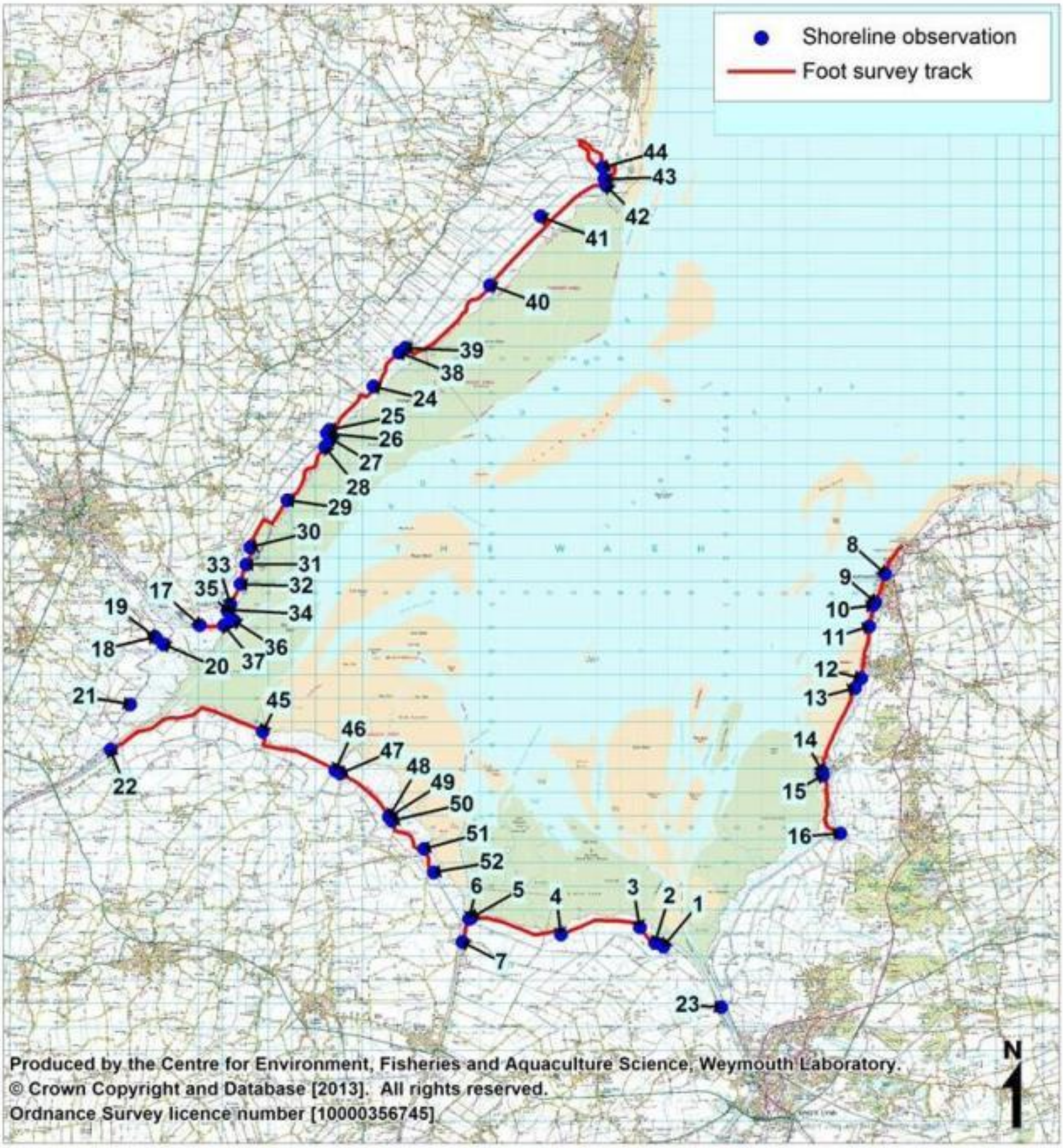


Figure XIII.1 Locations of shoreline observations (see Table XIII.1 for details)

Table XIII.1: Details of shoreline observations

No.	NGR	Time	Description	Photo
1	TF 57817 25441	09/09/2013 10:01	Cattle drink with signs of recent use	
2	TF 57448 25592	09/09/2013 10:07	Sluice outfall, flowing (via gravity) 125cmx45cmx0.158m/s. Water sample 1.	Figure XIII.3
3	TF 56818 26252	09/09/2013 10:27	Blocked sluice not flowing. Cattle shed behind seawall. Cattle hoofprints all over saltmarsh.	Figure XIII.4
4	TF 53451 25946	09/09/2013 11:24	20 cattle on seawall with access to saltmarsh	
5	TF 49645 26673	09/09/2013 12:27	Inspection covers (probably groundwater monitoring)	
6	TF 49537 26599	09/09/2013 12:31	Flap valve outfall to river channel.	
7	TF 49254 25619	09/09/2013 12:59	Water sample 2.	
8	TF 67248 41326	10/09/2013 09:49	3 old pipes in eroded cliff face, pigeons using them for shelter.	Figure XIII.5
9	TF 66818 40117	10/09/2013 10:09	Possible sewage pumping behind caravan park	
10	TF 66746 39975	10/09/2013 10:13	Marker post off boat ramp	
11	TF 66573 39064	10/09/2013 10:25	Enclosure in garden, related to sewage or water supply	
12	TF 66235 36868	10/09/2013 11:03	Heacham river outfall. Not flowing, outfall covered by tide. Water sample 3.	Figure XIII.6
13	TF 65964 36453	10/09/2013 11:16	Old cotton bud in tideline	
14	TF 64574 32897	10/09/2013 12:07	Yacht club. Only small sailing dinghies in yard.	
15	TF 64602 32731	10/09/2013 12:10	3 larger yachts on moorings	
16	TF 65338 30254	10/09/2013 13:00	Ingol Outfall, Water sample 4	Figure XIII.7
17	TF 38059 39134	11/09/2013 09:52	Water sample 5	
18	TF 36137 38644	11/09/2013 10:31	35 cattle in field	
19	TF 36191 38601	11/09/2013 10:32	53 cattle in field. Hundreds of waders and ducks on ponds.	
20	TF 36513 38323	11/09/2013 10:38	~100 cattle on seawall and saltmarsh, some quite far out.	Figure XIII.8
21	TF 35087 35740	11/09/2013 11:08	About 50 cattle on saltmarsh and 40 in field.	
22	TF 34264 33819	11/09/2013 11:35	Water sample 6	
23	TF 60257 22854	11/09/2013 12:29	Water sample 7	
24	TF 45450 49317	12/09/2013 08:51	25 cattle on marsh	
25	TF 43590 47455	12/09/2013 09:28	30 cattle on marsh	
26	TF 43478 47307	12/09/2013 09:33	Pumping station. Water sample 8.	
27	TF 43619 47097	12/09/2013 09:41	40 cattle on marsh	

No.	NGR	Time	Description	Photo
28	TF 43399 46726	12/09/2013 09:50	10 cattle on marsh	
29	TF 41792 44453	12/09/2013 10:28	Pumping station. Water sample 9.	
30	TF 40210 42456	12/09/2013 11:09	~30 sheep around pond (fenced in)	
31	TF 40028 41710	12/09/2013 11:22	45 cattle in field.	
32	TF 39794 40886	12/09/2013 11:33	30 cattle in field.	
33	TF 39347 40009	12/09/2013 11:46	80 sheep in field. Cattle dung all over seawall	
34	TF 39240 39787	12/09/2013 11:52	Prison STW. Outfall to ditch.	Figure XIII.9
35	TF 39283 39667	12/09/2013 11:55	~300 sheep in fields around prison.	
36	TF 39502 39308	12/09/2013 12:02	30 cattle on seawall.	
37	TF 39092 39130	12/09/2013 12:09	20 cattle on seawall	
38	TF 46546 50735	16/09/2013 10:08	60 cattle in field	
39	TF 46809 50949	16/09/2013 10:14	Pumping station. Water sample 10	Figure XIII.10
40	TF 50426 53611	16/09/2013 11:29	37 cattle	
41	TF 52586 56564	16/09/2013 13:07	Pumping Station. Water sample 11	Figure XIII.11
42	TF 55380 57858	16/09/2013 14:00	23 yachts in creek.	
43	TF 55294 58150	16/09/2013 14:08	Pumping station. Water sample 12	
44	TF 55214 58647	16/09/2013 15:43	Pumping station. Water sample 13.	
45	TF 40734 34593	17/09/2013 11:05	Pumping station. Water sample 14	Figure XIII.12
46	TF 43829 32924	17/09/2013 12:11	Pumping station. Water sample 15	Figure XIII.13
47	TF 44049 32803	17/09/2013 12:18	Possible septic tank in military compound.	Figure XIII.14
48	TF 46117 30961	17/09/2013 13:00	Enclosure, probably contains generator rather than sewage plant.	
49	TF 46121 30955	17/09/2013 13:00	Pumping station. Water sample 16.	
50	TF 46259 30783	17/09/2013 13:07	Septic tank for control tower. Built into seabank, no outfall visible.	Figure XIII.15
51	TF 47614 29595	17/09/2013 13:38	8 cattle on marsh	
52	TF 48034 28588	17/09/2013 13:54	14 cattle on marsh	

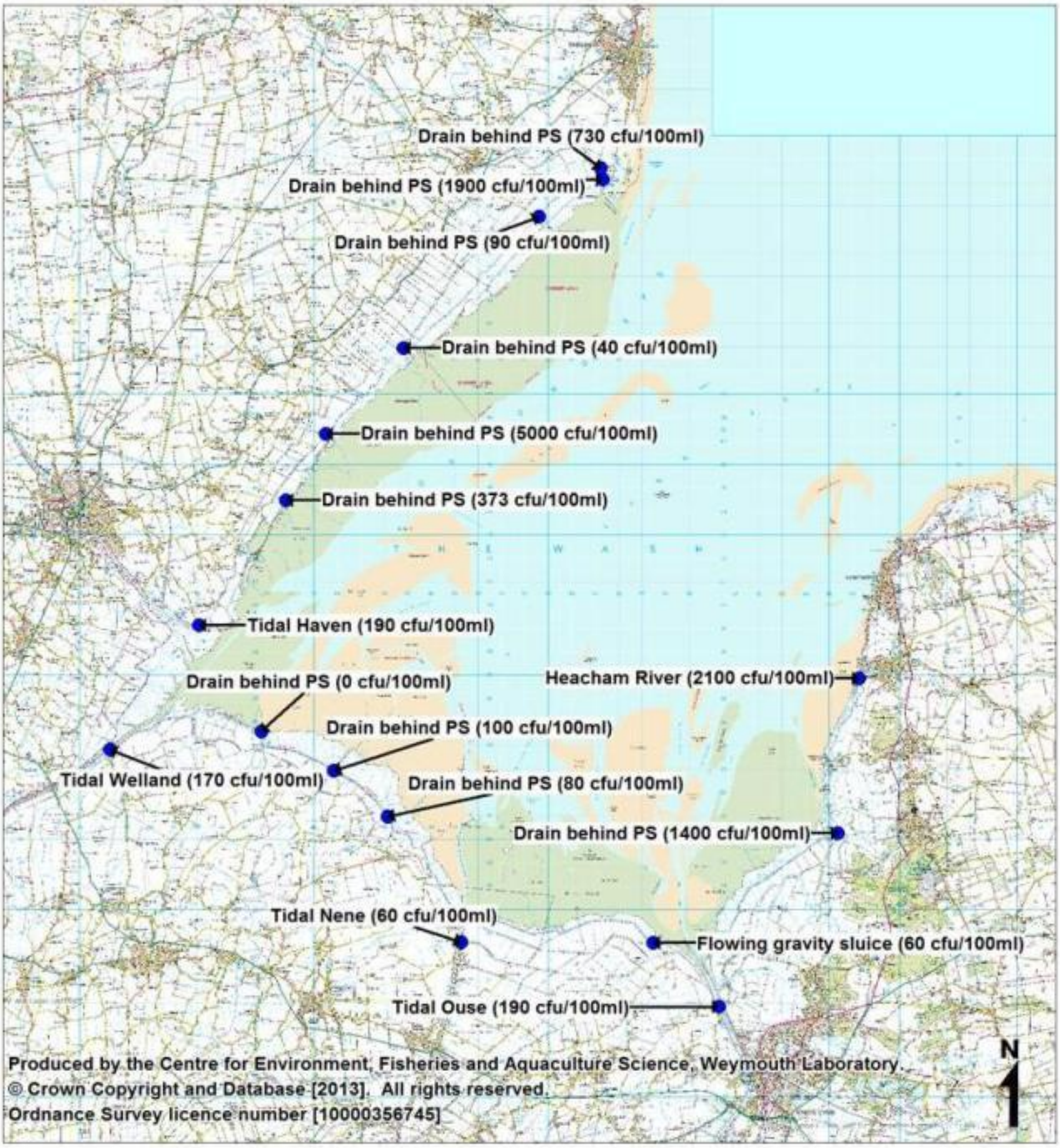


Figure XIII.2: Water sample results

Table XIII.2: Water sample *E. coli* results

Sample No.	Date and time	NGR	Description	Type	*E. coli* (cfu/100ml)
1	09/09/2013 10:07	TF 57448 25592	Flowing gravity sluice (0.089m^3/sec)	Freshwater	60
2	09/09/2013 12:59	TF 49254 25619	Tidal Nene (ebbing)	Seawater	60
3	10/09/2013 11:03	TF 66235 36868	Heacham river outfall (not running)	Freshwater	2100
4	10/09/2013 13:00	TF 65338 30254	Behind pumping station (not running)	Freshwater	1400
5	11/09/2013 09:52	TF 38059 39134	Tidal Haven (ebbing)	Seawater	190
6	11/09/2013 11:35	TF 34264 33819	Tidal Welland (ebbing)	Seawater	170
7	11/09/2013 12:29	TF 60257 22854	Tidal Ouse (ebbing)	Seawater	190
8	12/09/2013 09:33	TF 43478 47307	Behind pumping station (not running)	Freshwater	5000
9	12/09/2013 10:28	TF 41792 44453	Behind pumping station (not running)	Freshwater	373
10	16/09/2013 10:14	TF 46809 50949	Behind pumping station (not running)	Freshwater	40
11	16/09/2013 13:07	TF 52586 56564	Behind pumping station (not running)	Freshwater	90
12	16/09/2013 14:08	TF 55294 58150	Behind pumping station (not running)	Freshwater	1900
13	16/09/2013 15:43	TF 55214 58647	Behind pumping station (not running)	Freshwater	730
14	17/09/2013 11:05	TF 40734 34593	Behind pumping station (not running)	Freshwater	ND
15	17/09/2013 12:11	TF 43829 32924	Behind pumping station (not running)	Freshwater	100
16	17/09/2013 13:00	TF 46121 30955	Behind pumping station (not running)	Freshwater	80

Figure XIII.3

Figure XIII.4


Figure XIII.5


Figure XIII.6

Figure XIII.7

Figure XIII.8

Figure XIII.9

Figure XIII.10

Figure XIII.11

Figure XIII.12

Figure XIII.13

Figure XIII.14

Figure XIII.15

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List of Abbreviations

AONB	Area of Outstanding Natural Beauty
BMPA	Bivalve Mollusc Production Area
CD	Chart Datum
Cefas	Centre for Environment Fisheries & Aquaculture Science
CFU	Colony Forming Units
CSO	Combined Sewer Overflow
CZ	Classification Zone
Defra	Department for Environment, Food and Rural Affairs
DWF	Dry Weather Flow
EA	Environment Agency
E. coli	Escherichia coli
EC	European Community
EEC	European Economic Community
EO	Emergency Overflow
FIL	Fluid and Intravalvular Liquid
FSA	Food Standards Agency
GM	Geometric Mean
IFCA	Inshore Fisheries and Conservation Authority
ISO	International Organization for Standardization
km	Kilometre
LEA (LFA)	Local Enforcement Authority formerly Local Food Authority
M	Million
m	Metres
ml	Millilitres
mm	Millimetres
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MPN	Most Probable Number
NM	Nautical Miles
NRA	National Rivers Authority
NWSFC	North Western Sea Fisheries Committee
OSGB36	Ordnance Survey Great Britain 1936
mtDNA	Mitochondrial DNA
PS	Pumping Station
RMP	Representative Monitoring Point
SAC	Special Area of Conservation
SHS	Cefas Shellfish Hygiene System, integrated database and mapping application
SSSI	Site of Special Scientific Interest
STW	Sewage Treatment Works
UV	Ultraviolet
WGS84	World Geodetic System 1984

Glossary

Bathing Water	Element of surface water used for bathing by a large number of people. Bathing waters may be classed as either EC designated or non-designated OR those waters specified in section 104 of the Water Resources Act, 1991.
Bivalve mollusc	Any marine or freshwater mollusc of the class Pelecypoda (formerly Bivalvia or Lamellibranchia), having a laterally compressed body, a shell consisting of two hinged valves, and gills for respiration. The group includes clams, cockles, oysters and mussels.
Classification of bivalve mollusc production or relaying areas	Official monitoring programme to determine the microbiological contamination in classified production and relaying areas according to the requirements of Annex II, Chapter II of EC Regulation 854/2004.
Coliform	Gram negative, facultatively anaerobic rod-shaped bacteria which ferment lactose to produce acid and gas at 37°C. Members of this group normally inhabit the intestine of warm-blooded animals but may also be found in the environment (e.g. on plant material and soil).
Combined Sewer Overflow	A system for allowing the discharge of sewage (usually dilute crude) from a sewer system following heavy rainfall. This diverts high flows away from the sewers or treatment works further down the sewerage system.
Discharge	Flow of effluent into the environment.
Dry Weather Flow (DWF)	The average daily flow to the treatment works during seven consecutive days without rain following seven days during which rainfall did not exceed 0.25 mm on any one day (excludes public or local holidays). With a significant industrial input the dry weather flow is based on the flows during five working days if production is limited to that period.
Ebb tide	The falling tide, immediately following the period of high water and preceding the flood tide.
EC Directive	Community legislation as set out in Article 189 of the Treaty of Rome. Directives are binding but set out only the results to be achieved leaving the methods of implementation to Member States, although a Directive will specify a date by which formal implementation is required.
EC Regulation	Body of European Union law involved in the regulation of state support to commercial industries, and of certain industry sectors and public services.
Emergency Overflow	A system for allowing the discharge of sewage (usually crude) from a sewer system or sewage treatment works in the case of equipment failure.
Escherichia coli (E. coli)	A species of bacterium that is a member of the faecal coliform group (see below). It is more specifically associated with the intestines of warm-blooded animals and birds than other members of the faecal coliform group.
E. coli O157	E. coli O157 is one of hundreds of strains of the bacterium Escherichia coli. Although most strains are harmless, this strain produces a powerful toxin that can cause severe illness. The strain O157:H7 has been found in the intestines of healthy cattle, deer, goats and sheep.
Faecal coliforms	A group of bacteria found in faeces and used as a parameter in the Hygiene Regulations, Shellfish and Bathing Water Directives, E. coli is the most common example of faecal coliform. Coliforms (see above) which can produce their characteristic reactions (e.g. production of acid from lactose) at 44°C as well as 37°C. Usually, but not exclusively, associated with the intestines of warm-blooded animals and birds.
Flood tide	The rising tide, immediately following the period of low water and preceding the ebb tide.
Flow ratio	Ratio of the volume of freshwater entering into an estuary during the tidal cycle to the volume of water flowing up the estuary through a given cross

	section during the flood tide.
Geometric mean	The geometric mean of a series of N numbers is the Nth root of the product of those numbers. It is more usually calculated by obtaining the mean of the logarithms of the numbers and then taking the anti-log of that mean. It is often used to describe the typical values of skewed data such as those following a log-normal distribution.
Hydrodynamics	Scientific discipline concerned with the mechanical properties of liquids.
Hydrography	The study, surveying, and mapping of the oceans, seas, and rivers.
Lowess	Locally Weighted Scatterplot Smoothing, more descriptively known as locally weighted polynomial regression. At each point of a given dataset, a low-degree polynomial is fitted to a subset of the data, with explanatory variable values near the point whose response is being estimated. The polynomial is fitted using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. The value of the regression function for the point is then obtained by evaluating the local polynomial using the explanatory variable values for that data point. The LOWESS fit is complete after regression function values have been computed for each of the n data points. LOWESS fit enhances the visual information on a scatterplot.
Telemetry	A means of collecting information by unmanned monitoring stations (often rainfall or river flows) using a computer that is connected to the public telephone system.
Secondary Treatment	Treatment to applied to breakdown and reduce the amount of solids by helping bacteria and other microorganisms consume the organic material in the sewage or further treatment of settled sewage, generally by biological oxidation.
Sewage	Sewage can be defined as liquid, of whatever quality that is or has been in a sewer. It consists of waterborne waste from domestic, trade and industrial sources together with rainfall from subsoil and surface water.
Sewage Treatment Works (STW)	Facility for treating the waste water from predominantly domestic and trade premises.
Sewer	A pipe for the transport of sewage.
Sewerage	A system of connected sewers, often incorporating inter-stage pumping stations and overflows.
Storm Water	Rainfall which runs off roofs, roads, gulleys, etc. In some areas, storm water is collected and discharged to separate sewers, whilst in combined sewers it forms a diluted sewage.
Waste water	Any waste water but see also “sewage”.

Acknowledgements

Ruth Moore (King’s Lynn Council), Trevor Darnes (Boston Council), Sarah Johnson (East Lindsey District Council), Steven Bass (Fenland District Council), Ron Jessop (Eastern IFCA).