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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Lune

October 2013

Cover photo: Cockerham Sands

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Statement of use

This report provides a sanitary survey relevant to bivalve mollusc beds within the Lune Estuary, 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

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1	Draft for internal consultation	Simon Kershaw	28/10/2013
2	Draft for client/consultee comment	Simon Kershaw	29/10/2013
3	Final	Simon Kershaw	17/03/2014

Consultation

Consultee	Date of consultation	Date of response
Lancaster City Council	29/10/2013	27/11/2013
Wyre Borough Council	29/10/2013	27/11/2013
North Western IFCA	29/10/2013	None received
Environment Agency	29/10/2013	27/11/2013
United Utilities	29/10/2013	None received
Shellfish Association of Great Britain	29/10/2013	None received

Dissemination

Food Standards Agency, Wyre Borough Council and Lancaster City Council.

Recommended Bibliographic Reference

Cefas, 2013. Sanitary survey of the Lune. 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 undertake a sanitary survey for mussels (*Mytilus* spp.) and cockles (*Cerastoderma edule*) within the Lune bivalve mollusc production area. The area was prioritised for survey in 2013-14 by a shellfish hygiene risk ranking exercise of existing classified areas.

1.2. Area Description

The Lune production area is situated in the southern end of Morecambe Bay, on the north west coast of England and extends from Heysham to Fleetwood. It is a relatively open embayment, predominantly of intertidal sandflats, into which the estuaries of the Lune and the Wyre drain.

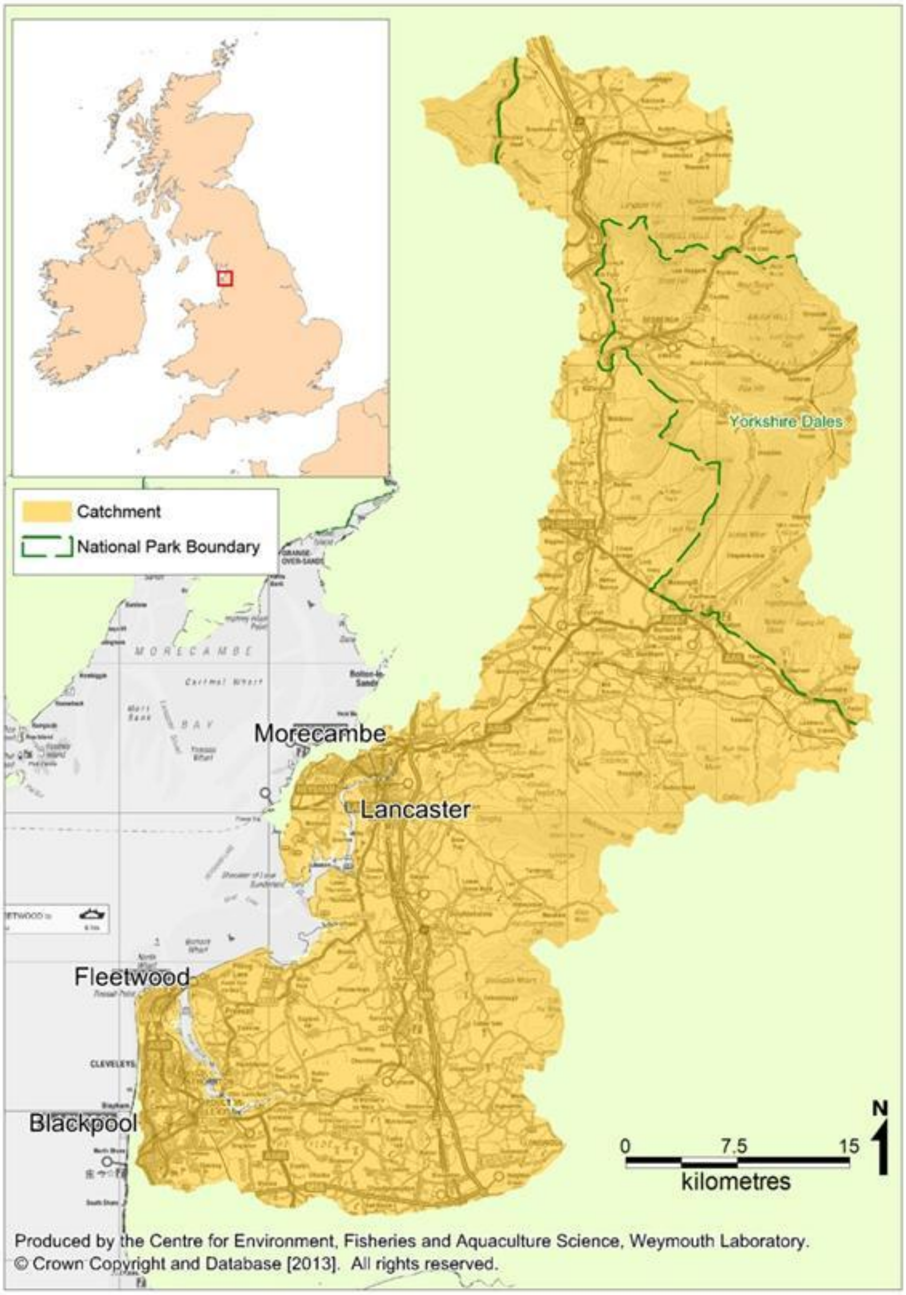


Figure 1.1 Location of the Lune

The survey area forms part of the Morecambe Bay Special Protection Area (SPA), Special Area of Conservation (SAC) and Ramsar Site. Sections have also been designated as Sites of Special Scientific Interest (SSSIs) and a National Character

Area (NCA). These designations are a result of its estuarine habitats; large intertidal flats, salt marshes, reefs and sand/shingle banks and the wildlife that they attract including aggregations of internationally and nationally important species of overwintering birds.

The adjoining estuaries host a commercial port and a ferry port, two yacht clubs and two marinas, and a significant fishing fleet. Shellfisheries within the area are for wild mussels, which grow on several discrete rocky areas, and every few years there are major settlements of cockles which attract high levels of commercial harvesting.

1.3. Catchment

Figure 1.2 illustrates land cover within the hydrological catchment which covers an area of approximately 1,300 km² (Environment Agency, 2009). It is predominantly covered by rural land (pasture), with small clusters of urbanised land primarily concentrated close to the coast representing the towns of Blackpool, Fleetwood and Heysham. Approximately 20% of the catchment, in the north east, is within the Yorkshire Dales and a small corner in the north west of the catchment is within the Lake District; both largely comprise moors and heathland with smaller areas of peat bogs and mixed and coniferous forest. The Forest of Bowland and Arnside/Silverside Areas of Outstanding Natural Beauty (AONB) exist in the south of the catchment. Arable land is restricted to the southern catchment where the soil quality is more suitable (Environment Agency, 2009).

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 north and west of the catchment features steep slopes whereas flatter terrain exists to the east and south. Soils are of low permeability in the upper catchment, and are generally of moderate permeability in the lower catchment (NERC, 2012).

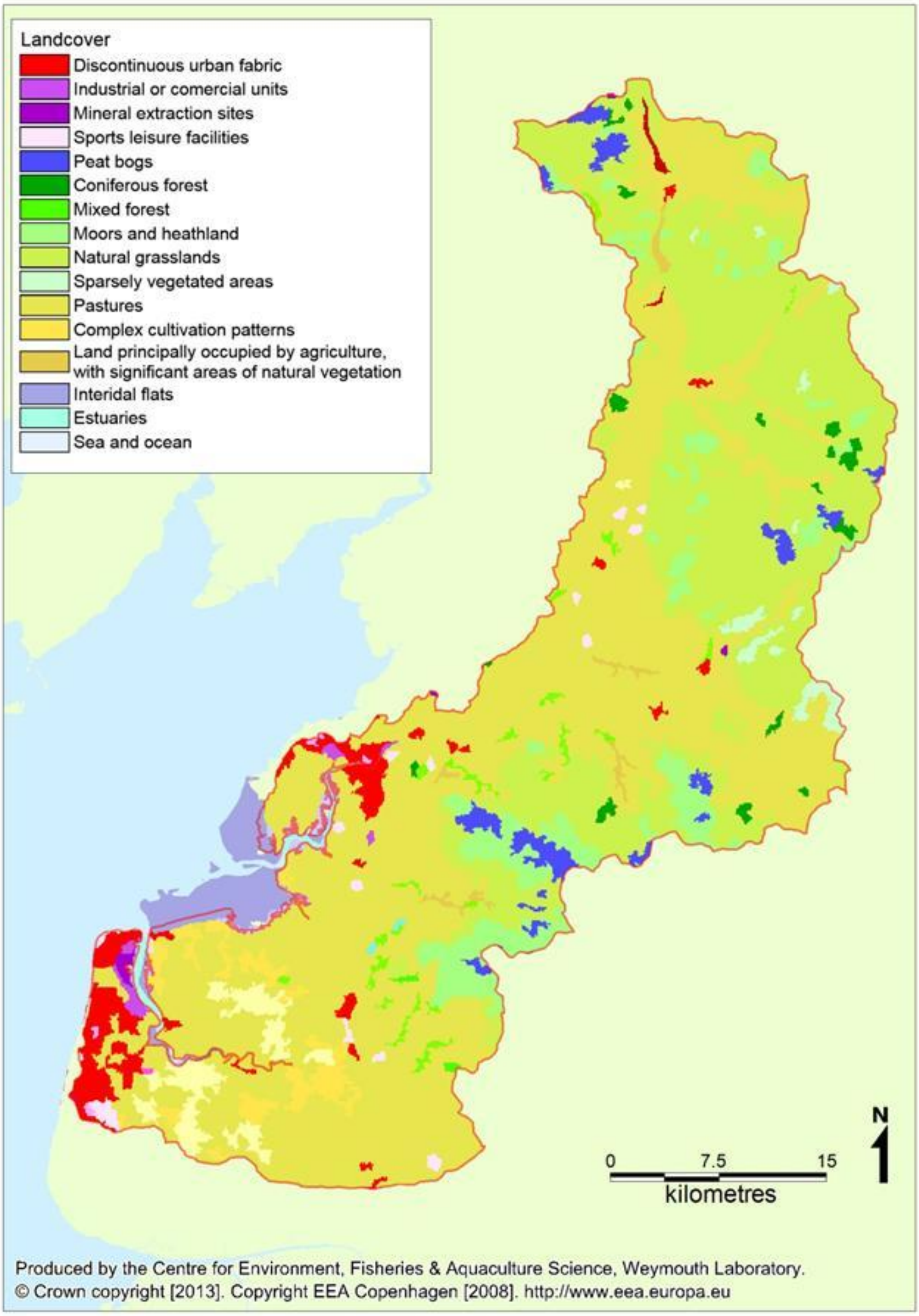


Figure 1.2 Landcover in the Lune catchment area

2. Recommendations

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, noted on sample submission forms, and communicated to Cefas.

2.1. Cockles

The following four zones are proposed for cockles:

Middleton Sands. This zone lies to the north of the Lune estuary approach channel, and contains the Middleton Sands cockle bed. The main contaminating influence is the ebb plume from the Lune estuary. It is therefore recommended that the RMP be located at the south eastern tip of this bed to best capture contamination from this source.

Lune Island. This zone contains a discrete cockle bed (Lune Island) which lies on a sandbank just to the south of the Lune approach channel. Again, the main contaminating influence will be the ebb plume from the Lune estuary, so it is recommended that the RMP is located at the eastern tip of this bed to best capture contamination from this source.

Pilling Sands. This zone includes the Pilling Sands cockle bed. The ebb plume from the Lune estuary will pass this bed to the north under most conditions, and the ebb plume from the Wyre will be carried north and west, and therefore away from this bed. The most significant local sources are three watercourses/surface water outfalls. Contamination washing off the Cockerham saltmarshes where sheep are grazed, and from geese which graze the saltmarshes and adjacent fields during the winter, are also likely to be an influence. Contamination from all these will be carried through the area in drainage channels at lower states of the tide, within which quite high concentrations of bacterial indicators may arise. The river Cocker and the Cockerham marshes are likely to represent the largest combined input. It is therefore recommended that the RMP be located immediately adjacent to the Cocker drainage channel, or if the bed does not extent this far east, at its eastern tip.

Fleetwood. This zone includes a small cockle bed at Marine Beach Fleetwood. It is in close proximity to the mouth of the Wyre estuary, the ebb plume from which will be the main contaminating influence. It is therefore recommended that the RMP be located at the south eastern tip of this bed to best capture contamination from this source.

The following specifications apply to all cockle RMPs:

- They will only require classification if the IFCA identify that there are sufficient stocks to open a fishery. This may only occur every 5-10 years, but when it does a high level of effort is anticipated, so classifications must be in place before the fishery opens. Not all beds/zones may require classification when such an event does occur.
- The sampling interval should be monthly. The months of May and June may be omitted assuming all other 10 months are sampled. Currently preliminary classification may be issued immediately using data from current monitoring of other classification species (following a RMP assessment). A provisional classification can be issued on the basis of 10 samples taken not less than a week apart.
- Samples should be of animals of a harvestable size (20 mm).
- Samples should be hand gathered.
- A tolerance of 100 m applies to ensure that there are sufficient stocks for repeated sampling.

2.2. Mussels

The following four zones are proposed for Mussels:

Plover Scar. The Plover Scar bed does not currently hold harvestable stocks of mussels, but has in the past so a sampling plan is required in case it regenerates. It lies on the southern shore of the mouth of the Lune estuary. As such, the ebb plume from this estuary will be the main contaminating influence. It is therefore recommended that the RMP is located on the north eastern tip of this bed to best capture contamination from this source.

Wyre Estuary. This includes the Sea Centre mussel bed which lies on the east bank of the outer reaches of the Wyre estuary. Within this estuary there is likely to be an underlying gradient of increasing levels of contamination towards its head. Preesall STW discharges to the east bank of the Wyre estuary about 500 m south of this mussel bed, although it provides UV treatment and so the bacterial loading it generates is typically minor. It is therefore recommended that the RMP is located at the southern extremity of this mussel bed.

Wyre Approaches. This zone includes several discrete mussel beds lying either side of the Wyre estuary approach channel. The ebb plume from the Wyre estuary will be the main contaminating influence within this zone. It is therefore recommended that the RMP is located at the southern extremity of the Knott Spit mussel bed.

Rossall and Kings Scar. This zone includes three discrete mussel beds which lie on the edge of the intertidal between Rossall Point and Kings Scar. The ebb plume from the Wyre estuary is likely to be an influence here, but not to the extent that it is in the Wyre approaches. There is an intermittent discharge to the subtidal about 1km west of Rossall Point, but this will only be an occasional influence. The Fleetwood Marsh STW, which is a large works only providing secondary treatment discharges to the edge of the Lune Deep about 5 km off Rossall Point. The flood tide will carry the plume from this discharge along the edge of this deepwater channel directly towards the Kings Scar mussel bed, which also lies on the edge of this channel. Although the distance between the two is just over 4km, given the high bacterial loading the STW generates, and the direct path towards the bed, it is recommended that the RMP is located on the north western corner of the King Scar mussel bed to best capture its' plume.

There are also some intermittent discharges in the Rossall Point area

The following specifications apply to all mussel RMPs:

- The sampling interval should be monthly, and sampling should be undertaken all year round.
- Samples should be of animals of a harvestable size (45 mm).
- Samples should be hand gathered.
- A tolerance of 50 m applies to ensure that there are sufficient stocks for repeated sampling.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Lune
Cefas Main Site Reference	M066
Ordnance survey 1:25,000 map	296
Admiralty Chart Nos.	2010, 1552

Shellfishery

Species/culture	Mussels	Wild
	Cockles	Wild
Seasonality of harvest	Currently closed on conservation grounds. Closed season for cockles 1st May to 31st August when open. No closed season for mussels.	

Local Enforcement Authorities

Name	Environmental Health Wyre Borough Council Wyre Civic Centre Breck Road Poulton-Le-Fylde Lancashire FY6 7PU
Environmental Health Officer	Neil Greenwood
Telephone number ☎	01253 891000
Fax number	-
E-mail	ngreenwood@wyrebc.gov.uk
Name	Environmental Health Department Lancaster City Council Town Hall Morecambe Lancashire LA4 5AF
Environmental Health Officer	Suzanne Lodge
Telephone number ☎	01524 582935
Fax number	01524 582709
E-mail	shellfishaction@lancaster.gov.uk

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 Lune

	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Middleton Sands	B066U*	Middleton Sands South	SD 4162 5450	53° 58.99'N 02° 53.50'W	Cockles	Wild	Hand	Hand	100 m	Ten samples, sampled not less than 1 week apart, if provisional classification is required. Otherwise monthly. The months of May and June need not be sampled, assuming all other 10 months are.	Only requires classification if and when the IFCA identify the prospect of a fishery opening. Feasibility of sampling Marine Beach needs to be confimed.
Lune Island	B066V**	Lune Island East	SD 3952 5314	53° 58.25'N 02° 55.41'W							
Pilling Sands	B066W*	Pilling Sands East	SD 4183 5241	53:57.87'N 02° 53.29'W							
Fleetwood	Existing RMP B066R**	Marine Beach	SD 3320 4870	53° 55.81'N 03° 01.13'W							
Plover Scar	B066X*	Plover Scar	SD 4250 5435	53° 58.92'N 02° 52.70'W	Mussels	Wild	Hand	Hand	50 m	Monthly	No harvestable stock at present, may require reclassification if stocks recover.
Wyre Estuary	B066Y**	Sea Centre South	SD 3450 4722	53° 55.02'N 02° 59.92'W							Little, if any harvesting activity in the area at present. Feasibility of sampling King's Scar needs to be confirmed.
Wyre Approaches	B066Z**	Knott Spit	SD 3419 4862	53° 55.77'N 03° 00.23'W							
Rossall and Kings Scar	B66AA**	Kings Scar	SD 3056 5049	53° 56.75'N 03° 03.57'W							

* Lancaster CC; **Wyre CC

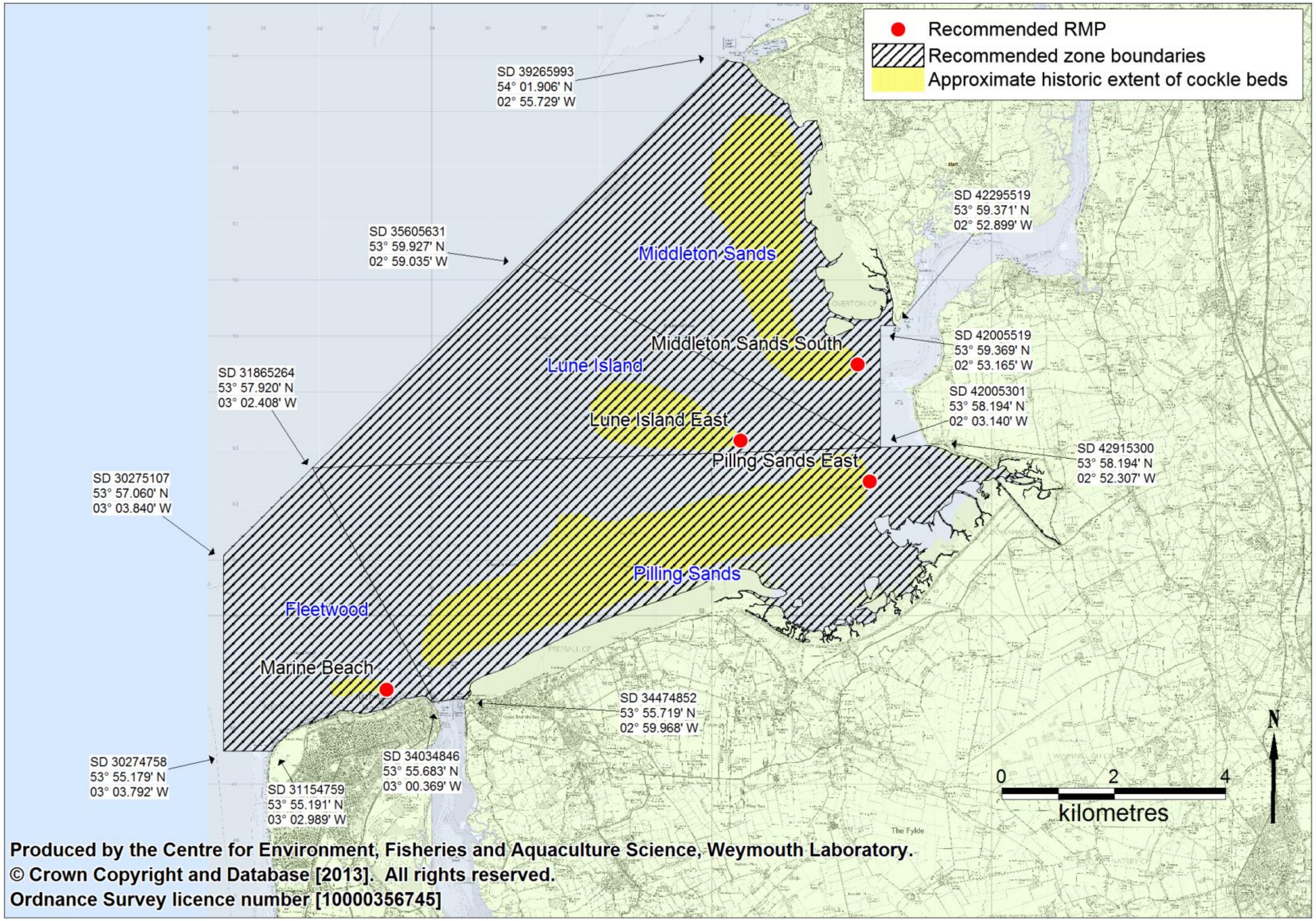


Figure 3.1: Recommended zoning and monitoring arrangements (cockles)

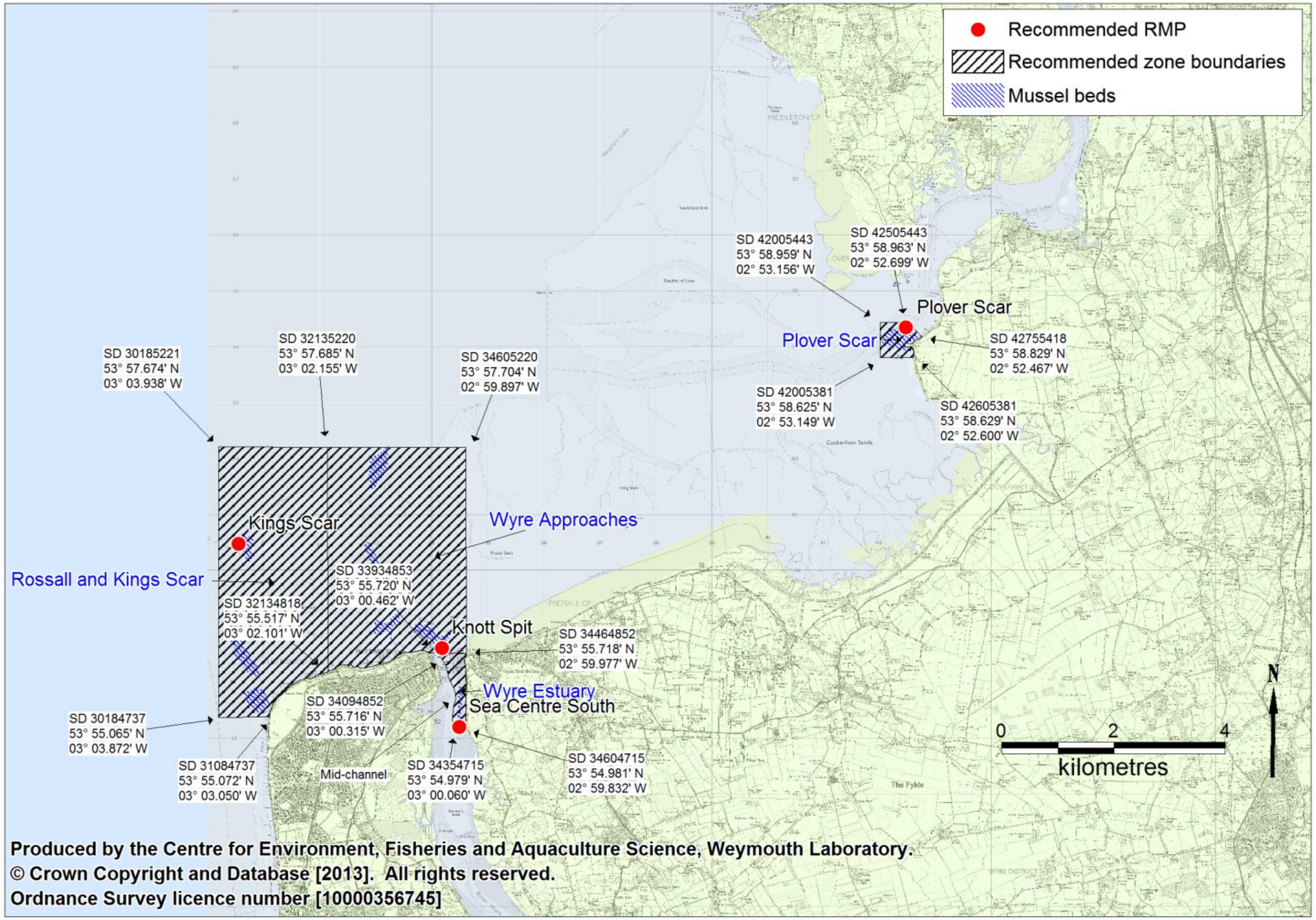


Figure 3.2: Recommended zoning and monitoring arrangements (mussels)

4. Shellfisheries

4.1. Species, location and extent

Shellfish resources within the survey area comprise naturally occurring cockles and mussels. These are all managed by the North Western IFCA under their local byelaws.

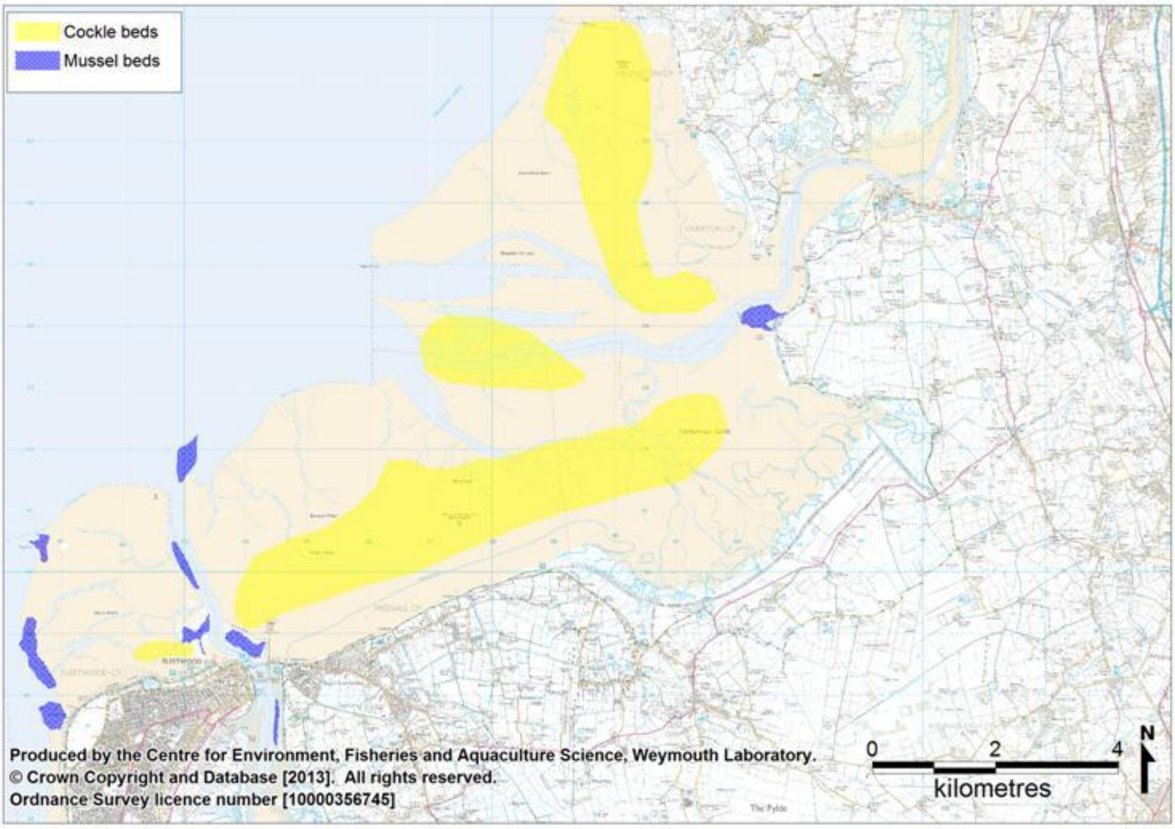


Figure 4.1: Approximate distribution of shellfish within the survey area

Distributions and densities of cockles vary significantly from year to year, and this is reflected in harvesting. There has not been any significant cockle recruitment in the Morecambe Bay area since 2008, and although there are small numbers of cockles still present in the area there are no beds holding commercial densities at present. Significant spatfalls are likely to occur at some point in the future, and the main resulting concentrations of harvestable stocks tend to fall in the discrete areas indicated in Figure 4.1. Historically, some very dense settlements have occurred within the survey area, and up to 650 individuals have been recorded working in harvesting the Morecambe Bay area at such times. The last significant fisheries occurred in 2003-2005 and 2007-2008, and were preceded by a long period of low stocks stretching back to the mid 1990s. The cockle fishery within the survey area (and the wider Morecambe Bay area) is currently closed under byelaw 13a to protect remaining stocks, which are considered to be below safe biological limits.

Mussel distributions tend to be more stable from year to year, as they only settle on firm substrates such as the rocky skears off Fleetwood, although the amount of harvestable stock may vary. Currently there is no commercial stock on the Plover Scar bed, by the mouth of the Lune estuary. The Wyre Estuary and Fleetwood mussel beds had abundant recruitment in 2012, and some recruitment in 2013, although some stock has been lost to storms and natural mortality. These beds are currently open for harvesting, and have been harvested commercially in recent years. The IFCA indicate that recent mussel harvesting activity in the Morecambe Bay area has been directed towards beds outside of the area considered in this survey however.

4.2. Growing Methods and Harvesting Techniques

All stocks considered in this report are wild. The intertidal cockles and mussels are exploited by hand gathering.

4.3. Seasonality of Harvest, Conservation Controls and Development Potential

Currently, the fishery is managed under the NW IFCA's byelaws. The cockle fishery in this district, when open, operates a closed season running from 1st May to 31st August to protect settling spat. There is no closed season for mussels. Statutory minimum landing sizes apply to cockles (20 mm) and mussels (45 mm). Gear limitations (hand gathering only) apply to the intertidal cockle and mussel fisheries, limiting levels of exploitation and preventing the use of techniques more destructive to the stocks and the habitat. Both cockles and mussels are a public fishery and anyone is allowed to take up to 5 kg of each species per calendar day (unless the fishery is closed under byelaw 13a). Greater (commercial) quantities can only be taken by licensed operators. Permits are issued by the NW IFCA, allowing exploitation of cockle and mussel beds within the entire district. A total of 280 permits were issued for the 2013/14 season.

Cockle stocks are likely to fluctuate significantly in their overall biomass and their distribution around the area. Success of spatfalls may vary greatly between years and storms, temperature extremes, diseases, predation and of course exploitation can all affect them and mass mortalities may occur at times. A pattern of long periods of low stock levels, with sporadic large recruitment events resulting in a significant fishery for a year or two has been apparent in the recent past in cockle beds in the north west. The next significant recruitment event is likely to spark a major fishery in the area.

Mussel stocks are likely to vary in quantity from year to year, but not in their distribution. As such they are a much more stable resource, but are of course subject to natural fluctuations in population size and structure. Over the last decade hand-gathering for market size mussels has declined to very low levels, probably due to a combination of low prices and a diminishing demand for the wild product as the availability of high quality "clean" cultivated mussels has increased (Knott & Houghton, 2012).

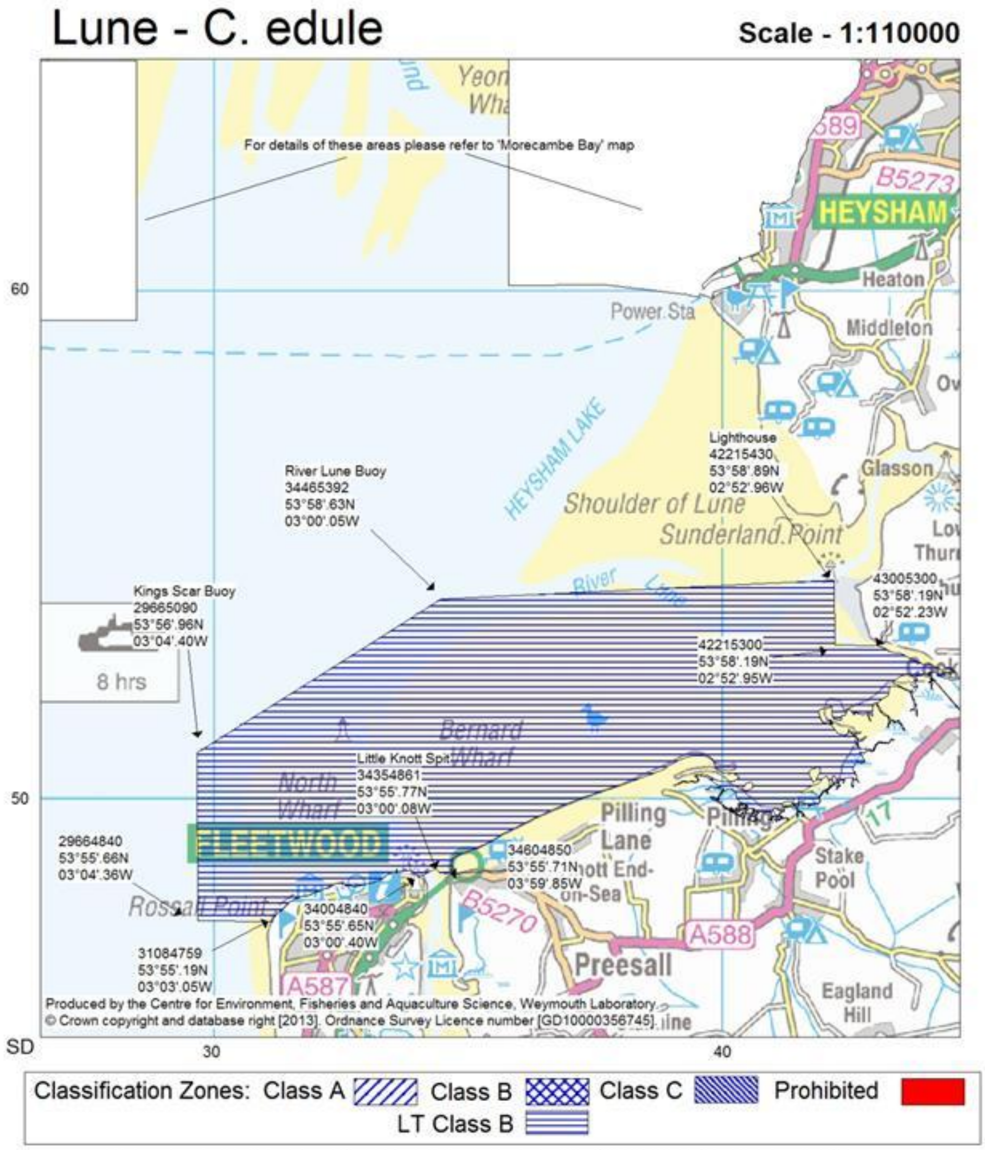
There are proposals to replace local byelaws with a hybrid fishery order in the near future. Implementing a hybrid order would allow a 'suite' of adaptive management measures that are flexible to stock levels and environmental considerations, including restricting numbers of licences and fishing methods, setting fees, implementing permanent and temporary spatial and temporal closures, designating access and landing points, enforcing total allowable catches (TACs) and bag limits, and restricting fishing hours' (Knott & Houghton, 2012).

4.4. Hygiene Classification

Table 4.1 Historical hygiene classifications, 2004 to present

Bed name	Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Sunderland Bank	Cockles	B	B-LT	B	B	B	B	B-LT			
Cockerham Sands	Cockles	B	B-LT	B	B	B	B	B-LT	B-LT	B-LT	B-LT
Middleton Sands	Cockles			B	B	B	B	B-LT			
Pilling Sands	Cockles			B	B	B	B	B-LT	B-LT	B-LT	B-LT
Knott Spit	Mussels	C	B	B	B	B	B	B	B	B-LT	B-LT
Wyre End Scar	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Perch Scar	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Kings Scar	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
North Wharf	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Plover Scar	Mussels	P	P	C	B	B	B	B-LT	B-LT	B-LT	
Rossall Point	Mussels	B	B	B	B	B	B				
The Neckings	Mussels	B	B	B	B	B	B				
Sea Centre	Mussels	C	C	C	C	C	C	B	B	B	B
Marine Beach	Cockles	B	B	B	B	B	B	B-LT	B-LT	B-LT	B-LT

Since 2004 all cockle classifications have been B. C classifications have arisen at Sea Centre, Knott Spit and Plover Scar. Plover Scar was prohibited in 2004 and 2005, but improved to a long term B before it was declassified. All cockle beds to the south of the Lune channel remain classified, despite the current closure.



Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2013

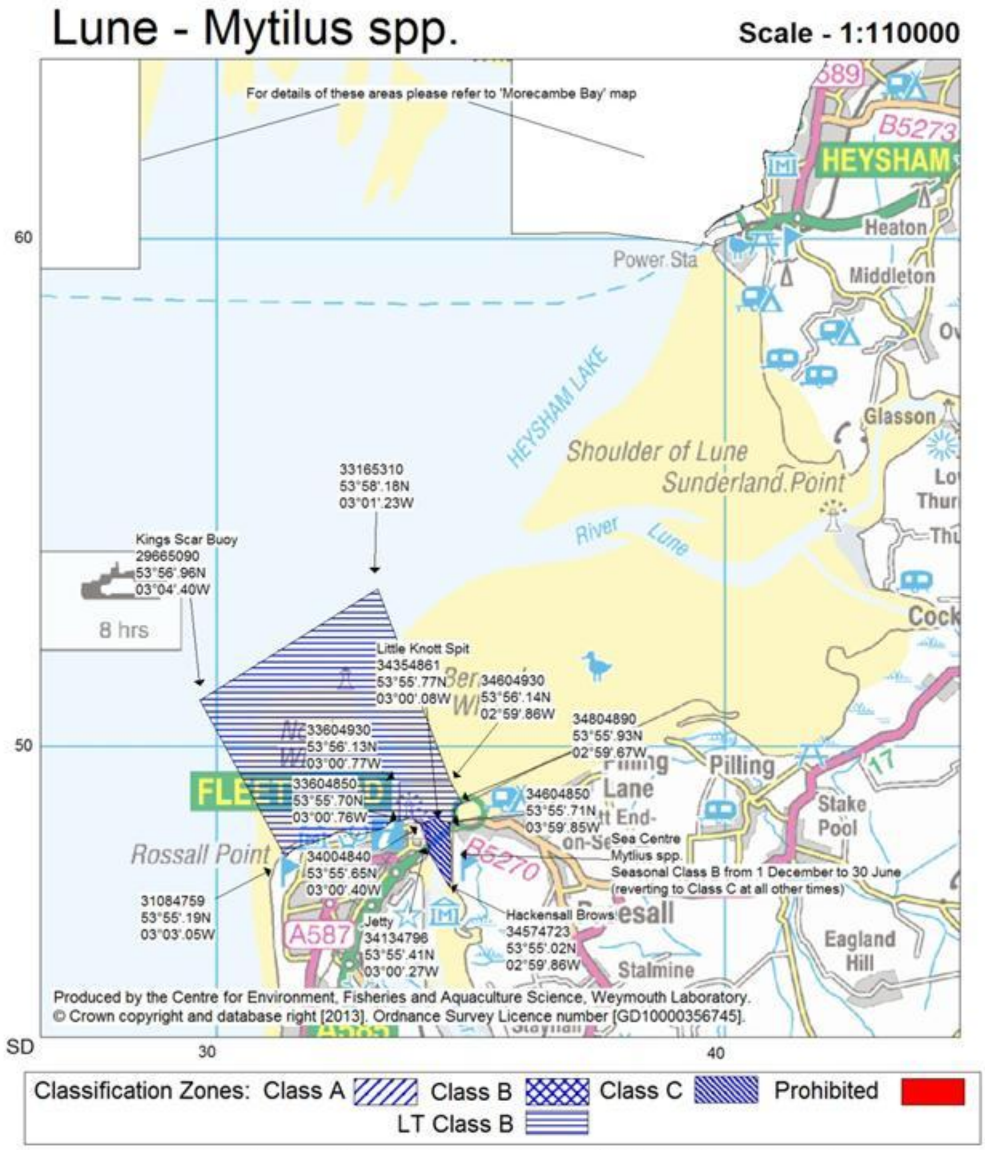
The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

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. at Lune

Food Authorities: Lancaster City Council (Sunderland Bank, Middleton Sands & Cockerham Sands)
Wyre Borough Council (Marine Beach, Pilling Sands)

Figure 4.2: Current cockle classifications



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(Tel: 01305 206600 Fax: 01305 206601)

N.B. Lat/Longs quoted are WGS84
Separate map available for C. edule at Lune

Food Authorities: Lancaster City Council (Plover Scar)
Wyre Borough Council (Knott Spit, Wyre End Scar, North Wharf, Perch Scar King Scar and Sea Centre)

Figure 4.3: Current mussel classifications

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

Historically, commercial density settlements of cockles have occurred on three main discrete beds; Middleton, Lune Island and Pilling Sands. They have also occurred on a much smaller area just to the west of the mouth of the Wyre estuary. Sporadically, dense settlements occur in these areas which attract a particularly high level of commercial harvesting. The last major cockle fishery in the Morecambe Bay area occurred in 2007-8, but all cockle beds in the Morecambe Bay area have been closed since this time due to low stock levels. A sampling plan will be required to cover all of these potential resources so it can be applied when the next significant fishery arises. Although commercial concentrations, when they do arise, tend to occur in broadly similar places their exact distribution may vary significantly. A degree of flexibility in RMP location will therefore be required to ensure they are located in positions which are suitably protective of public health but also have sufficient stocks for sampling. There is a closed season for cockles in the district which runs from the 1st May to the 31st August. It will therefore not be strictly necessary to sample the months of May and June, assuming all other 10 months of the year are sampled.

There are also significant mussel resources in the area. These are mainly located on the rocky skears to the north of Fleetwood, but they do extend into the outer reaches of the Wyre estuary. Although these do hold significant stocks, recent harvesting activity in the Morecambe Bay area has focussed on beds at Foulney, some distance to the north of the area considered in this survey. There has also historically been a mussel bed at Plover Scar, just south of the mouth of the Lune estuary, and although this currently holds little stock it could regenerate in the future. It is therefore concluded that sampling plans will be required to cover all of these beds, and should be applied or otherwise on the advice of the IFCA. Mussel settlements are limited to these hard substrates and therefore only occur in these areas, so less flexibility in RMP location is needed for this species. Harvest of mussels may occur at any time of the year, so any classification sampling should occur monthly and on a year round basis.

Cockles and mussels accumulate *E. coli* to similar levels, but a tendency for cockles to return more extreme high results has been noted (Younger & Reese, 2011). As such, the use of cockle monitoring results to classify mussels may be justified on public health protection grounds. However, the borderline class B compliance in the area around the Wyre estuary mouth would preclude this approach here as it may potentially result in an unfairly poor classification for mussels. Also, the geographical distribution of the two species is very different throughout, with cockles typically lying further away from the main estuary drainage channels. As such, the use of surrogate species to reduce the monitoring burden is not considered appropriate within this survey area.

5.3. Pollution Sources

Freshwater Inputs

All rivers and streams 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 two main freshwater inputs to the survey area are the Lune and the Wyre. The Lune has a drainage catchment of about 1,300 km^2 and is a high gradient spate river. The Wyre drains an area of about 300 km^2 which is generally low lying. Both receive contamination from agricultural runoff as well as several sewage works. The Lune has a mean daily discharge of 38 m^3/s, whereas the Wyre has a mean daily discharge of about 7.4 m^3/s. For both the high flow rate (Q_{10}) exceeds the base flow rate (Q_{95}) by a factor of about 25, indicating there is a large amount of variation in discharge. Both rivers pass through enclosed estuaries before reaching the main shellfish concentrations, although there are some mussel stocks in the outer reaches of the Wyre estuary. As such there will be significant dilution before contamination carried by these rivers reaches the shellfisheries, but both are anticipated to deliver variable and potentially very large bacterial loadings to coastal waters within the survey area. As such the plumes from them are likely to have wide ranging influence, particularly that from the Lune. Their impacts will be most acute in and around the drainage channels they follow across the sand flats.

There are several other smaller freshwater inputs to the survey area which may nevertheless cause significant hotspots of contamination at times. The most significant of these are probably the River Cocker and several other surface water outfalls to the Cockerham Marshes. Between Cockerham and Pilling there are two main surface water outfalls (Broadfleet and Mill House). Shoreline survey observations suggest they discharge significant volumes (although they were not measured) and generally carry quite high concentrations of faecal indicator bacteria, presumably of largely agricultural origin, particularly the outfalls in the vicinity of the Cockerham Marshes. There is also a pumped surface water outfall at Preesall. RMPs located where their drainage channels cut through any cockle beds would best capture contamination from these watercourses.

Flow gauging records indicate a strong seasonality in discharge rates with river flows highest in the colder months. Whether this translates to an overall seasonal variation in the bacterial loadings delivered by these rivers is uncertain. Although the largest flood events tended to occur in the autumn and winter, high flow events were recorded in most if not all months of the year.

Human Population

The total resident population within the Lune catchment area was approximately 334,000 at the time of the last census (2011). The main population centres are, Morecambe and Lancaster located around the mouth of the Rivers Lune and Blackpool and Fleetwood around the mouth of the River Wyre. The highest population density that is directly adjacent to the shellfisheries is Fleetwood and this area will be at the most risk from contaminated urban runoff. Impacts from sewage will depend on the nature and locations of discharges associated with these settlements.

Approximately 44% of the catchment lies within either the Lake District or Yorkshire Dales national parks or the Bowland Forest Area of Outstanding Natural Beauty. This explains the relatively low population densities in much of the catchment, up to 100 persons per km^2. However this number is likely to increase during the summer months when tourists visit these areas for outdoor activities such as walking or cycling. Therefore it can be assumed that there will be a significant seasonal variation of population levels in the catchment and bacterial loadings from sewage treatment works serving the area would be expected to fluctuate accordingly.

Sewage Discharges

There are several major sewage works discharging to tidal waters in and around the survey area. The largest of these is the Fleetwood Marsh STW, which provides secondary treatment for a consented dry weather flow of 62,000 m^3/day. It discharges via a long sea outfall, about 5 km WNW of Rossall Point, to the southern edge of the Lune Deep, in about 6m of water. This works is likely to deliver a large bacterial loading, estimated at around $2x10^{14}$ faecal coliforms/day. As such, it is likely to impact over a wide area. The geographical profile of these impacts will depend on water circulation patterns in the area.

There are two further major sewage works discharging to coastal waters here. Lancaster STW discharges to the enclosed Lune estuary, about 5 km from its mouth. It provides UV disinfection for a consented dry weather flow of 35,210 m^3/day. Final effluent testing data indicates that the disinfection is generally very effective, although occasionally the concentration of faecal coliforms in the effluent is up to two orders of magnitude higher than the average. The average bacterial loading this works delivers is minor, at about $4x10^{10}$ faecal coliforms/day. As such it will make a small and generally insignificant contribution to levels of faecal indicator bacteria in the plume emanating from the mouth of the Lune estuary. Morecambe STW discharges to the shallow subtidal just off Middleton Sands. This works also provides UV disinfection and has a consented dry weather flow of 13,820 m^3/day. Again, effluent testing data indicates that the disinfection step is usually very effective, although occasionally elevated concentrations of indicator bacteria were found. Given the average bacterial loading it delivers is also around $4x10^{10}$ faecal coliforms/day, it will also generally be of only very localised significance.

There is another sewage works discharging direct to the Lades Marsh on the north shore of the outer reaches of the Lune estuary (Middleton/Overton STW). This is a mid- sized secondary works which generates an estimated bacterial loading of about $5x10^{12}$ faecal coliforms/day. This will make a contribution to the bacterial loading delivered to the survey area by the ebb plume from this estuary. The Wyre estuary receives effluent from the Preesall STW, a mid-sized works which provides UV treatment and discharges to the east bank of the outer estuary about 500m south of a mussel bed. Whilst it only delivers an average bacterial loading of $3x10^{10}$ faecal coliforms/day, it may be of some impact on this mussel bed, particularly on occasions when the treatment is working less effectively than normal.

The more rural inland areas of the catchment are served by a series of relatively small sewage works which discharge to watercourses. The total volume discharged is >8000 m^3/day and most works provide secondary treatment. Most discharge to the Wyre or Lune river catchments, so will contribute to the bacterial loadings carried by these watercourses to some extent.

The River Cocker receives effluent from Cockerham STW, a small secondary treated works located at its tidal limit and this will contribute to the bacterial loading delivered by this watercourse. There was no consented flow rate specified in the database for this discharge. The Broad Fleet receives effluent from Pilling STW, a small works providing UV disinfection. The average loading it generates is only about $2x10^9$ faecal coliforms/day and as such its impacts will be negligible.

In addition to the continuous sewage discharges, there are a large number of intermittent water company discharges associated with the sewerage networks (85 within a 2 km radius of the survey area). The vast majority are clustered around the Wyre and Lune estuaries, so it is assumed that these are impacted to the greatest extent. Only a small proportion of the intermittent discharges have spill records, which extend back between one and four years. Records for the 2012-13 reporting period are most complete, so comparisons of spill frequencies are drawn from data covering this period. These indicate that three of the 17 monitored discharges spilled for between 5 and 10% of the time, all three discharge to the Lune estuary upstream of the shellfisheries. A further five discharges for between 1 and 5% of the time of which two discharge to the Lune estuary, two to the Wyre estuary, and one to the subtidal about 1km west of Rosall Point. The other monitored discharges spilled for less than 1% of the time. For those with no event monitoring it is difficult to assess their significance apart from noting their location and their potential to spill significant volumes of untreated sewage.

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 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.

Although the vast majority of the survey area is served by water company sewerage infrastructure, there are also a number of private sewage discharges. Where specified, these are generally treated by small treatment works such as package plants. The majority of these are small, serving one or a small number of properties. Of the 99 private discharges that lie within 2 km of the estuary, 91 discharge to water and 8 to ground via soakaway. Most of those within 2 km of the estuary lie on the eastern shore of the Lune or are clustered upstream in the River Wyre, around Hambleton, Singleton and other villages.

Agriculture

The majority of land within the hydrological catchment is used for agriculture. Most are pastures, although there are many smaller pockets where crops are cultivated in the Wyre catchment. A total of 126,715 cattle and 510,799 sheep were recorded within the catchment area in the 2010 agricultural census, so significant and widespread impacts from grazing animals are anticipated. Faecal matter from grazing livestock is either deposited directly on pastures, or collected from livestock sheds if animals are housed indoors during the colder months and then applied to agricultural lands as a fertilizer. Some poultry and pigs are also farmed in the catchment. Manure from these is typically stored and applied tactically to nearby farmland.

The majority of the agricultural land lies within parts of the catchment drained by the Lune and the Wyre, so impacts will primarily be felt via the ebb plume from these estuaries and RMPs should be located in areas most affected by these plumes.

Most other watercourses will be affected to some extent. High concentrations of grazing animals were seen during the shoreline survey between the mouth of the Lune and Pilling. These were not only on fenced fields, but also on the saltmarsh on the foreshore.

The primary mechanism for mobilisation of faecal matter from agricultural land is via land runoff, so fluxes of livestock related contamination into the estuary will be highly rainfall dependent. Rainfall and river flows are generally higher during the winter months, although 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 significantly in the spring, with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. The seasonal pattern in application of manures and slurries to agricultural land is uncertain. Cattle may be housed indoors during the winter, so applications of slurry collected from such operations is likely to be spread in the late winter and spring, depending on the storage capacities of each farm.

The saltmarsh at Cockerham is used extensively for grazing sheep. Contamination deposited in the intertidal areas will be carried into the estuary via tidal inundation which is a particularly direct and predictable mechanism, the risk of which is greater during spring tides. Sheep are present for most of the year, and are only removed during the larger spring tides, and for about a month in late winter for lambing.

In summary, the majority of contamination of agricultural origin will be delivered to the survey area via the Lune and to a lesser extent the Wyre estuaries. Therefore, RMPs as close to the estuary mouths (or as far up-estuary) as shellfish stocks extend would best capture contamination of agricultural origin. Other watercourses, namely the Cocker and the Broadfleet and Mill House outfalls are likely to be significantly impacted by agriculture. There are likely to be hotspots associated with drainage channels which smaller watercourses follow across the intertidal areas, notably the Cocker and other outfalls to the Cockerham Marshes, and the Broadfleet and Mill House outfalls in the Pilling area. Tidal inundation of the Cockerham Marshes is likely to result in significant fluxes of sheep faeces directly into adjacent coastal waters.

Boats

The survey area is used by a variety of craft in transit to and from the Lune and Wyre estuaries. This includes commercial shipping, fishing vessels, and recreational craft of various sizes. Both the Lune and the Wyre estuaries support a small commercial port each, a marina each, and areas of boat moorings in their outer reaches. Between the two marinas there are around 640 berths, and only the Glasson Basin Marina in the Lune has sewage pumpout facilities. The RYA describe the routes to these two estuaries as receiving 'medium recreational use'. A fleet of around 30 fishing vessels operate out of Fleetwood on the Wyre, which is also used by vessels associated with wind farms in the Irish Sea. Commercial shipping from the Wyre consists of twice daily ferry sailings to Northern Ireland. The Port of Glasson handles grain imports and cargo shipping to and from the Isle of Mann and the Western Isles.

Commercial shipping is not permitted to discharge to inshore waters so should be of little or no impact, although it is possible that they make discharges in the Lune Deeps. It is likely that the larger of the private vessels (yachts, cabin cruisers, fishing vessels and possibly wind farm traffic) which have onboard toilets make overboard discharges from time to time. This may occur whilst boats are on passage, and it is quite likely that any boats in overnight occupation on the moorings will make a discharge at some point during their stay. On this basis, the outer reaches of the two estuaries, and navigation routes to and from the ports and marinas are likely to be most at risk. There will be higher volumes of recreational craft during the summer, but other vessel types will operate all year round. However, it is difficult to be more specific without any firm information about the locations, timings and volumes of such discharges, and as such boating will have little material bearing on the sampling plan.

Wildlife

The Lune estuary features a variety of different estuarine habitats including intertidal sand and mud flats, salt marshes, reefs, and sand/shingle banks. These features attract significant populations of waterbirds (waders and wildfowl) with the Lune estuary supporting around 13,000 overwintering birds the Wyre estuary supporting around 6,000. Pink footed geese frequent the Pilling Marsh during the winter months, with numbers reportedly reaching over 30,000 at peak times.

Some species of waders feed on intertidal invertebrates so will forage (and defecate) directly on the shellfish beds across a wide area. They may tend to aggregate in certain areas holding the highest densities of their preferred size and species of prey, but this may vary from year to year. They will therefore represent a diffuse input and whilst they may be a significant contaminating influence at times, they will not influence the positioning of any RMPs. Other overwintering waterbirds such as grazing geese will mainly frequent the saltmarsh and pastures, where their faeces will be carried into coastal waters via runoff into tidal creeks or through tidal inundation. RMPs positioned in or by creeks and channels draining from such areas would be best positioned to capture contamination from these. Given the large numbers of geese which aggregate on the Pilling Marshes, creeks draining this area may be quite heavily impacted at times.

Although the majority of waterbirds migrate elsewhere to breed, other species such as gulls and terns are present during the summer months. Relatively small numbers of gulls use the area to breed. They are likely to forage around the estuary so represent a minor source of diffuse contamination, but this will not influence the sampling plan.

There are no seal colonies in the vicinity of the survey area, so whilst the occasional seal may visit the area this will have no influence on the sampling plan. No other wildlife population which may affect shellfish hygiene within the survey area have been identified.

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. 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
Agricultural runoff												
Urban runoff												
Continuous sewage discharges												
Intermittent sewage discharges												
Birds												
Boats												

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

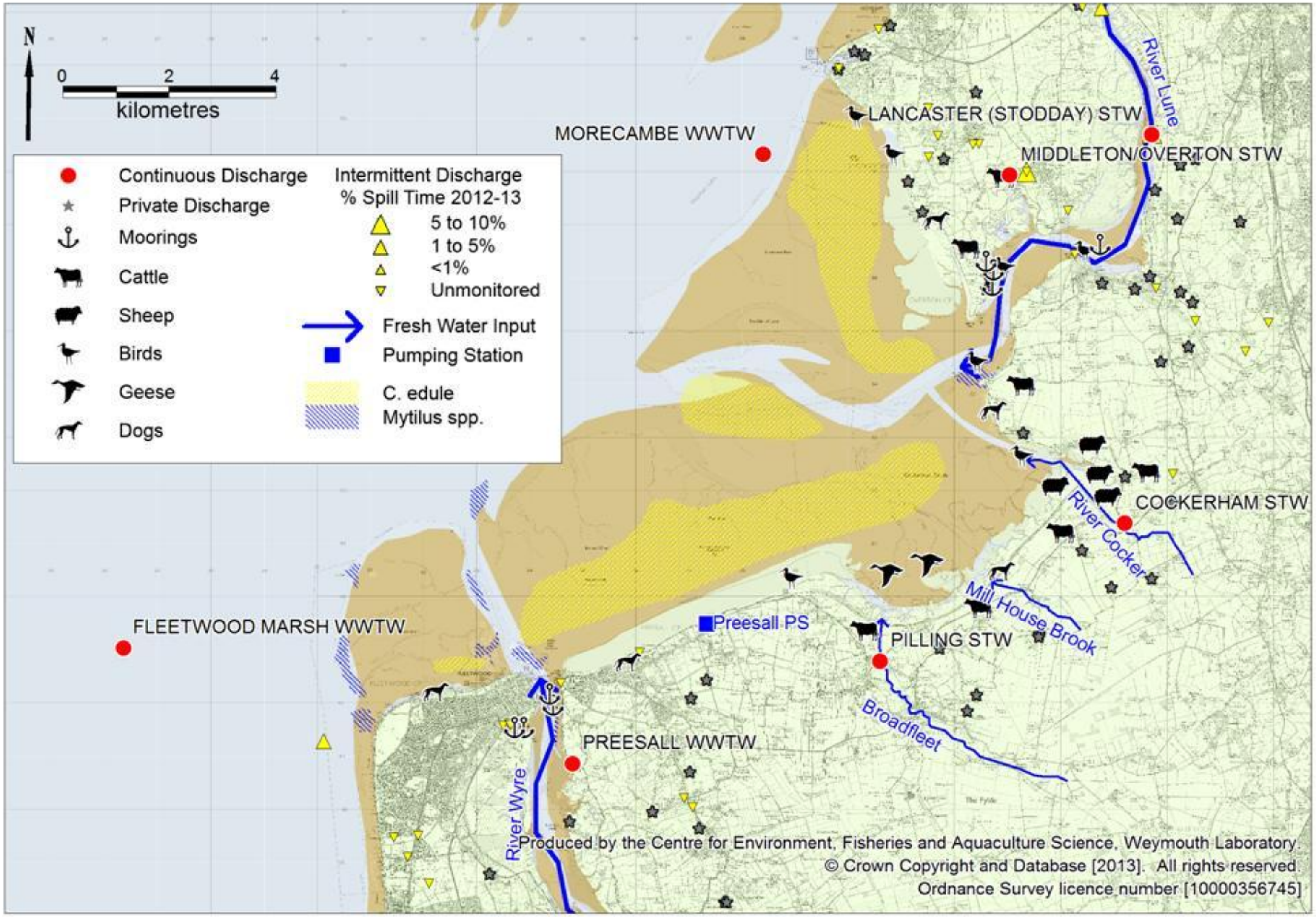


Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The survey area is an open and largely intertidal embayment at the southern end of Morecambe Bay, to which the estuaries of two significant rivers drain. It consists of a large area of intertidal sand flats, through which the two subtidal estuary approach channels cut. There are also a number of smaller intertidal drainage channels across the flats, some of which carry minor freshwater inputs. A large proportion of water is exchanged each tide, but the dilution potential will be relatively low. Concentrations of faecal indicator bacteria are likely to be highest in the estuary approach channels and the intertidal drainage channels around low water. At the outer edge of the survey area, depths drop away rapidly into the Lune Deep. The Lune and Wyre estuaries are enclosed, relatively narrow, and characterised by a meandering river channels flanked by intertidal areas. As they are enclosed, and receive significant sources of contamination including significant rivers draining to their heads, they will contain higher concentrations of faecal indicator bacteria then the open embayment to which they drain. As such the plumes emanating from the estuary mouths will be major contaminating influences within the embayment. Within the estuaries, a gradient of increasing levels of runoff borne contamination towards their heads are anticipated. There are slight constrictions at their mouths, which may accelerate flows and induce some vertical mixing of the water column.

Water circulation in the area will largely be driven by tides. Tidal range is large, at around 8.2 m on spring tides and 4.2 m on neap tides. The only tidal diamonds are located in the Lune Deep, and these indicate a bidirectional circulation, with water moving up this channel and into Morecambe Bay on the flood, with the reverse occurring on the ebb. Estimates of tidal excursion along this channel vary from about 11-15 km on spring tides, and about 5-10 km on neap tides. Within the embayment, the early flood tide progresses from the Lune Deep up the estuary approach channels and into the estuaries. As the intertidal areas become covered, flows progress across the intertidal in an easterly direction, so they start to run primarily across the Wyre approach channel rather than along it. Across the shallower areas, current speeds will be lower. Flood streams across Pilling Sands will be in an easterly direction. It is likely that flood streams across Middleton Sands originate from the Lune Deep and generally progress in an easterly direction across the flats. The reverse will occur on the ebb. The plume from the Wyre estuary will therefore impact across the intertidal area to the north of Fleetwood, and along its approach channel. The ebb plume from the Lune estuary will primarily impact within and adjacent to its approach channel. The Fleetwood Marsh STW discharges via long sea outfall to the inshore edge of the Lune Deep in about 6m of water, about 5 km WNW of Rossall Point. Contamination from this discharge will be carried up the Lune Deep on the flood tide, and as the plume spreads it will impact along the edge of the intertidal and may progress some way up the estuary approach channels before the tide reverses. The discharge is over 4km from the nearest shellfish resource (Kings Scar mussel bed). Significant dilution and dispersion will occur in the Lune Deep before it impacts on the shellfishery, though tidal streams will carry the plume directly towards this mussel bed. Contamination from shoreline sources discharging direct to the embayment will follow drainage channels until it meets tidal waters, after which it will tend to be carried east on the flood, and west on the ebb. It will be most concentrated within these drainage channels when they are not covered by the tide.

Freshwater may modify water circulation via density effects. Such effects, if they do arise, are likely to be confined to the enclosed river estuaries, and will result in a net seaward movement in the upper water column, with a corresponding return of more saline waters at depth. Strong correlations were found between salinity and the concentrations of faecal indicator bacteria in the water column for all bathing waters and shellfish waters monitoring points in the area. This suggests that salinity is a useful indicator of levels of runoff borne contamination. The spatial profile of salinities across five monitoring points within the embayment showed little variation, with all points showing an average salinity of just under that of full strength seawater, even for locations in close proximity to the estuary mouths. It must be noted however that these samples were taken around high water, when the extent of the influence of these estuary plumes is lowest. Within the enclosed estuaries there is likely to be a gradient of decreasing salinity towards the upper reaches, although there were no measurements available to substantiate this. One density effect of potential relevance is the tendency for plumes from sewage outfalls to rise to the surface as they are less dense than the receiving seawater. This may increase its propensity to spread across the intertidal flats, and will also allow wind effects to significantly modify the path the plume follows.

Strong winds will modify surface currents by driving surface water currents, which will in turn drive return currents at depth or along sheltered margins. The embayment is most exposed to the west. The prevailing south westerly winds will tend to push surface water in a north easterly direction. North westerly winds may advect the plume from Fleetwood Marsh STW towards and across the intertidal flats where the shellfisheries are located. Exact effects of wind are dependent on its 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 re suspended.

5.5. Summary of Existing Microbiological Data

The Lune estuary 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. The last major sewage treatment upgrades occurred in 2002, so data from 2003 onwards is considered in this assessment.

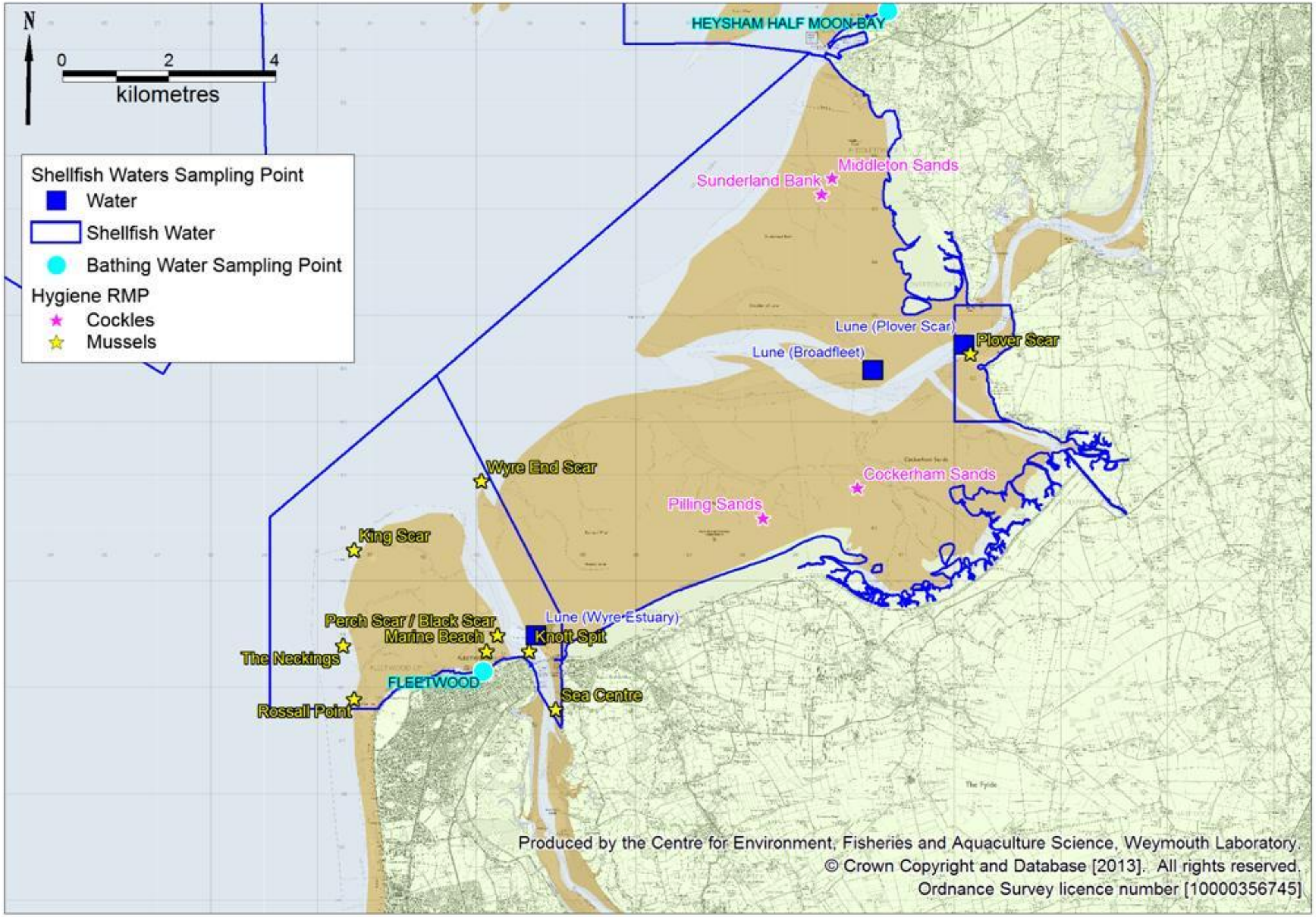


Figure 5.2: Microbiological sampling sites

Bathing Waters

Two sites were monitored under the Bathing Waters monitoring programme. Around twenty water samples were taken from each of these monitoring points during each bathing season (May to September) between 2003 and 2011 and were enumerated for faecal coliforms. Average results were quite high at both, but were significantly higher at Half Moon Bay compared to Fleetwood Beach (geometric means of 117.2 and 68.0 faecal coliforms/100ml respectively. A comparison of paired (same day) samples indicated a strong correlation between results from the two sites, despite the distance between them. This suggests that they are influenced by sources which respond to environmental variables such as rainfall in a similar way. Since 2003, results from both have been similar on average, perhaps with a slight increase in faecal coliform concentrations at Fleetwood Beach during 2007/8. A significant but weak correlation between tidal state on the high/low cycle was found for Fleetwood Beach, but no strong pattern was apparent when this data was plotted. At Half Moon Bay, a significant influence of the spring/neap tidal cycle was detected, and faecal coliform concentrations tended to be higher on average just before and during spring tides. A rapid and strong influence of recent rainfall was apparent at both sites. This was stronger at Fleetwood Beach, likely due to its proximity to the mouth of the Wyre estuary. Similarly, strong negative correlations between faecal coliform concentrations and salinity were found at both, suggesting that land runoff is an important contaminating influence.

Shellfish Waters

The survey area includes three shellfish waters, where water samples are taken on a quarterly basis and enumerated for faecal coliforms. Two of these monitoring points lie in close proximity to the Lune approach channel (Plover Scar and Broadfleet) and the third lies just outside the mouth of the Wyre estuary (Number 16 Buoy). The average result was highest at Number 16 Buoy (46.7 faecal coliforms/100ml) and was almost identical at Plover Scar and Broadfleet (22.0 and 21.5 faecal coliforms/100ml). Between these two latter sites the highest peak result was recorded at Plover Scar. Overall the results for Broadfleet and Plover Scar did not show a particularly strong gradient in levels of contamination across the 1.8 km between them. A comparison of paired (same day) samples indicated a very strong correlation between results from these two sites, as may be expected. There was insufficient paired data to make any comparisons between these two sites and Number 16 Buoy.

Since 2003, a slight increase in average and peak faecal coliform concentrations was seen across all three locations. All three exhibited significant seasonal variation, and average results were significantly higher in the autumn compared to the spring in all cases. The only significant tidal influence detected was at Number

16 Buoy, in relation to the high/low tidal cycle. Although sampling was strongly targeted towards the high water period, results were much higher on average once the tide had turned suggesting contamination from the Wyre estuary is a major influence here. Rainfall had a significant effect on faecal coliform levels at all three sites. At Number 16 Buoy, rainfall increased faecal coliform levels within 24 hours, but rainfall that occurred more than 3 days before sampling had no influence on faecal coliform levels. This difference may be explained by Plover Scar and Broadfleet being under the influence of the Lune estuary, whilst the Number 16 Buoy is under the influence of the Wyre estuary. Strong negative correlations between salinity and faecal coliform concentrations were found at all three, indicating that land runoff is an important contaminating influence.

Shellfish Hygiene Classification Monitoring

Since 2003, a total of five cockle and seven mussel RMPs have been sampled under the shellfish hygiene classification monitoring programme. Two of the mussel RMPs (Perch Scar and Marine Beach) were sampled on two or less occasions so were not used in the statistical analyses.

Across the five cockle RMPs, there was no significant difference in average result. The proportion of results exceeding 4600 *E. coli* MPN/100g did vary across the five RMPs, from 0% at Cockerham Sands up to 12.1% at Pilling Sands. Some caution should be applied when directly comparing all five cockle RMPs as they were not all sampled throughout the same period and as such results from some are not directly comparable with results from others. Middleton Sands and Pilling Sands were sampled from 2005 through to 2013. Pilling Sands had a higher average result than Middleton Sands (geometric means of 560 and 351 *E. coli* MPN/100g respectively) but had a lower proportion of samples exceeding 4600 *E. coli* MPN/100g (3.8 and 12.1% respectively). Sunderland Bank, Cockerham Sands and Marine Beach were sampled between 2003 and 2005/6. The geometric mean *E. coli* results were 385, 202 and 467 *E. coli* MPN/100g respectively, and the proportions of results exceeding 4600 *E. coli* MPN/100g were 5.3%, 0% and 8.7%. The one recorded prohibited level result was from Marine Beach. Relatively high results may be anticipated at Marine Beach, due to its close proximity to the mouth of the Wyre estuary. The reasons for the observed spatial variation across the other sites, which was relatively minor in terms of average result, but potentially significant in terms of classification thresholds is unclear. It may possibly be linked to the RMP locations in relation to the positions of drainage channels carrying contamination from shoreline sources.

Across the five mussel RMPs sampled on more than two occasions the geometric mean result was lowest at Wyre and Scar and Rossall Point (311 and 452 *E. coli* MPN/100g). It was highest at the two sites around/within the mouth of the Wyre estuary (Knott Spit and Sea Centre, 712 and 953 *E. coli* MPN/100g). The average result a Plover Scar was 596 *E. coli* MPN/100g. For the latter three RMPs the proportion of results exceeding 4600 *E. coli* MPN/100g was just over 10%, indicating that within and in the immediate vicinity of the estuary mouths, results are more likely to align with a C classification. No results exceeding 4600 *E. coli* MPN/100g were recorded at Wyre End Scar, but occasional high results, including one prohibited level result, were recorded at Rossall Point. It is possible that these high results may be related to intermittent sewage overflow discharges here. Correlations of paired (same day) samples from the four mussel RMPs around the mouth of the Wyre suggest that all four are subject to similar contaminating influences.

Since 2003, the overall temporal trends varied between RMPs, but overall there appears to have been a slight increase in *E. coli* levels in recent years. No significant seasonal variation was detected at any of the cockle RMPs, but there was a general tendency for higher results in the summer and autumn, with the exception of Cockerham Sands where *E. coli* levels were similar throughout the year. This suggests Cockerham Sands may be subject to slightly different contaminating influences. Three of the mussel RMPs showed significant seasonal variation, with a tendency for higher results during the summer and autumn. There was no significant seasonality at Rossall Point or Wyre End Scar. This suggests that these latter two RMPs, which lie farther from the estuary mouths, may be subject to a different profile of contamination sources.

Statistically significant correlations between *E. coli* levels and tidal states were found for the Knott Spit mussel RMP, across both the high/low and spring/neap tidal cycles. These correlations were weak, but some patterns were apparent when the data was plotted. Across the high/low cycle, there was a tendency for higher results during the late ebb compared to the early flood. Across the spring/neap cycle there was a tendency for lower results as the tide size increased from neap to springs. Neither of these patterns were particularly marked. All RMPs showed some influence of recent rainfall. The degree of influence was broadly similar across the five cockle RMPs. Across the mussel RMPs, three showed a strong and consistent influence of rainfall (Plover Scar, Sea Centre and Knott Spit) whereas at the other two, which are much more distant from the main estuary mouths, the influence of rainfall was much weaker (Wyre End Scar and Rossall Point).

Appendices

Appendix I. Human Population

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

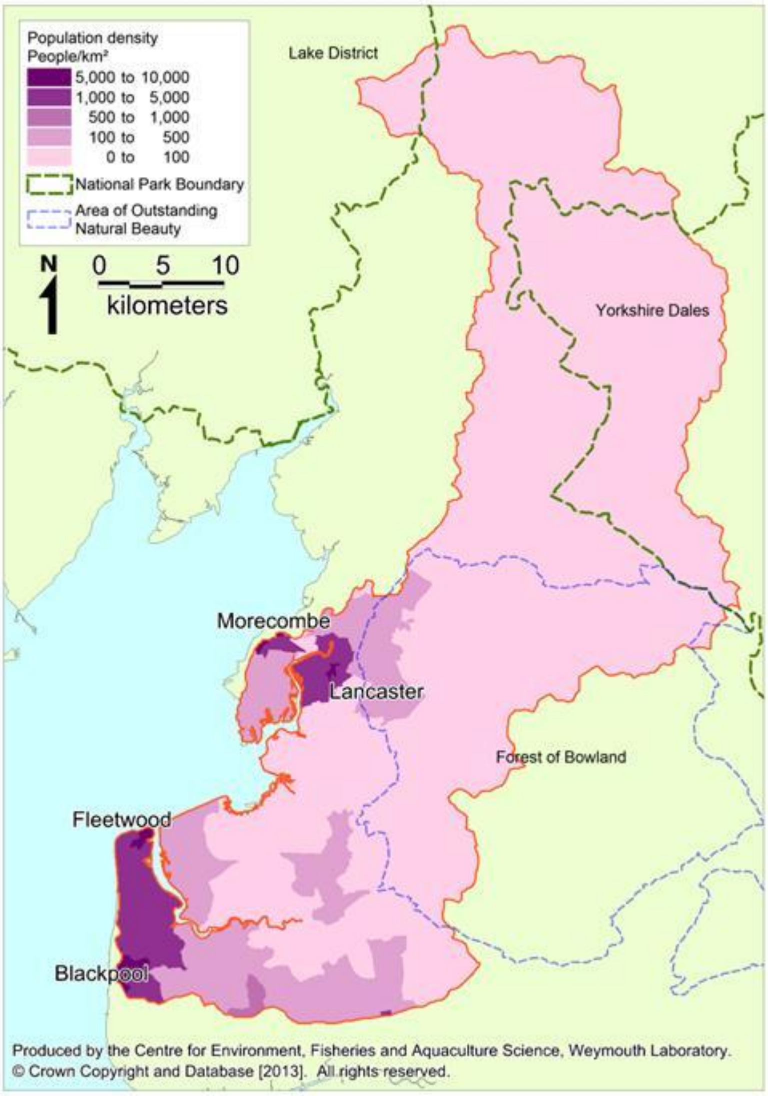


Figure I.1: Human population density in census areas in the Lune catchment.

Total resident population within the Lune catchment area was approximately 334,000 at the time of the last census. **Error! Reference source not found.** indicates that population densities are highest around the mouths of the Rivers Lune (Morecombe and Lancaster) and Wyre (Blackpool and Fleetwood). In parts of Lancaster and Blackpool population densities exceed 8,000 people/km². Fleetwood, which lies immediately adjacent to some shellfish resources also has high population densities of up to 5,200 people/km². These areas are therefore at the most risk from contaminated urban runoff. Impacts from sewage will depend on the nature and locations of discharges associated with these settlements and are discussed in detail in Appendix VII.

Approximately 44% of the catchment lies within either the Lake District or Yorkshire Dales national parks or the Bowland Forest Area of Outstanding Natural Beauty. Here population densities are low, not exceeding 100 persons per km^2.

The Lune catchment lies within three counties, Lancashire, North Yorkshire and Cumbria. In 2011 there were approximately 60 million visitors to Lancashire, with approximately 7.8 million visiting Blackpool (Marketing Lancashire, 2013). The majority of these tourists will have visited Blackpool during the summer months, and so will contribute to a significant increase in volumes of sewage received by sewage works serving this area during the holiday season. The Lake District, Yorkshire Dales and Bowland Forest also attract tourists, but not at the densities that the coastal resorts do.

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

Details of all water company owned sewage treatment works in the hydrological catchment and two discharging to nearby coastal waters were taken from the most recent update of the Environment Agency national permit database (March 2013). These are mapped in Figure II.1, and details are presented in Table II.1.

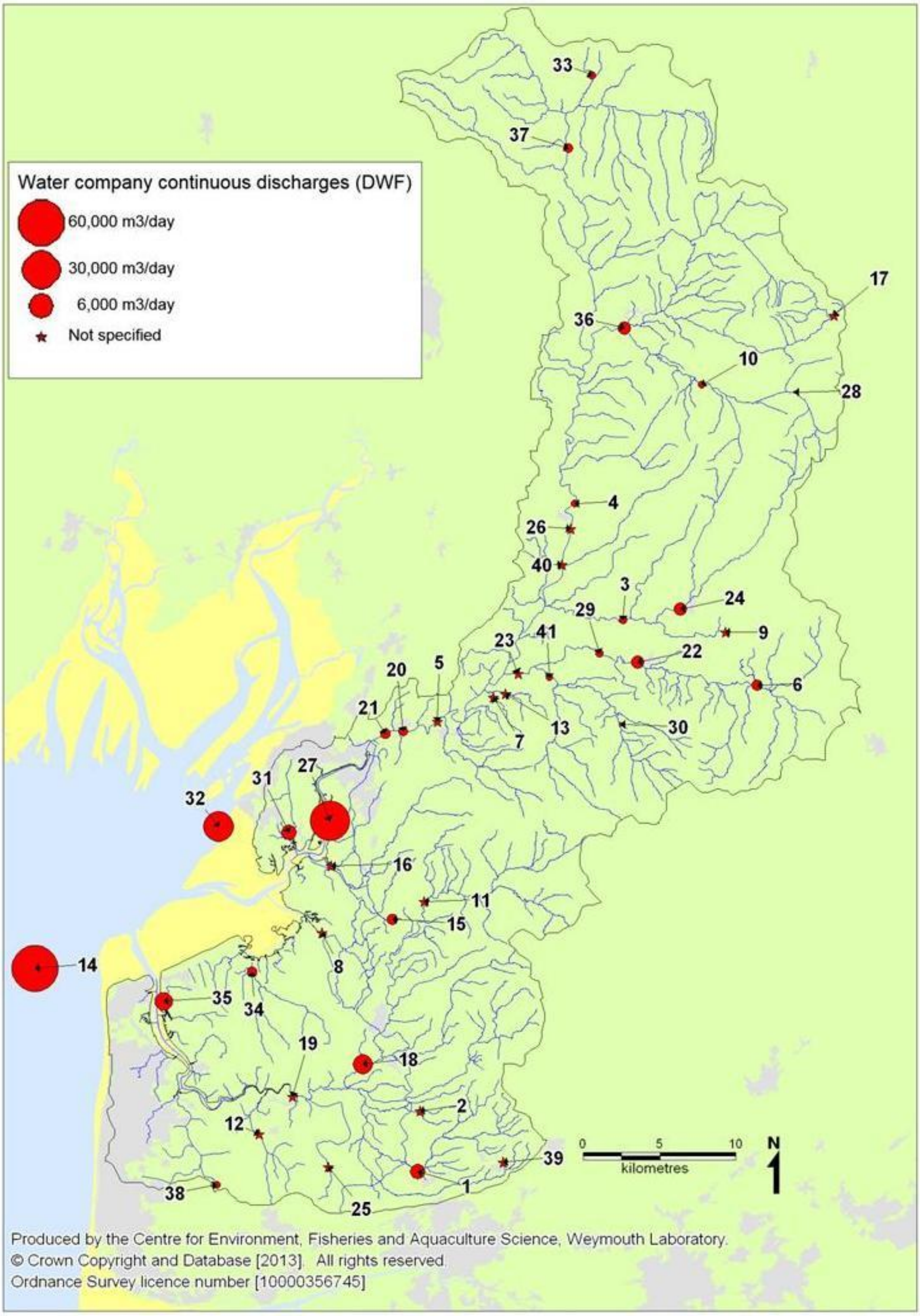


Figure II.1 Sewage discharges to the Lune catchment and nearby coastal waters

Table II.1: 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	Barton STW	SD5148035710	Biological filtration	1357	4.48×10^{12}	Barton Brook
2	Bilsbarrow STW	SD5160039680	Biological filtration	2	6.6×10^{9}	Bacchus Brook
3	Burton-in-Londsdale STW	SD6495071920	Biological filtration	190	6.27×10^{11}	River Greta
4	Casterton STW	SD6175079560	Biological filtration	80	2.64×10^{11}	River Lune
5	Caton STW	SD5277065250	Biological filtration	Unknown	Unknown	River Lune
6	Clapham STW	SD7372967616	Tertiary (Biological)	393	1.30×10^{12}	River Wenning
7	Claughton STW	SD5644066820	Biological filtration	Unknown	Unknown	Claughton Beck
8	Cockerham STW	SD4520051400	Biological filtration	Unknown	Unknown	Cocker Estuary
9	Cold Cotes STW	SD7165071100	Unspecified	Unknown	Unknown	Aspland Beck
10	Dent STW	SD7010087350	Biological filtration	84	2.77×10^{11}	River Dee trib.
11	Dolphinholme STW	SD5187053420	Biological filtration	Unknown	Unknown	River Wyre
12	Elswick STW	SD4105038170	Biological filtration	Unknown	Unknown	Thistleton Brook
13	Farleton STW	SD5723067080	Biological filtration	Unknown	Unknown	Farleton Beck
14	Fleetwood Marsh STW	SD2636049050	Biological filtration	62000	2.05×10^{14}	Irish Sea (Lune Deep)
15	Forton STW	SD4982052250	Sand filtration	390	1.29×10^{12}	Potters Brook
16	Galgate Outfall	SD4578055790	Unspecified	Unknown	Unknown	River Conder
17	Garsdal Head STW	SD7877091920	Biological filtration	Unknown	Unknown	Mud Beck Gill
18	Garstang STW	SD4788042750	UV disinfection	3550	1.17×10^{13}	River Wyre
19	Great Ecclestone SPS	SD4325040650	Biological filtration	Unknown	Unknown	Wyre Estuary
20	Halton East STW	SD5053064610	Biological filtration	203	6.70×10^{11}	River Lune
21	Halton West Lune STW	SD4933564438	Biological filtration	330	1.10×10^{12}	River Lune
22	Higher Bentham	SD6589069140	Biological filtration	840	2.77×10^{12}	River Wenning
23	Hornby STW	SD5805068390	Biological filtration	Unknown	Unknown	River Wenning
24	Ingleton STW	SD6868072620	Biological filtration	858	2.83×10^{12}	River Greta
25	Inskip STW	SD4559036020	Biological filtration	Unknown	Unknown	Lords Brook
26	Kirby Lonsdale STW	SD6152077880	Biological filtration	Unknown	Unknown	River Lune
27	Lancaster (Stodday) STW	SD4571058720	UV disinfection	35210	3.73×10^{10}**	Lune Estuary
28	Lea Yeat STW	SD7618086880	Package plant	7.95	2.62×10^{10}	Soakaway

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)	Receiving environment
29	Low Bentham STW	SD6339069720	Biological filtration	186	6.14 $x10^{11}$	River Wenning
30	Lowgill STW	SD6481065040	Biological filtration	12.8	4.22 $x10^{10}$	River Hindburn
31	Middleton/Overton STW	SD4304057960	Oxidation ditch	1359	4.50 $x10^{12}$	Lades Pool
32	Morecambe STW	SD3840058350	UV disinfection	13820	3.66 $x10^{10}$**	Morecambe Bay
33	Orton STW	NY6291007660	Biological filtration	143	4.72 $x10^{11}$	Chapel Beck
34	Pilling STW	SD4060048800	UV disinfection	289	1.66 $x10^{9}$**	Broad Fleet
35	Preesall STW	SD3481046870	UV disinfection	2333	3.47 $x10^{10}$**	Wyre Estuary
36	Sedbergh STW	SD6504091080	Biological filtration	800	2.26 $x10^{12}$	River Rawthey
37	Tebay STW	NY6135002880	Biological filtration	268	8.84 $x10^{11}$	River Lune
38	Weeton STW	SD3828034840	Biological filtration	122	4.03 $x10^{11}$	Main Dyke trib.
39	Whittingham Cottages STW	SD5707036320	Biological filtration	Unknown	Unknown	Blundell Brook trib.
40	Whittington STW	SD6092075560	Biological filtration	Unknown	Unknown	River Lune
41	Wray STW	SD6011068120	Biological filtration	68	2.24 $x10^{11}$	River Hindburn

*Faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs providing secondary treatment (Table II.2). This does not consider effluent testing data from the actual sewage works, so may be inaccurate.

** faecal coliforms (cfu/day) based on geometric mean final effluent testing data (Table II.3).

Data from the Environment Agency

Table II.2: 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	$3.6x10^{2}$

n - number of samples.

Figures in brackets indicate the number of STWs sampled.

Data from Kay et al. (2008b).

Table II.3: Summary statistics for final effluent testing data from UV treated works, January 2007 to March 2012 (faecal coliforms cfu/100ml)

Sewage works	No.	Geometric mean	Minimum	Maximum
Lancaster STW	134	106	1	43,000
Morecambe STW	129	265	1	700,000
Pilling STW	130	576	0	940,000
Preesall STW	136	1488	20	84,000

Data from the Environment Agency

Bacteriological testing results for the final effluents indicate that disinfection is generally effective. The estimated (average) bacterial loading they generate is therefore very small, although the maximum concentration of faecal coliforms recorded is over two 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).

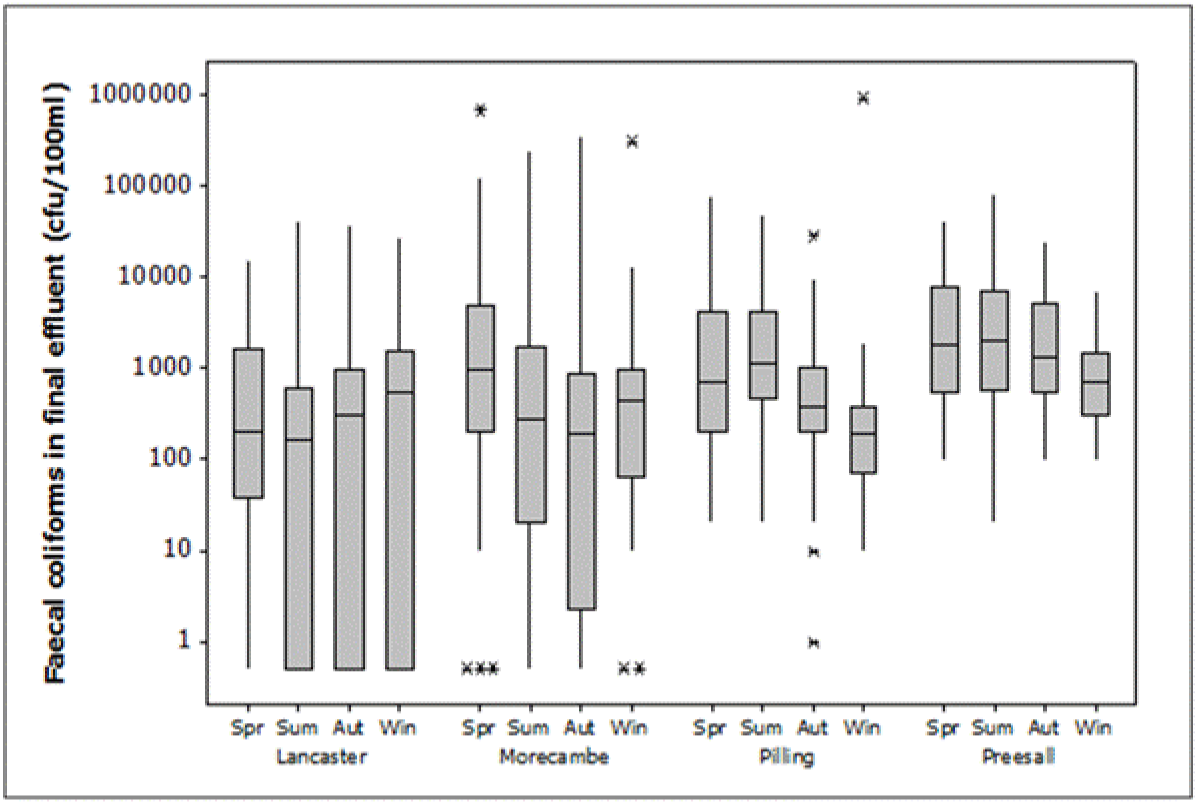


Figure II.2: Boxplot of faecal coliform concentrations in STW final effluent by season.
Data from the Environment Agency.

Some seasonality in faecal coliform concentrations was apparent at all four UV treated sewage works. Both Lancaster STW and Morecambe STW had higher average results in the spring. At Morecambe STW there were also fewer very low results in the winter. At Pilling STW and Preesall STW lower average results arose in the autumn and winter, with slightly higher average results in the spring and summer. This pattern was more marked at Pilling. UV disinfection of the effluent from Garstang STW commenced in March 2013 and as such sufficient efficacy data has not been generated to analyse as yet.

The three largest continuous water company sewage discharges are Lancaster STW, Morecambe STW and Fleetwood Marsh STW. The former two discharges receive UV disinfection and the efficacy and seasonality of this treatment is discussed above. Lancaster STW discharges to the River Lune, approximately 6.4km north east of the nearest shellfishery. Morecambe STW discharges to Morecambe Bay, just off Middleton Sands. Given that these two discharges are tertiary treated only limited, localised impacts are anticipated. Fleetwood Marsh STW has a consented dry weather flow of 62,000 m^3/day and discharges about 5 km WNW of Rossall Point, to the southern edge of the Lune Deep, in about 6 m of water. As it is a very large sewage works providing secondary treatment only the bacterial loading it generates is likely to be very large, so it will impact over a wide area. The spatial pattern of impacts will depend on water circulation patterns in the area.

Preesall STW discharges UV treated effluent to the Wyre estuary about 0.5 km from the nearest mussel shellfisheries (current classification zone). Given its close proximity to shellfisheries and large size Preesall STW will make a limited contribution to microbiological loading locally. Pilling STW is also tertiary treated and discharges to Broad Fleet, approximately 0.75 km from the nearest current classification zone. As with Preesall STW, limited microbiological impact will be associated with this discharge. Garstang STW is located >14 km inland from the coast, is tertiary treated and as such is unlikely to have a significant impact on the shellfisheries.

The more rural inland areas of the catchment are served by a series of relatively small sewage works which discharge to watercourses. The total volume discharged is >8000 m^3/day and most works provide secondary treatment. Most discharge to the Wyre or Lune river catchments, so will contribute to the bacterial loadings carried by these watercourses to some extent. The River Cocker receives effluent from Cockerham STW, a small secondary treated works at its tidal limit.

In addition to the continuous sewage discharges, there are many intermittent discharges associated with the sewerage networks. The locations of those and of private discharges within 2 km of the survey area, including the tidal waters of the Lune and Wyre estuaries are shown in Figure II.3.

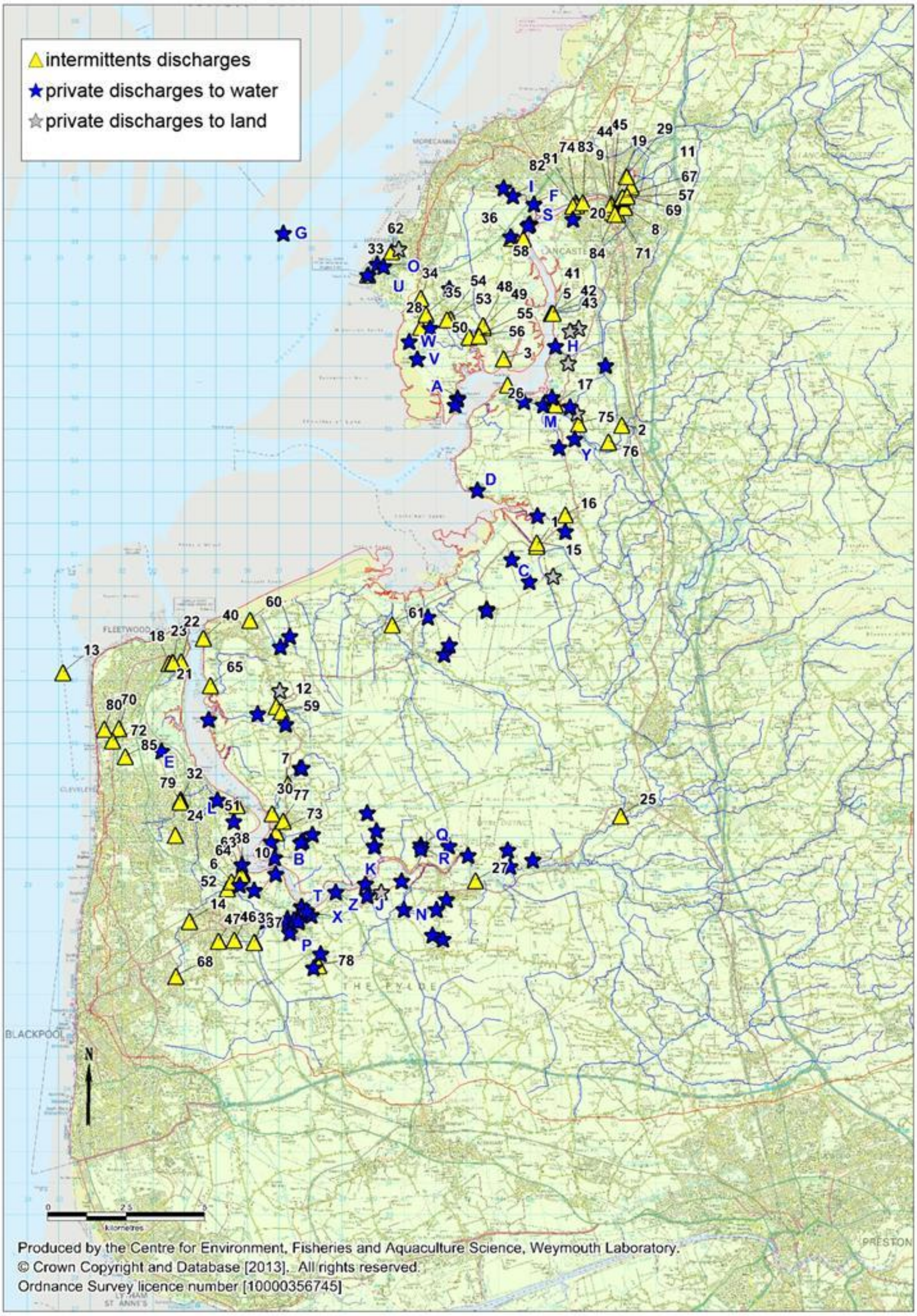


Figure II.3: Intermittent and private discharges within 2 km of the area

Table II.4: Details of intermittent discharges within 2km of the Lune estuary (and those on the EA PRP)

No.	Name (permit database)	Permit No.	NGR	Receiving water	Type
1	Adj Manor Inn Car Park SSO	17280280	SD4520051300	Trib River Cocker	Storm Overflow
2	Aqueduct	01LAN0082	SD4790055150	River Conder	Storm Overflow
3	Bazil Lane SSO	17260027	SD4413057270	Lune Estuary	Pumping Station
~~4*~~	~~Beech Drive CSO*~~	~~WYR0041~~	~~SD36210438690~~	~~Wyre Estuary~~	~~Storm Overflow~~
5	Bowerham/ Scotforth CSO	17280377	SD4566058710	Lune Estuary	Storm Overflow/ Storm Tank
6	Breck Rd	17260201	SD3548040610	Trib Skippool Creek	Storm Overflow
7	Brickhouse Lane PS	01WYR0046	SD3727043730	Wardleys Pool	Pumping Station
8	Bulk Road CSO	17280370	SD4799062091	Lune Estuary	Storm Overflow
9	Cable Street CSO	17280369	SD4761061941	Lune Estuary	Storm Overflow
~~10*~~	~~Car Lane CSO*~~	~~WYR0043~~	~~SD 35840 40920~~	~~Wyre Estuary~~	~~Storm Overflow~~
11	Caton Rd/ Langdale Rd	17270191	SD4819062740	River Lune	Storm Overflow
12	Cemetry Lane SPS	17280221	SD3690046200	Nearby Dyke	Pumping Station
13	Chatsworth Avenue SPS	17260171	SD3012047280	Irish Sea	Storm Overflow
14	Chiltern Avenue	17280299	SD3414039350	Horse Bridge Dyke	Storm Overflow
15	Cockerham STW	17260072	SD4520051400	River Cocker Estuary	Emergency
16	Cockerham STW (SPS)	17270091	SD4610052300	Hasty Beck	Storm Overflow/ Storm Tank
17	Conder Green PS	17290468	SD4579055800	River Conder	Pumping Station
18	Cop Lane	17280294	SD3350047570	Copse Brook	Storm Overflow/ Storm Tank
19	Damside CSO	17280381	SD4757062060	River Lune Estuary	Storm Overflow
20	Damside CSO	17280278	SD4756062020	Mill Race	Storm Overflow
21	Dock St	17260200	SD3361047610	Copse Brook Culvert	Storm Overflow
22	Dock St Overflow	01WYR0028	SD3389047630	Copse Brook Culvert	Storm Overflow/ Storm Tank
23	Dock Street Storage Tank	17290502	SD3363047580	Copse Brook Culvert	Storm Overflow
24	Fleetwood Road South SPS	17280223	SD3370042100	Dyke in Thornton	Pumping Station
25	Garstang STW	017260046	SD47870 42720	River Wyre	Storm Overflow/ Storm Tank

No.	Name (permit database)	Permit No.	NGR	Receiving water	Type
26	Glasson (Fishnet Point) PS	17290467	SD4426056440	Lune Estuary	Pumping Station
27	Great Eccleston SPS	01WYR0051	SD4325040650	Wyre Estuary	Storm Overflow
28	Greendales Caravan Park SPS	01LAN0066	SD4151058270	Unnamed Trib of River Lune	Pumping Station
29	Halton Rd/ Aldrens Lane	17270190	SD4804063060	Unknown	Storm Overflow
30	Hambleton PS	17280397	SD3677042790	Wardley's Creek	Pumping Station
31	Hardhorn Rd	01WYR0021	SD3622038690	4m Long, Main Dyke	Storm Overflow
32	Heys Street PS	17290503	SD3386043240	Freshwater river	Storm Overflow
33	Heysham Harbour 5th Quay	17490061	SD3982059940	Heysham Harbour	Storm Overflow
34	Heysham Ind Estate A	01LAN0021	SD4150059200	Unknown	Pumping Station
35	Heysham Ind Estate B	01LAN0022	SD4168058680	Unknown	Pumping Station
36	Heysham Sewage PS	17370022	SD4440061100	Lune Estuary	Storm Overflow
37	Highcross Road	17280298	SD3622038690	Main Dyke	Storm Overflow
38	Holts Lane Detention Tank	NPSWQD001283	SD3584040920	Wyre Estuary	Emergency
39	Holts Lane Detention Tank	NPSWQD001283	SD3621038690	Wyre Estuary	Storm Overflow
40	Knott End PS	17260103	SD3458048370	Wyre Estuary	Storm Overflow/ Storm Tank
41	Lancaster (Stodday) STW	17270050	SD4570058710	Lune Estuary	Pumping Station
42	Lancaster (Stodday) STW	17270050	SD4571058720	Lune Estuary	Storm Overflow/ Storm Tank
43	Lancaster (Stodday) STW	17270050	SD4571058720	Lune Estuary	Storm Overflow/ Storm Tank
44	Lune St PS	17270195	SD4757062170	River Lune	Storm Overflow
45	Lune St PS	17280224	SD4757062170	River Lune	Pumping Station
~~46**~~	~~M.H. G1, Holt Lane*~~	~~01WYR0042~~	~~SD3557038770~~	~~Old Field Carr Culvert~~	~~Storm Overflow~~
47	Manhole No E3 Beech Drive CSO	01WYR0041	SD3508038730	Old Field Carr Culvert	Storm Overflow
48	Middle Pool PS	17280289	SD4348058330	Trib River Lune	Storm Overflow
49	Middle Pool PS	17280289	SD4348058240	Trib River Lune	Pumping Station
50	Middleton/Overton STW	17270051	SD4304057960	Lades Pool	Storm Overflow/ Storm Tank
51	Miller Rd	17190369	SD3567043040	Trib River Ribble	Emergency
52	Myrtle Avenue	17280296	SD3535040400	Horse Bridge Dyke	Storm Overflow

No.	Name (permit database)	Permit No.	NGR	Receiving water	Type
53	Overton Garden Terrace PS	17280288	SD4245058520	Trib River Lune	Storm Overflow
54	Overton Garden Terrace PS	01LAN0098	SD4234058510	Trib River Lune	Storm Overflow
55	(Overton) Peddar- Far PS	17280291	SD4335057990	Lades Pool,Trib River Lune	Pumping Station
56	Overton Peddar- Near PS	17280290	SD4335057990	Trib River Lune	Storm Overflow
57	Owen Road CSO	17280424	SD4788062360	Lune Estuary	Storm Overflow
58	Oxcliffe Rd PS No 1 & EO to Overton	01LAN0028	SD4476061080	Lune Estuary	Pumping Station
59	Park Lane PS Preesall	01WYR0040	SD3707046030	Freshwater stream	Pumping Station
60	Pilling Lane PS	01WYR0073	SD3607048950	Wyre Estuary	Pumping Station
61	Pilling STW	17260137	SD4060048800	Broad Fleet	Pumping Station
62	Port of Heysham PS	17370211	SD4057060680	Trib of Heysham Lake	Pumping Station
63	Poulton PS	17260059	SD3582040850	Wyre Estuary	Storm Overflow/ Storm Tank
64	Poulton STW o/f Pumped	01WYR0044	SD3580040850	Wyre Estuary	Storm Overflow/ Storm Tank
65	Preesall WWTW	17260071	SD3481046870	Wyre Estuary	Storm Overflow/ Storm Tank
66	Railway Farm CSO	017220120	SD48080	River Conder	Storm Overflow
67	Ramparts (Mainway) CSO	17280425	SD4792062410	Lune Estuary	Storm Overflow
68	Ravenswood Drive	017290504	SD33710 37610	Freshwater river	Storm Overflow
69	Riverside PS	17270198	SD4806062430	River Lune	Pumping Station
70	Rosal Square PS (No24)	17280229	SD3190045500	Gravity Sewer	Pumping Station
71	Rosemary Lane	17280276	SD4777061870	Mill Race	Storm Overflow
72	Rossall School	17280230	SD3170045100	Adjoining Dyke	Emergency
73	Salt Marsh Lane	17280305	SD3691042180	Pegs Pool	Storm Overflow
74	Scale Hall PS	17270196	SD4643062230	Lune Estuary	Pumping Station
75	Scale House	01LAN0083	SD4652055190	River Conder	Storm Overflow
76	Sellery Pond	01LAN0084	SD4747054610	Freshwater river	Storm Overflow
77	Sherbourne Road PS	17280306	SD3713042550	Trib River Wyre	Pumping Station
78	Singleton PS	17290649	SD3826037940	Unnamed Trib of Main Dyke	Storm Overflow/ Storm Tank
79	Trunnah Rd	01WYR0063	SD3384043160	Royles Brook	Storm Overflow

No.	Name (permit database)	Permit No.	NGR	Receiving water	Type
~~80***~~	~~Westway SSO**~~	~~01WYR0055~~	~~SD3144045470~~	~~Copse Brook~~	~~Storm Overflow/ Storm Tank~~
81	Willow Ln SPS	17280226	SD4645062140	River Lune	Emergency
82	Willow Ln SPS	17270197	SD4634062120	River Lune	Pumping Station
83	Willow Ln SPS	17280342	SD4665062230	River Lune	Pumping Station
84	Wood Street CSO	17280277	SD4768061870	Mill Race	Storm Overflow
85	Woodcock Wood SPS (No 23)	17280232	SD3210044600	Surface water culvert	Pumping Station

Data from the National Environment Agency database and EA PRP

*NW EA inform that these discharges have been revoked, and effluent now discharges via Holts Lane Detention Tank. This discharge was noted as being significant to the Shellfish Waters in the EA Pollution Reduction Plans 2009.

** NW EA inform that these discharges have been revoked, and effluent now discharges via Holts Lane Detention Tank. It is included as is stated as being a current discharge in the EA national discharges database..

*** NW EA inform that this discharge has been revoked, but it is current in National EA database

For those without event monitoring it is difficult to assess their potential impacts aside from noting their location and potential to spill untreated sewage. For those with event monitoring some spill summary statistics from between the period January 2008 to March 2012 are shown in Table II.5.

Table II.5: Summary of spill records from monitored intermittent discharges

Discharge Name (spill records)	2008			2009			2010			2011			2012-13**		
	N	Sum hrs	%	N	Sum hrs	%	N	Sum hrs	%	N	Sum hrs	%	N	Sum hrs	%
Chatsworth Avenue PS	37*	115	1.31*	47*	265.8*	3.03*	17*	94.3**	1.08*	26	53.84	0.96	50	153.19	1.74
Dock Street CSO	Data only recently available												10	24.22	0.28
Hey Street CSO	No data available									56	88.2	1.01	24	25.43	0.29
Holts Lane Detention Tank	Data only recently available- spill reduction due from August 2014												20	175.63	2.00
Knott End PS CSO	Data only recently available												5	40.33	0.46
Lancaster (Stodday) STW Storm Tank	No data available			30	439.62	5.02	17	161.5	1.84	19	182.2	2.1	48	610.8	6.95
Lune St PS	No data available												28	333.49	3.80
Middleton/Overton STW Storm O/F	No data before October 2011 but monitoring shows no spills recorded since October 2011.														
Owen Road CSO	No data available												66	618.73	7.04
Oxcliffe Road PS CSO	No data available												40	259.45	2.95
Peddar Far PS	No data available									7	14.48	0.2	23	65.92	7.50
Pilling Lane CSO	Data only recently available												7	38.88	0.44
Preesall STW	No data available									4	4.36	0.05	32	159.25	1.81
Railway Farm	No data available									80	19.71	0.23	36	39.08	0.45
Ramparts CSO	No data available												19	39.49	0.45
Riverside PS	No data available												0	0	0
Singleton PS	This is a new reporting site. No data available for previous years as discharge did not exist before.												1	0.08	0.001

Data from the Environment Agency and United Utilities
*N.B Only 6 months of data was available
**Compiled data from United Utilities, reported on Apr-Mar

There are a total of 85 intermittent discharges within the area considered in this survey. The vast majority are clustered around the Wyre and Lune estuaries, so it is assumed that these are impacted to the greatest extent. Only a small proportion of the intermittent discharges have spill records, and for those with detailed spill records, many only cover the 2012-13 reporting year. Reporting in 2012-13 only consisted of the summary statistics, whereas data from before this time consisted of event start stop records. The 2012-13 records showed that three of these intermittent discharges spilled for between 5 and 10% of the time (Lancaster STW Storm Tank, Owen Road CSO and Peddar Far PS). All three discharge to the Lune estuary upstream of the shellfisheries. A further five discharges spilled for between 1 and 5% of the time (Chatsworth Avenue PS, Holts Lane Detention Tank, Lune St PS, Oxcliffe Road PS CSO, Preesall STW). Of these two discharge to the Lune estuary, two to the Wyre estuary, and one to the subtidal about 1km west of Rosall Point. The other discharges spilled for less than 1% of the time. For those with no event monitoring it is difficult to assess their significance apart from noting their location and their potential to spill significant volumes of untreated sewage.

Several intermittent discharges have been improved as of March 2013 as part of the water company asset management programme (AMP5): 8 agglomerated discharges, discharging to the River Lune at Lancaster and 4 discharges, also agglomerated, discharging to the River Wyre. These discharges are now designed to spill less than 10 times per year in agglomeration. This should result in a reduced impact from these storm overflows on microbiological loading to the Lune and Wyre respectively. The storm overflow at Garstang STW has also been improved to <10 spills per year on average discharging upstream in the River Wyre from March 2013.

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 a small number of properties. Of the 99 private discharges that lie within 2 km of the estuary, 91 discharge to water and 8 to ground via soakaway. Most of those within 2 km of the estuary lie on the eastern shore of the Lune or are clustered upstream in the River Wyre, around Hambleton, Singleton and other villages. Details of the larger private discharges (>5 m^3/day maximum permitted flow) are presented in Table II.6. There are several larger discharges (>20 m^3/day) treated either to secondary or tertiary level, and these mostly discharge to the east coast or tributaries leading to the Rivers Lune or Wyre. The River Cocker and Broad Fleet also receive effluent from several private discharges. Within the wider catchment, most of the larger watercourses and various streams draining to the Wyre and Lune also receive inputs from private discharges and will add to the bacterial loadings carried by watercourses leading to the shellfisheries.

Table II.6: Details of private sewage discharges of over 5m^3/day

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	8 First Terrace	SD4267056020	Biological filtration	5	River Lune
B	Bank House Nursing Home	SD3685041400	Tertiary biological	24	Trib of Pergs Pool
C	Braides Farm	SD4440050880	Biological filtration	5	Unnamed trib of River Cocker
D	Cockerham Sands Country Park	SD4330053100	Biological filtration	54.6	Trib of River Cocker
E	Colchester House	SD3325044790	Biological filtration	5	Trib of River Wyre
F	Gypsy Site	SD4510062200	Biological filtration	14	Oxcliffe Dyke
G	Heysham Power Station No. 2	SD3713161272	Tertiary via reed beds	38	Heysham Lake
H	Lancaster Golf Club	SD4578057670	Biological filtration	12	Burrow Beck Trib Lune
I	Land Adjacent to WFC House	SD4443562456	Package Treatment Plant	7	Unnamed trib of River Lune
J	Larbreck Caravan Park	SD3980040200	Septic Tank	20	Dyke trib Thistleton Brook
K	Larbreck Hall Caravan Park	SD3975040570	Package Treatment Plant	23.5	River Wyre Estuary
L	Main Outfall	SD3503043240	Package Treatment Plant	5	Royles Brook
M	Marina Caravan Park	SD4540055800	Biological filtration	27.3	River Conder Estuary
N	Meagles Lane Barns	SD4097039750	Biological filtration	6.3	Wall Pool Beck
O	North Quay	SD4012060280	Biological filtration	33	Haysham Harbour
P	Pool Brow Caravan Site	SD3733339000	Unspecified	8.6	River Wyre Estuary
Q	Rawcliffe Hall & Cottages	SD4150041800	Biological filtration	10	Trib Wyre Estuary
R	Rawcliffe Hall & Cottages	SD4150041670	Biological filtration	10	Trib River Wyre
S	Riverside Caravan Park	SD4498061560	Package Treatment Plant	18	River Lune
T	Riverside Chalet Pk STP	SD3771039840	Biological filtration	5	Wyre Estuary
U	Sea Erminal STP	SD4032060210	Biological filtration	5	Heysham Lake
V	Shorefields Caravan Park	SD4139957261	Package Treatment Plant	25	Trib of Lune Estuary
W	Shorefields Caravan Park	SD4113257828	Package Treatment Plant	25	Trib of Lune Estuary
X	Singleton Hall Campus	SD3801039570	Biological filtration	10	Unnamed Trib of Wyre
Y	Thurnham Hall	SD4640054720	Package Treatment Plant	68.2	Unnamed Trib of Conder
Z	Windy Harbour Caravan Park	SD3880040300	Biological filtration	429	River Wyre Estuary

Data from the Environment Agency.

*DWF m^3/day

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

The vast majority of agricultural land within the hydrological catchment is pasture. Table III.1 presents livestock numbers and densities for this area. The data was provided by Defra and is based on the 2010 census, which provides a higher level of detail than those undertaken in 2011 and 2012. 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 of livestock within the catchment.

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

Cattle		Sheep		Pigs		Poultry	
No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)
126,715	77	510,799	311	27,965	17	1,297,766	791

Data from Defra

The concentration of faecal coliforms excreted in the faeces of animals and humans 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 125,000 cattle and 500,000 sheep at relatively high densities. 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. Some poultry and pigs are also raised within the catchment. Manure from pig and poultry operations is typically collected, stored and spread on nearby farm land (Defra, 2009). Digested sludge from Lancaster STW is also taken to farms in the catchment and spread onto land as a fertiliser (Environment Agency, 2009c).

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 survey area 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 via the rivers Lune and Wyre. Higher impacts may therefore be anticipated within their estuaries and drainage channels on this basis, although there are other watercourses feeding in at various points around the shore which will also carry some agricultural contamination.

There are extensive areas of saltmarsh between Pilling and Cockerham and around the Lune estuary and to a lesser extent the Wyre estuary. The Cockerham saltmarshes are extensively used for grazing, particularly sheep, where about 1,000 animals were seen during the shoreline survey. Creeks draining saltmarsh areas will carry associated faecal contamination into coastal waters either via runoff or through tidal inundation. An Environment Agency study found a significant increase in levels of faecal coliforms within such creeks in the Ribble estuary as the tide started to ebb following saltmarsh inundation (Dunhill, 2003). Impacts will be greatest in the vicinity of any drainage channels cutting across the intertidal, and the fluxes are likely to be much greater on large spring tides when much more of the marsh is covered. Sheep are grazed on the marsh on a year round basis, but have to be removed during the larger spring tides as well as for about a month in late winter for lambing (Farmers Guardian, 17 May 2013). Cattle and sheep were also commonly observed grazing on fenced fields between Pilling and the Lune estuary during the shoreline survey, so watercourses draining these areas are likely to be subject to contamination of livestock origin.

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.

Appendix IV. Sources and variation of microbiological pollution: Boats

The discharge of sewage from boats is potentially a significant source of bacterial contamination of shellfisheries within the Lune estuary. There is significant boat traffic within the estuary; it hosts two commercial ports, two marinas, two sailing clubs and a sizeable fishing fleet. 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 in the Lune

Fleetwood Port has been established as a major fishing port for 90 years, to which significant landing continue to be made today (ABP, 2010-2013). It services twice daily ferry sailings to Northern Ireland (Ports and Harbours website, 2013) and is a landing port for boats working on the offshore wind farms in the Irish Sea.

Glasson Dock deals with imports of agricultural products including animal feed, cereals, grass seeds and fertilisers (Glasson Group, 2013) as well as general cargoes to the Isle of Man and the Western Isles. The port handles around 150,000 tonnes of general cargo and bulk each year (Lancaster City Council, 2009).

A small passenger ferry runs across the mouth of the Wyre, between Fleetwood and Knott End. An occasional summer ferry also runs between Fleetwood and Douglas on the Isle of Man. Merchant shipping vessels are not permitted to make overboard discharges within three nautical miles of land[1] so vessels associated with the port and ferry terminal should produce little or no impact in the vicinity of the fisheries.

There is a sizeable commercial fishing fleet within the Lune. In August 2013 nine vessels with a length of 10 metres and over and 20 vessels under 10 metres were recorded as operating from Fleetwood Port (MMO, 2013). Several charter boats are also available for recreational fishing trips within the Lune and Morecambe Bay.

There is potentially significant recreational boat traffic within the Lune. The Lune and Wyre estuaries have been categorised as receiving ‘medium recreational use’ (RYA, 2004). There are two marinas which collectively hold berths for 640 boats (Glasson Basin Marina and Fleetwood Haven Marina websites) and several moorings exist in the sheltered waters of the Lune and Wyre. Drying berths are available at Blackpool and Fleetwood Sailing Club for keelboats and larger yachts. Sewage pumpout facilities for Elsan toilets are available at the Glasson Basin Marina (The Green Blue, 2010).

A couple of sailing clubs exist within the Lune estuary, which offers a range of sailing courses and racing opportunities. Kitesurfing, canoeing, kayaking, windsurfing and powerboating also take place within the estuary. However, the smaller recreational boats are not large enough to contain onboard toilet facilities and therefore are unlikely to make overboard discharges.

The more sizeable private vessels such as yachts, cabin cruisers and fishing vessels are likely to make overboard discharges from time to time. Those in overnight occupation on moorings or at anchor may be more likely to make overboard discharges, so higher impacts may be anticipated within moorings or anchorages. Occupied yachts on pontoon berths may be less likely to make overboard discharges as this is somewhat antisocial in the crowded marina setting, and facilities on land

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

are easier to access. Boats may also make overboard discharges whilst underway, so the main navigation channels may also be more susceptible to impacts from boat traffic. Peak pleasure craft activity is anticipated during the summer, therefore associated impacts are likely to follow this seasonal pattern. 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.

Appendix V. Sources and Variation of Microbiological Pollution: Wildlife

The Lune estuary features a variety of different estuarine habitats; intertidal sand and mud flats, salt marshes, reefs, and sand/shingle banks. The estuary and its wildlife are protected by several national and international conservation designations including the Wyre Special Site of Scientific Interest (SSSI) and National Character Area (NCA). It also forms part of the Morecambe Bays Special Area of Conservation (SAC), Special Protection Area (SPA) and Ramsar site.

Studies in the UK have found significant concentrations of microbiological contaminants (thermophilic campylobacters, salmonellae, faecal coliforms and faecal streptococci) from intertidal sediment samples supporting large communities of birds (Obiri-Danso and Jones, 2000). Over the five winters up until 2010/11 an average total count of 209,498 overwintering birds and wildfowl were recorded (Holt *et al*, 2012) within the wider Morecambe Bay area, which includes the intertidal flats considered in this survey. The Lune and Wyre estuaries support smaller but nevertheless significant populations of overwintering birds, with around 12,742 in the Lune estuary and 5,997 in the Wyre Estuary (Musgrove et al, 2007). Species include oystercatchers, grey plover, turnstone, knot, pink footed geese, curlew, redshank and dunlin. Pink footed geese frequent the Pilling Marsh during the winter months. A study undertaken by Bickerton et al (2008) revealed numbers of Pink footed geese were highest in November, at 33,750 individuals.

Waders forage for food (and defecate) on the intertidal mudflats, across a wide area and therefore potentially, directly onto shellfish beds. Contamination via direct deposition may be quite patchy, with some shellfish containing quite high levels of *E. coli* with others a short distance away unaffected. 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. Goose faeces deposited on the Pilling Marshes will be carried into coastal waters either via land runoff or tidal inundation. The large numbers of birds in this relatively small area may result in some quite acute impacts.

During the warmer months of the year the vast majority of these birds migrate elsewhere to breed, so bird numbers will be much lower. There are some seabirds (e.g. gulls and terns) which use the area for breeding in the spring and summer. These populations are very small in relation to the overwintering waterbirds, with only 32 pairs recorded within a 5 km radius of the survey area (Mitchell *et al*, 2004). Seabirds are likely to forage widely throughout the area, therefore faecal inputs could be considered as diffuse.

There are no major seal colonies in the vicinity of the Lune estuary, the closest colony is in southern Scotland and Northern Island (SCOS, 2012) Whilst there may be occasional seal sightings as these animals forage widely, they will not be a significant source of contamination to the shellfishery. No other wildlife species which may have a bearing on the sampling plan have been identified.

Appendix VI. Meteorological Data: Rainfall

The Stodday WWTW weather station, received an average of 1020 mm per year between 2003 and 2012. Figure VI.1 presents a boxplot of daily rainfall records by month at Stodday WWTW.

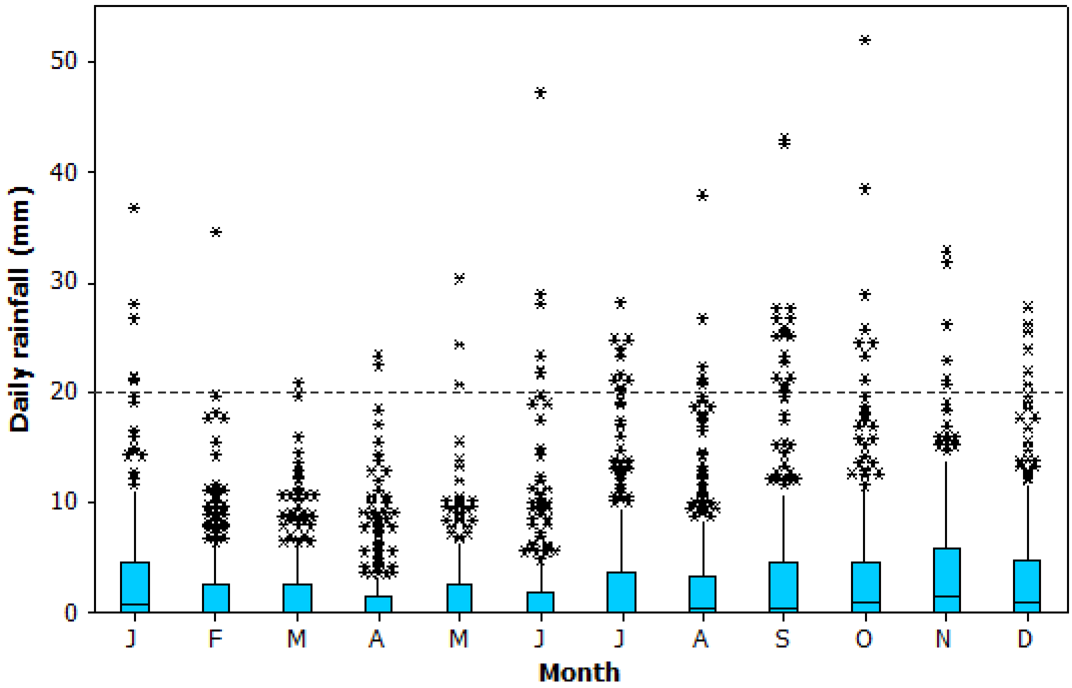


Figure VI.1: Boxplot of daily rainfall totals at Stodday WWTW, January 2003 to December 2012.
Data from the Environment Agency

Rainfall records from Stodday WWTW, which is representative of conditions in the vicinity of the shellfish beds indicate relatively low seasonal variation in average rainfall. However there was slightly more rainfall from September to December than the rest of the year. Rainfall was lowest on average in April and highest on average in September and November. Daily totals of over 20 mm were recorded on 1.9% of days and 42% of days were dry. High rainfall events (>20 mm/day) occurred in all months, but were less frequent from February to May inclusive. Further inland, where elevations are higher, rainfall increases significantly and is around double that at Stodday in the very upper reaches (NERC, 2012).

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

NW England and the Isle of Man are among the more exposed parts of the UK, being relatively close to the Atlantic and containing large upland areas. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest in the winter half of the year, especially from December to February, and this is when mean speeds and gusts (short duration peak values) are strongest (Met Office, 2013).

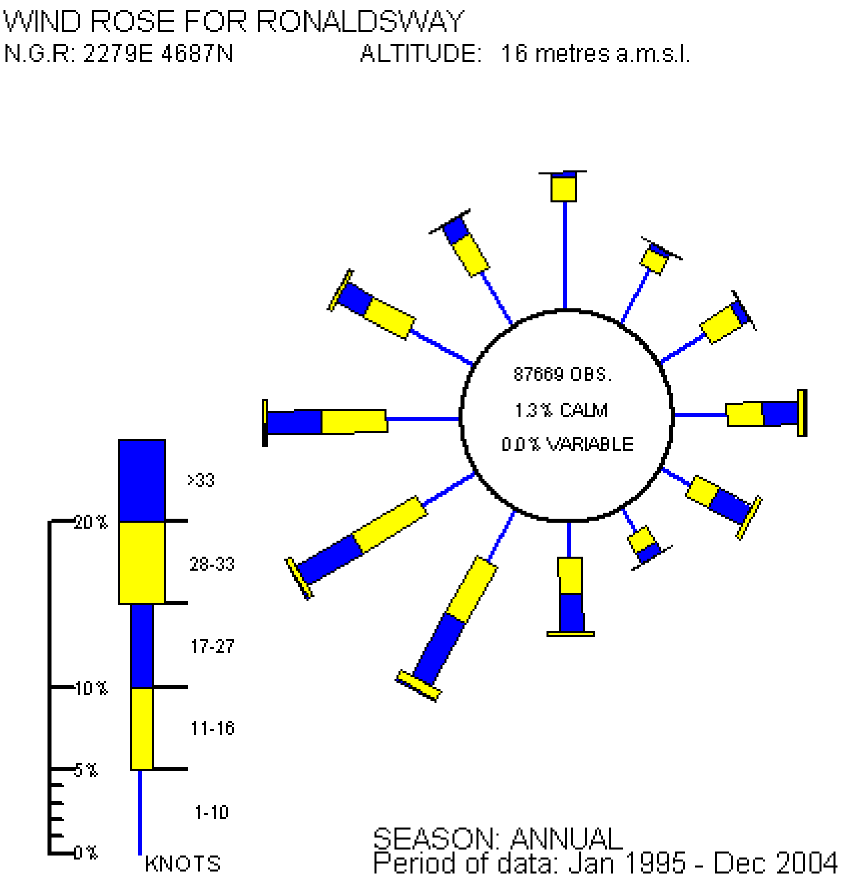


Figure VII.1: Windrose for Ronaldsway, Isle of Man
Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The annual wind rose for Ronaldsway is typical of open, level locations across the region. The prevailing wind is from the south west throughout the year but there is a high frequency of winds from the north east in the spring. The Lune is relatively exposed to the prevailing winds as it opens out to the west in to Morecambe Bay, which has a wide mouth and faces south west. However the presence of the Isle of Man and Irish landmasses situated to the west offer some protection (Thornhill *et al*, 2012).

Appendix VIII. Hydrometric Data: Freshwater Inputs

The Lune has a drainage catchment of 1,300 km² (EA, 2009a) and the Wyre a smaller catchment of approximately 300 km² (EA, 2009b). The Lune and the Wyre represent the two main freshwater inputs to the survey area. The River Cocker, a much smaller river, discharges into the survey area just to the south of the mouth of the Lune estuary.

Figure VIII.1: Freshwater Inputs into the Lune

The Lune is a large, upland, high gradient spate river, whereas the Wyre drains an area of low relief apart from in its very upper reaches. They both mainly drain rural areas, but have significant settlements in their lower reaches by their estuaries. Hydrogeology ranges from very low permeability in the upper reaches of the Lune catchment to moderate in its lower reaches and throughout the Wyre catchment (NERC, 2012). Surface water flows therefore dominate. Summary statistics for flow gauges closest to the tidal limits of these rivers are presented in Table VIII.1.

Table VIII.1 Summary flow statistics for six gauging stations draining into the Lune (2003-2013)

Watercourse	Station Name	Catchment Area (Km²)	Mean Annual Rainfall 1961-1990 (mm)	Mean Flow (m³s-1)	Q95[1] (m³s-1)	Q10[2] (m³s-1)
Lune	Caton	983	1525	38.02	3.72	91.82
Wyre	St. Michaels	275	1245	7.42	0.75	19.31
Condor	Galgate	29	1181	0.68	0.06	1.55

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

The Lune is the most significant freshwater input into the survey area delivering a daily mean discharge of 38 m³/s. The Wyre, the second largest watercourse, has a daily mean discharge 5 times smaller. The Condor, which discharges to the Lune estuary has a mean daily discharge of less than 1 m^3/sec. High flows exceed base flows by a factor of about 25 for all three. Boxplots showing mean daily flow records for individual gauging stations are presented in **Error! Reference source not found.** to **Error! Reference source not found.**.

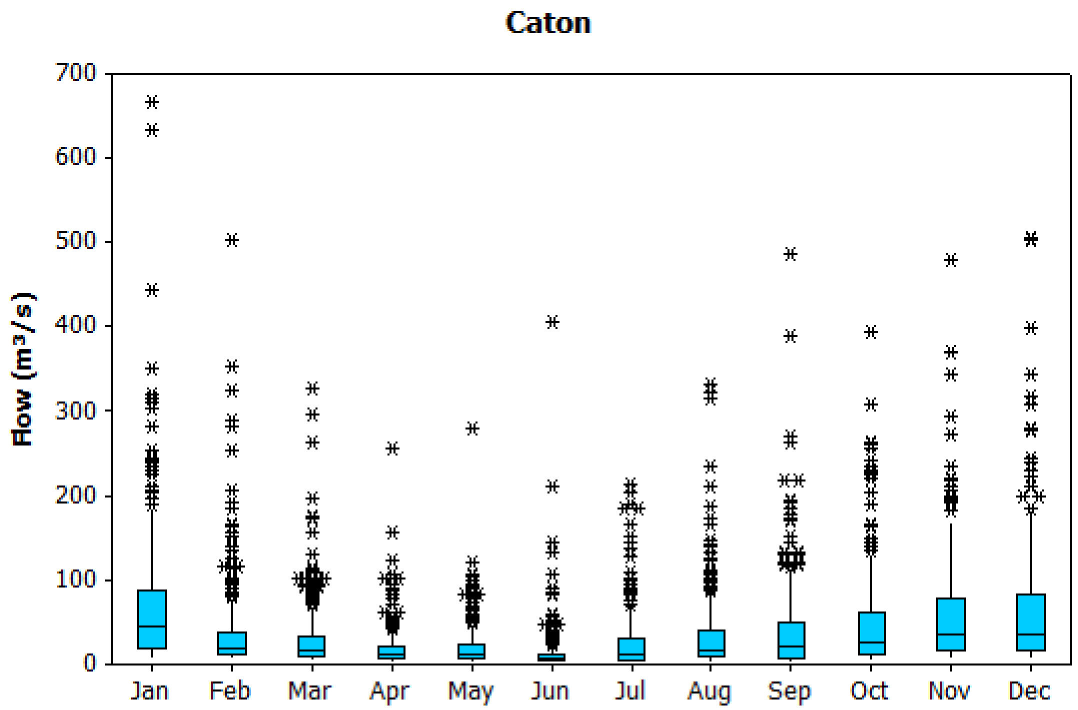


Figure VIII.2: Boxplots of mean daily flow records from the Caton gauging station on the Lune watercourse (2003-2013)

Data from the Environment Agency

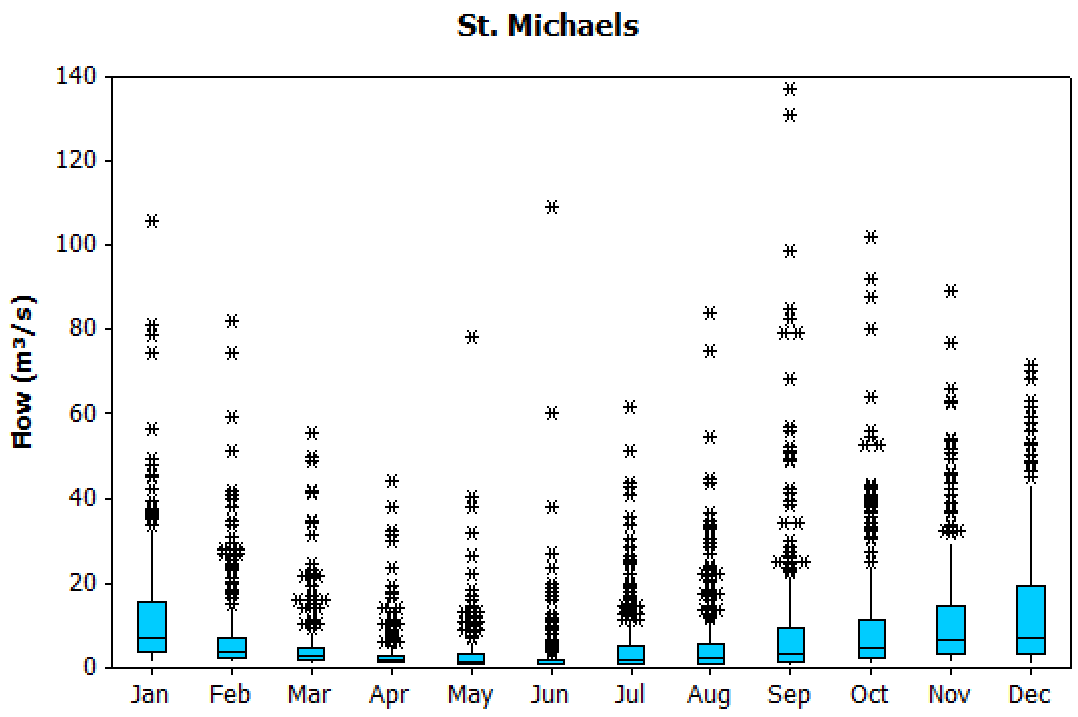


Figure VIII.3: Boxplots of mean daily flow records from the St. Michaels gauging station on the Wyre watercourse (2003-2013)
Data from the Environment Agency

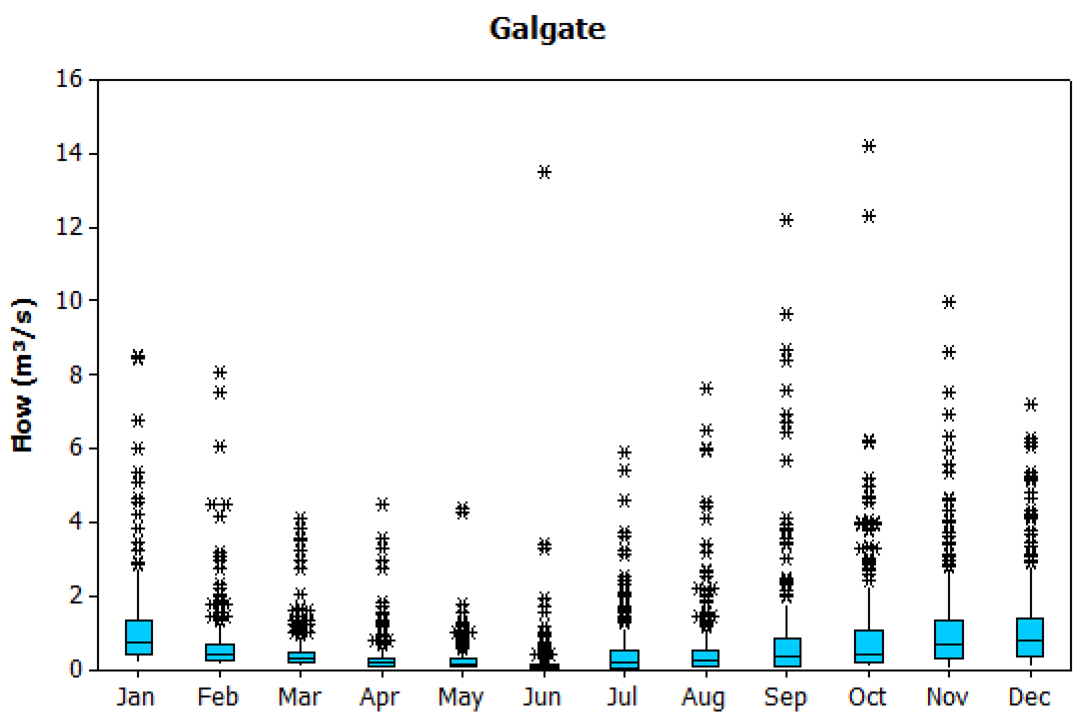


Figure VIII.4: Boxplots of mean daily flow records from the Galgate gauging station on the Condor watercourse (2003-2013)
Data from the Environment Agency

Flows were considerably higher on average during the colder months at all three gauging stations. High flow events were recorded in most if not all months of the year, but there tended to be a greater number of higher magnitude events during the autumn and winter. At Caton which is the most downstream gauging station on the Lune, flow rates peaked to an extremely high record of 667 m^3/s in January 2005. The seasonal pattern of flows is not entirely dependent on rainfall as during the colder months there is less evaporation and transpiration, leading to a higher water table. This in turn leads to a greater level of runoff immediately after rainfall. Increased levels of runoff are likely to result in an increase in the amount of microorganisms carried into coastal waters. Additionally, higher runoff will decrease residence time in rivers, allowing contamination from more distant sources to have an increased impact during high flow events.

There are also a series of smaller watercourses discharging at intervals along the shore of the Lune survey area, which may be of localised significance in some areas of the fishery. Numerous small watercourses were observed during the shoreline survey flowing through the marshes, and surface drainage pipes were seen in the more urbanised areas. The River Cocker and a few smaller outfalls drain to the Cockerham Marshes. Between Pilling and the Cockerham marshes the land is low lying and field drains run parallel to the sea wall. They discharge into the estuary via two main engineered outfalls (Broadfleet and Mill House sluices). There is also a pumped surface water outfall at Preesall.

During the shoreline survey, which was conducted under a combination of dry and wet conditions, watercourses which could be safely accessed were sampled for *E. coli* and spot flow measurements were taken. A large number of these could not be accessed for measurement, but could be sampled using a sampling pole. The larger watercourses were generally less accessible. The results and locations are presented in Table VIII.2 and in **Error! Reference source not found.**, and include results from surface water outfall pipes.

None of the freshwater inputs for which discharge measurements were obtained were particularly large, and all discharge estimates were less than 0.1 m^3/sec. Some contained high levels of *E. coli*, notably the River Cocker (10,000 cfu/100ml) and three other nearby outfalls from the pastures/grazing marsh in this area.

Table VIII.2: Details of freshwater inputs observed on shoreline survey

Sample	description	Discharge (m^3/day)	*E. coli* (cfu/100ml)	*E. coli* loading (cfu/day)
1	Stream	Inaccessible	8900	
2	Stream	Inaccessible	>20000	
3	Stream	Inaccessible	>20000	
4	Pipe	Insufficient flow	4300	
5	Pipe	63763	>20000	6.63×10^{10}
6	Stream/discharge	19008	8900	3.38×10^{10}
7	Large pipe	21427	420	1.13×10^{9}

Sample	description	Discharge (m^3/day)	*E. coli* (cfu/100ml)	*E. coli* loading (cfu/day)
8	Broadfleet Outfall	Inaccessible	870	
9	Tidal Flap	34214	3400	2.91×10^{11}
10	Drainage channel	19267	75	7.23×10^{7}
11	Presall Pumping Station	Not pumping	2400	
12	Drainage pipes	Insufficient flow	3100	
13	Land drainage	92621	13000	3.61×10^{10}
14	Mill House Outfall - Sluice	Inaccessible	1500	
15	River Cocker – Sluice gates	Inaccessible	10000	
16	Pipe	26093	3500	1.74×10^{10}
17	Hasty Beck Tidal Flap - Sluice	Inaccessible	>10000	
18	Bank End Tidal Flap - Sluice	Inaccessible	14000	

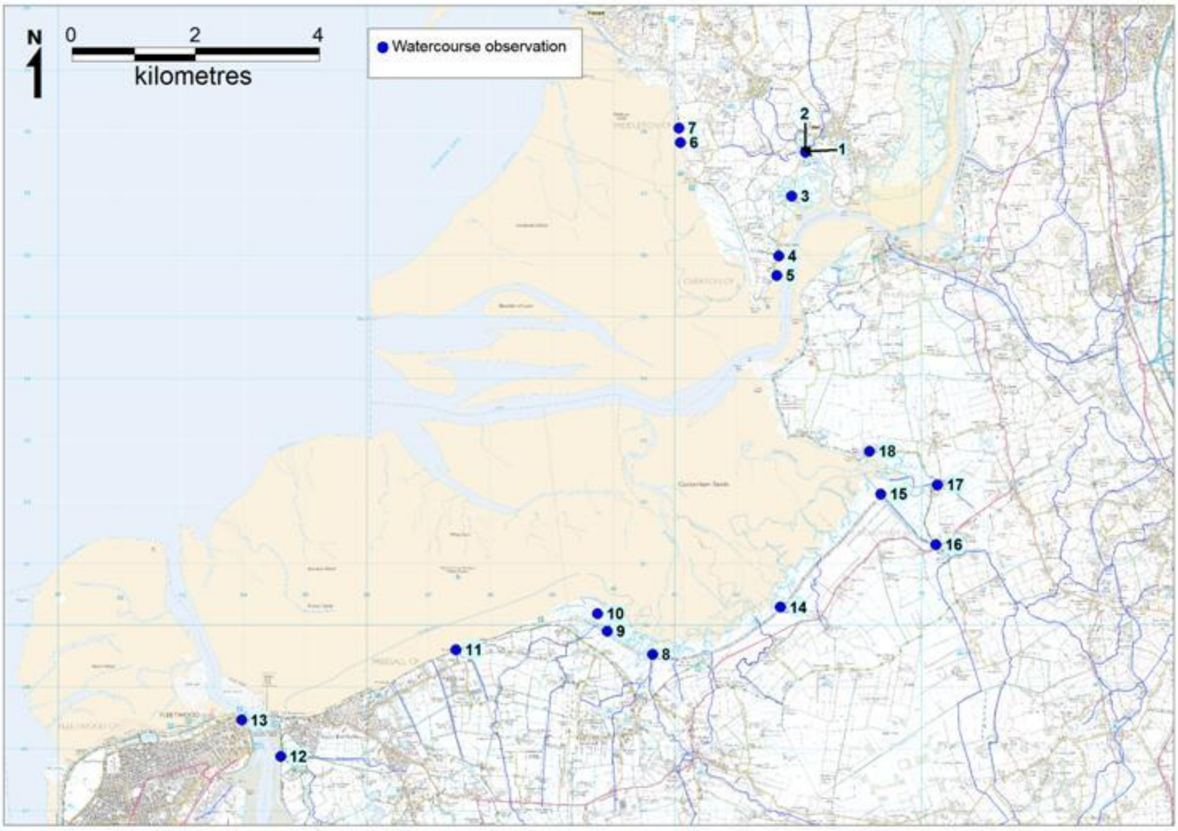


Figure VIII.5: Streams sampled and/or measured during the shoreline survey

Appendix IX. Hydrography

IX.1. Bathymetry

The survey area covers a relatively open and largely intertidal embayment at the southern end of Morecambe Bay, to which the estuaries of two significant rivers drain (the Lune and the Wyre). It also extends into the mouth of the Wyre estuary, which has a mussel bed in its outer reaches. A bathymetric chart for the area is shown in Figure IX.1

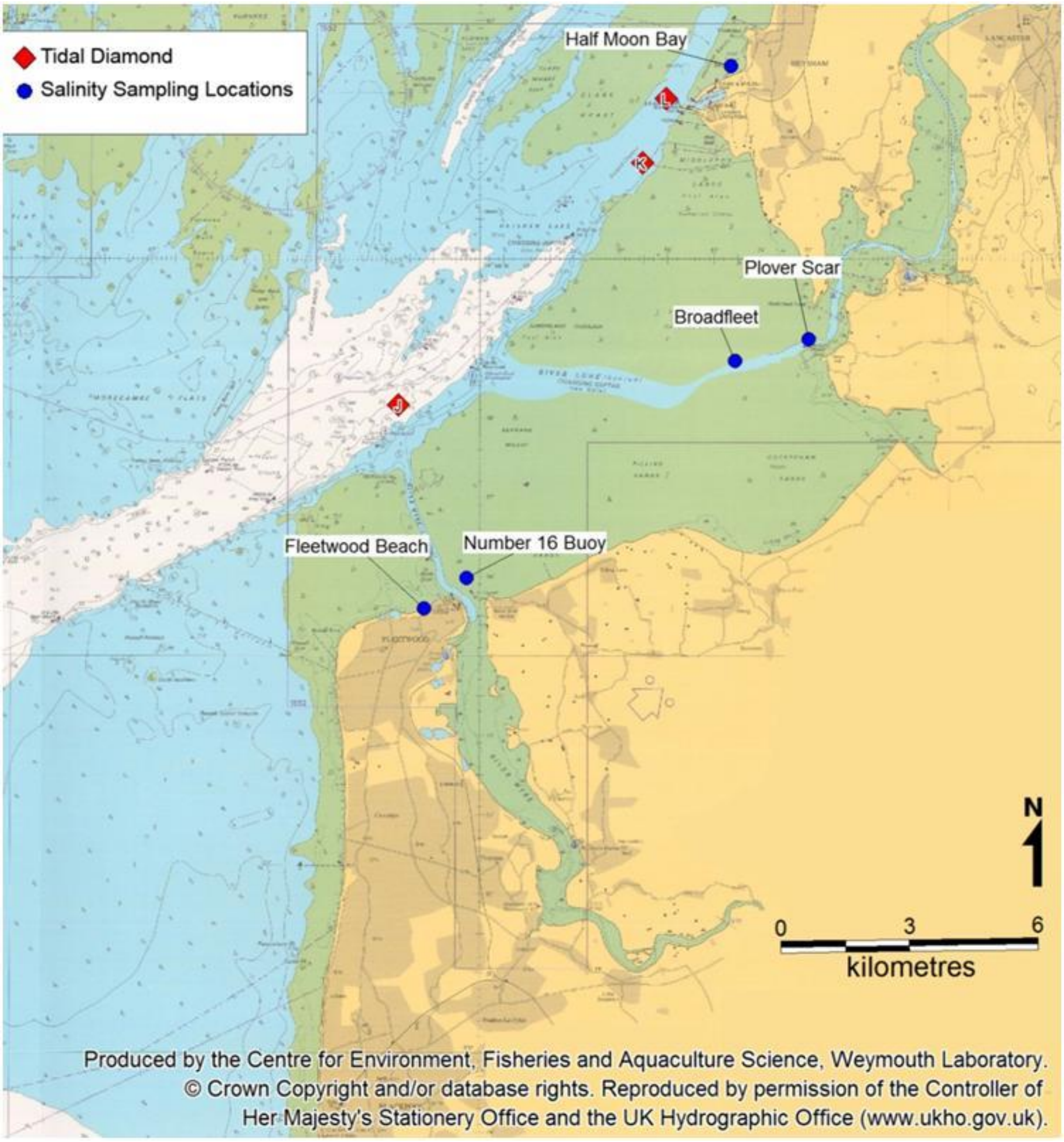


Figure IX.1: Bathymetry of the Lune estuary (Admiralty Chart 2010)

Overall the embayment covers approximately 90 km², of which around 90% is intertidal sand flats. Two subtidal channels cut through the intertidal flats from the mouths of the two estuaries out to the Lune Deep. The depths of these channels are changeable due to the high mobility of sediments (Annan, 2001) and are therefore not stated on the admiralty chart. The Lune Island cockle bed lies on a raised sandbank just to the south of the Lune approach channel, although this is not apparent on the chart. The Lune Deep off Fleetwood shelves steeply from the edge of the intertidal to depths over 30 m, whilst further north off Middleton Sands it only drops off to about 7 m relative to chart datum. The sand flats are flanked by saltmarsh in many areas, and these are backed by earth dykes between Cockerham and Pilling. There are several drainage creeks which cut through the intertidal area between the mouth of the Lune estuary and the mouth of the Wyre estuary which carry water draining from the adjacent saltmarsh and in some cases from freshwater inputs. Overall, the bathymetry of the area suggests the majority of the water is exchanged every tide, but that the potential for dilution is relatively low.

The two estuaries are both fairly narrow, and are characterised by a central meandering river channel flanked by intertidal areas. Both become progressively narrower and shallower towards their heads, and their mouths are both slightly constricted which may induce some mixing of the water column as tidal streams pass through. The Lune estuary has been modified by reclaimed land, flood embankments and training walls (Halcrow, 2010). The approaches to Fleetwood port in the Wyre are dredged regularly (Futurecoast, 2002).

IX.2. Tides and Currents

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The Lune is macro-tidal and expresses a semi diurnal cycle with an average tidal range on of 8.2 m and 4.2 m on spring and neap tides respectively (Table IX.3).

Table IX.3 Tidal Levels and ranges within the Lune

	Height above chart datum (m)				Range (m)	
Port	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Fleetwood	9.4	7.3	3.1	1.2	8.2	4.2
Glasson Dock	6.6	4.4	-	-	-	-
Wyre Lighthouse	9.2	7.3	-	-	-	-

Data from Admiralty TotalTide©

Data are available from three tidal diamonds stations, one in the Lune Deep off the mouth of the Wyre channel, one off Heysham Docks, South Pier and one in the buoyed channel between Heysham South Pier and Heysham Lake. **Error! Reference source not found.** shows their locations and Table IX.4 details the direction and rate of tidal streams.

Table IX.4 Direction and rate of tidal streams at three locations within Morecambe Bay on spring and neap tides and at hourly intervals before and after high water.

Time before /after High Water	Station J (Lune Deep)			Station K (Heysham Lake)			Station L (close to Heysham Harbour)		
	Direction	Rate (ms^{-1})		Direction	Rate (ms^{-1})		Direction	Rate (ms^{-1})	
		Spring	Neap		Spring	Neap		Spring	Neap
HW-6	249	0.15	0.10	230	0.10	0.05	209	0.05	0.00
HW-5	151	0.15	0.10	-	0.00	0.00	29	0.10	0.05
HW-4	55	0.46	0.26	47	0.31	0.15	29	0.31	0.21
HW-3	58	1.03	0.57	29	0.82	0.41	29	0.77	0.46
HW-2	59	1.18	0.72	30	1.03	0.51	29	1.29	0.77
HW-1	61	0.87	0.51	33	0.82	0.41	29	1.13	0.67
HW	65	0.31	0.15	50	0.15	0.10	29	0.31	0.21
HW+1	245	0.51	0.31	213	0.31	0.15	209	0.57	0.36
HW+2	236	1.03	0.51	211	1.03	0.51	209	1.08	0.67
HW+3	241	0.98	0.57	213	0.77	0.41	209	1.13	0.67
HW+4	234	0.72	0.41	212	0.57	0.31	209	0.57	0.41
HW+5	249	0.36	0.21	216	0.26	0.15	209	0.21	0.67
HW+6	254	0.15	0.10	225	0.15	0.05	209	0.05	0.05
Excursion (flood)		14.43	8.33		11.29	5.74		14.06	8.51
Excursion (ebb)		14.06	7.96		11.47	5.92		13.14	10.18

Data from Admiralty Chart 2010 (Morecambe Bay and Approaches)

All stations are located within deepwater channels and as a result the current velocities reported are likely to be higher than within the survey area, across the intertidal at least. Tides are bi-directional, flooding up the Lune Deep in a north easterly direction, with the reverse occurring on the ebb. The strongest currents are seen on the flood tide with the highest recorded velocity at Station L, of 1.29 ms^{-1} close to Heysham Harbour. Tidal currents at the mouth of Morecambe Bay have been reported at, 0.9 - 1.0 ms^{-1} (Halcrow, 2010). Tidal diamonds suggest some asymmetry, with a shorter duration and faster moving flood tide (flood dominant). Estimates of tidal excursions along the Lune Deeps, based on these tidal diamonds range from 11-15 km on spring tides, and about 5-10 km on neap tides. Current velocities are likely to be considerably slower over the intertidal areas.

Advection of pollutants by tidal currents is likely to be the main mode of contaminant transport in the Lune. The flood tide will convey relatively clean water originating from the Irish Sea into the area, whereas the ebb tide will carry contamination from shoreline sources out through the area. Flood streams cross the survey area will opriginate from the Lune Deep. They will progress up the two subtidal channels and into the estuaries, spreading over the intertidal flats as water levels rise. Therefore, at lower states of the tide, flows will move up the Wyre navigation channel in a southerly direction, whereas at higher states of tide there will be cross flows (from west to east). Flood streams across Pilling Sands will be in an easterly direction. It is likely that flood streams across Middleton Sands originate from the Lune Deep and generally progress in an easterly direction across the flats. Within the two river estuaries, flood tides will follow the river channels and spread across the intertidal from them. The reverse will occur on the ebb. This means that the ebb plume from the Lune will primarily impact in the vicinity of the estuary approach channel. The ebb plume from the Wyre will primarily be carried across the intertidal flats north of Fleetwood in a westerly direction for the earlier stages of the ebb, but towards low water it will move out through the Wyre approach channel. Contamination within the channels is likely to be more concentrated towards low water when dilution potential is lower. Contamination from shoreline sources outside of the two estuaries will tend to be pushed in an easterly direction by the flood tide, and carried in a westerly direction by the ebbing tide. At lower states of the tide contamination from such sources will follow drainage channels cut across the intertidal, where relatively high concentrations of indicator bacteria may arise.

In addition to tidally driven currents, are the effects of freshwater inputs and wind. The main freshwater inputs are, the River Lune discharging to the east and The River Wyre discharging to the south west. The freshwater input to tidal exchange ratio is relatively low for the whole of Morecambe Bay subsequently the system is well mixed (Futurecoast, 2002). Therefore it is expected that the Lune Survey area, will exhibit similar characteristics, outside of the enclosed river estuaries at least. Density driven circulation is therefore unlikely to modify tidal circulation except at times of high river flows here. One density effect of potential relevance is the tendency for plumes from sewage outfalls to rise to the surface as they are less dense than the receiving seawater.

Spatial variation in average salinity is likely to be a useful indicator of the spatial profile of impacts from land runoff. Strong positive correlations were observed between salinity measurements and concentrations of faecal indicator bacteria in Appendix X of this report for example. Repeated salinity measurements were taken between 2003 and 2013 at five points within the survey area. Their locations are shown in Figure IX.1 and the results in Figure IX.2. Salinities at all five locations were generally approaching that of full strength seawater, with the occasional lower value. This includes two sites in the Lune approach channel, and two sites in close proximity to the Wyre approach channel. It would however be misleading to conclude that there are no noticeable plumes of more contaminated, fresher, water from the mouths of these estuaries as samples were taken around high water and any plume would be most noticeable around low water. Within the enclosed estuaries, which are relatively narrow and both receive significant freshwater inputs, there is likely to be gradients of decreasing average salinity towards their heads, and this is likely to be associated with a gradient of increasing runoff borne contamination.

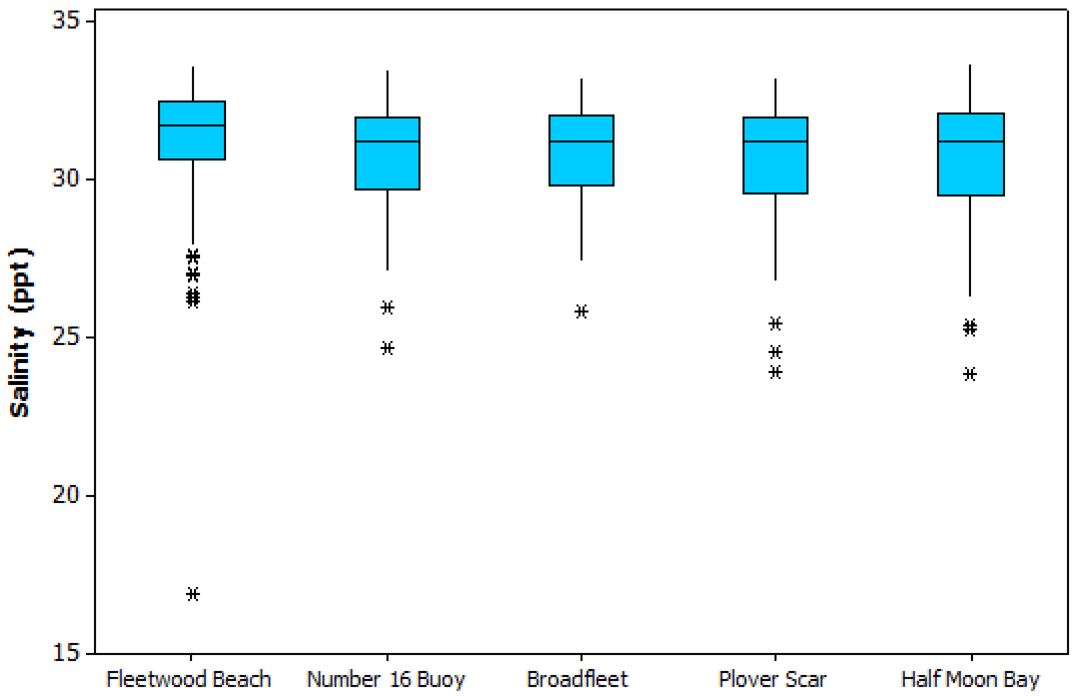


Figure IX.2: Boxplot of salinity readings taken in the Lune Survey Area, 2003-2013

Data from Environment Agency

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 surface water currents of about 1 m/s. These surface currents will in turn create return currents lower in the water column or along sheltered margins. The survey area is most exposed to westerly winds, although it is afforded some shelter by the Isle of Man and Ireland to the west (Thornhill *et. al*, 2012). The prevailing south westerly winds will tend to push surface water in a north easterly direction. Westerly or north westerly winds would tend to advect any buoyant plume from Fleetwood Marsh STW onto the tidal flats where the shellfish resources are located. Exact effects of wind are dependent on its 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 re suspended. The survey area is accumulating sediment due to tidal asymmetry (Aldridge, 1995), so any sediment associated microbiological contamination is therefore likely to remain within the embayment.

Appendix X. Microbiological Data: Seawater

X.1. Bathing Waters

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 was used in these analyses. There is currently only one bathing water in the vicinity of the survey area, designated under the Directive 76/160/EEC (Council of the European Communities, 1975). Another bathing water (Half Moon Bay) was de-designated in April 2013 (Defra, 2013).

Figure X.1: Location of designated bathing waters monitoring points around the Lune.

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 these samples. Summary statistics of all results by bathing water are presented in Table X.1, and Figure X.2 presents box plots of these data.

Table X.1:
Summary statistics for bathing waters faecal coliforms results, 2003-2011 (cfu/100 ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Half Moon Bay	184	01/05/2003	20/09/2011	117.2	<2	25,000	56.5	15.8
Fleetwood Beach	180	02/05/2003	19/09/2011	68.0	<2	8,000	39.4	7.8

Data from the Environment Agency

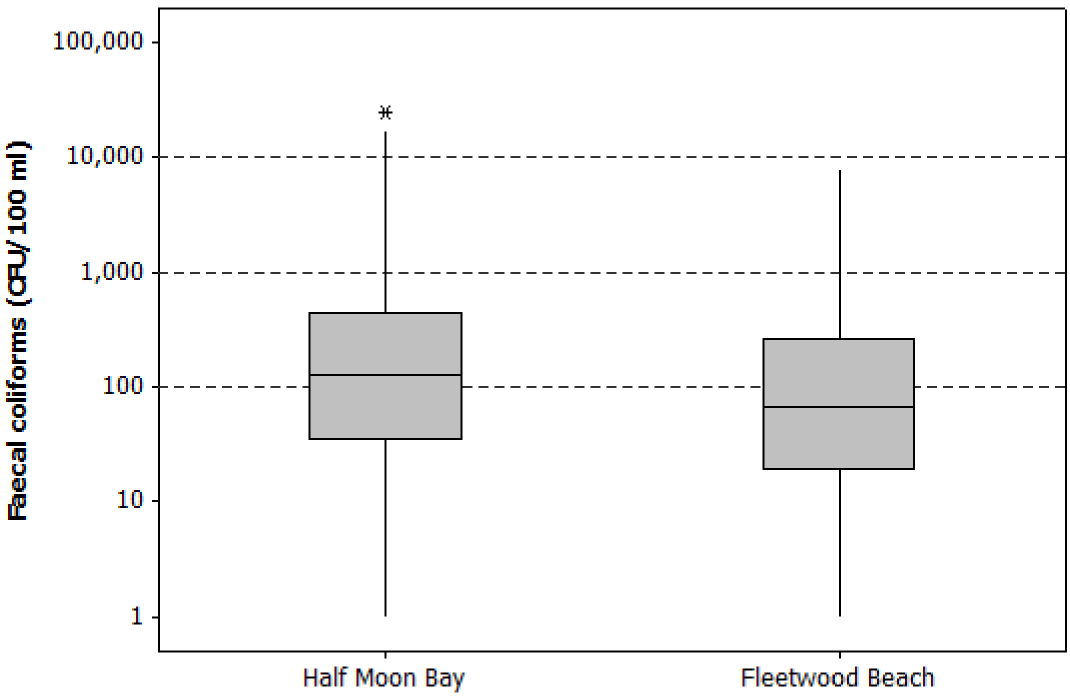


Figure X.2: Box-and-whisker plots of all faecal coliforms results by site
Data from the Environment Agency

Both sites had results exceeding 1,000 faecal coliforms/100 ml, but only Half Moon Bay had results exceeding 10,000 faecal coliforms/100 ml. Two sample T-tests showed that Half Moon bay had significantly higher results than Fleetwood Beach ($p = 0.007$). A comparison of paired (same day) samples taken from the two bathing waters sites indicated a strong correlation between (Pearsons correlation, $p=0.000$) despite the distance between them. This suggests that both sites are under the influence of sources which respond in a similar manner to environmental influences such as rainfall.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at bathing water sites is shown in Figure X.3.

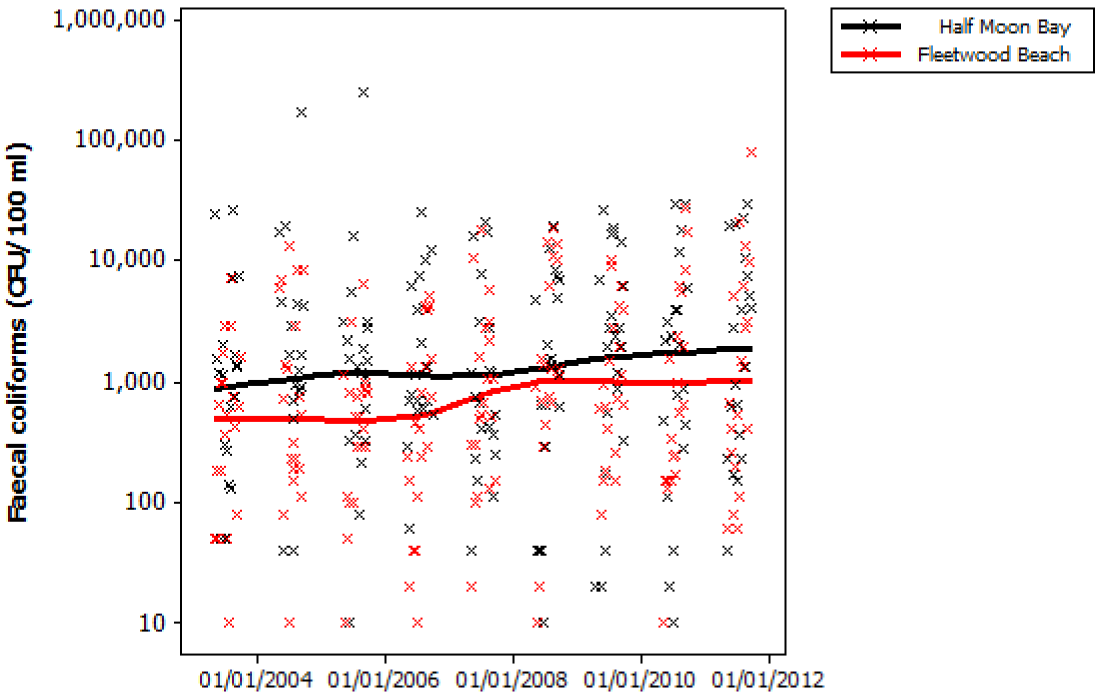


Figure X.3: Scatterplot of faecal coliform results for bathing waters around the Lune overlaid with loess lines.

Data from the Environment Agency

The level of faecal coliform remained mostly steady from 2003 to 2011, with a slight increase in faecal coliform levels at Fleetwood Beach from 2007 to 2008.

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 both of the bathing waters sampling points. Correlation coefficients are presented in Table X.2, with statistically significant ($p < 0.05$) correlations 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**
Half Moon Bay	0.117	0.083	0.142	0.026
Fleetwood Beach	0.137	0.036	0.043	0.717

Data from the Environment Agency

Figure X.4 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 Glasson Dock is at 0° and low water is at 180°. Results of 100 faecal coliforms/100 ml 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.

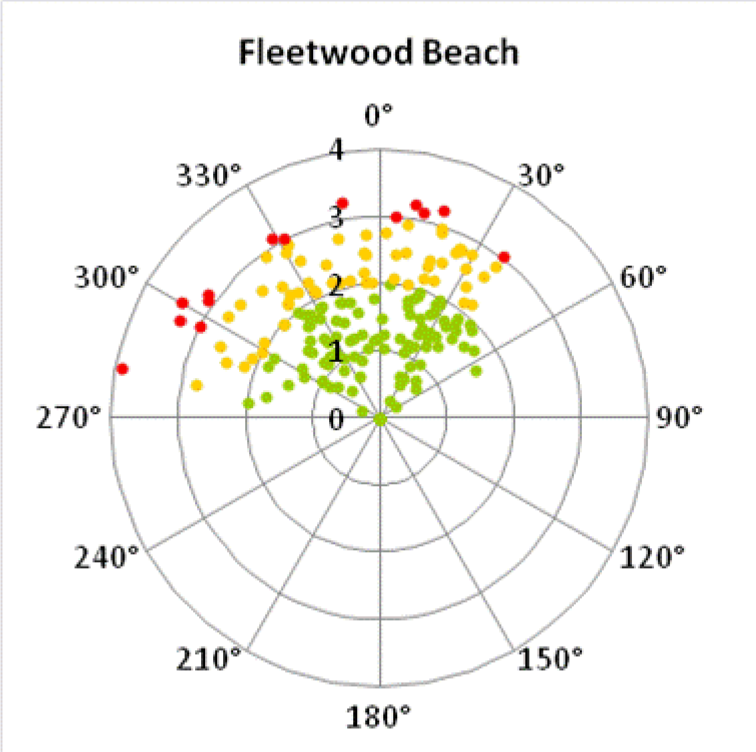


Figure X.4: Polar plots of log10 faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

Sampling at Fleetwood Beach was conducted around high tide. While a statistically significant (although weak) correlation was found, there was no obvious pattern between faecal coliform levels and tidal state are apparent in the polar plot.

Figure X.5 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 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

At Half Moon Bay, faecal coliform levels tended to be higher on average just before and around the period of spring tides.

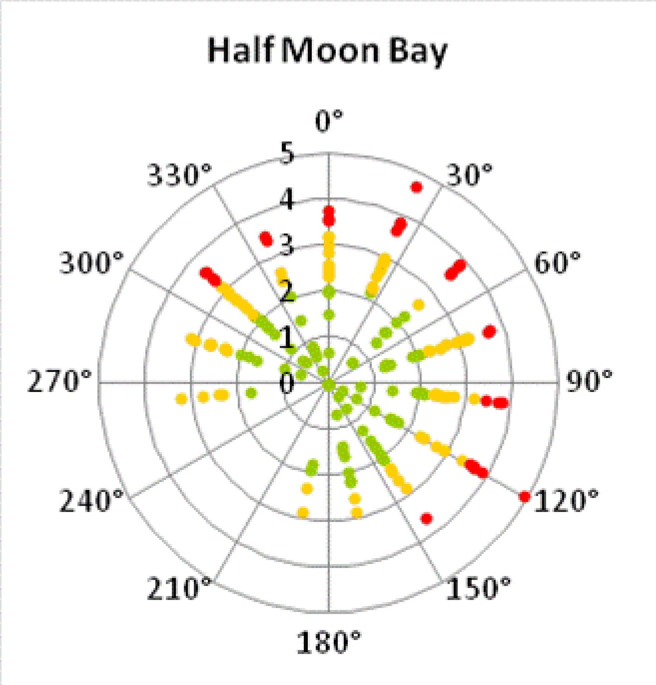


Figure X.5: Polar plots of log10 faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

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 Stodday weather station (Appendix II for details) over various periods running up to sample collection and faecal coliforms results. These are presented in Table X.3 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

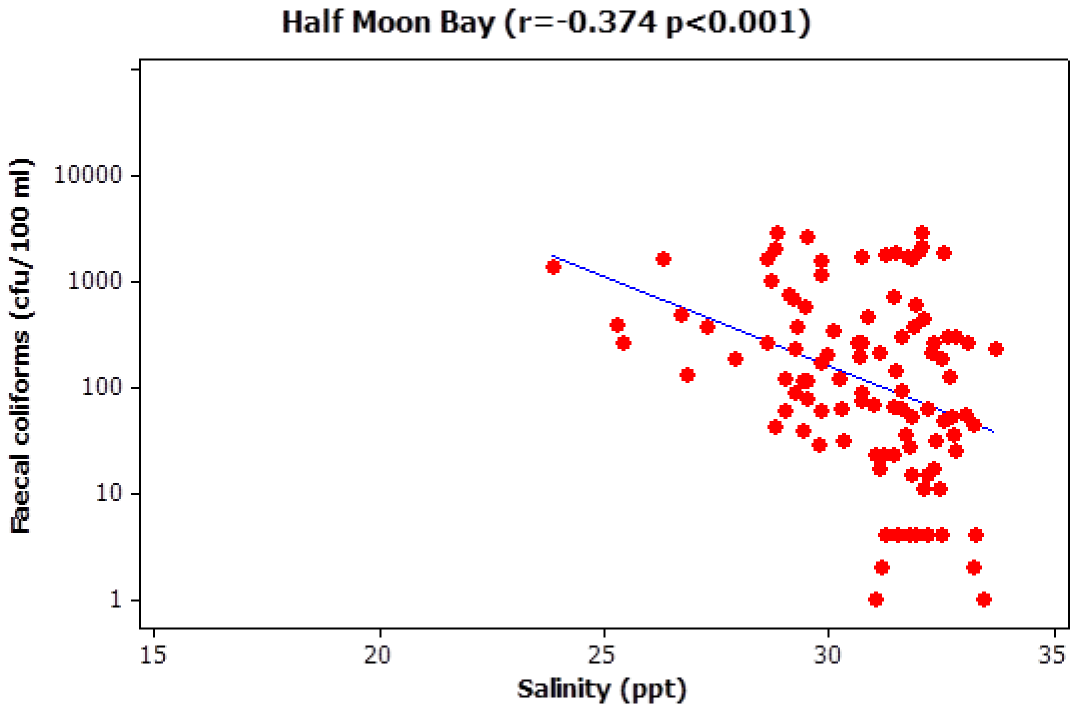
Table X.3: Spearmans Rank correlation coefficients for faecal coliforms results against recent rainfall

	Site	Half Moon Bay	Fleetwood Beach
	n	184	180
24 hour periods prior to sampling	1 day	0.201	0.155
	2 days	0.170	0.369
	3 days	0.317	0.395
	4 days	0.255	0.225
	5 days	0.257	0.187
	6 days	0.099	0.172
	7 days	0.258	0.050
Total prior to sampling over	2 days	0.226	0.329
	3 days	0.308	0.428
	4 days	0.346	0.439
	5 days	0.359	0.442
	6 days	0.339	0.428
	7 days	0.351	0.422

Rainfall rapidly had a large effect on bathing water quality at both sites. However, Fleetwood beach appeared to be affected to a greater extent than Half Moon Bay as is evidenced by the higher correlation coefficients.

Influence of salinity

Pearson's correlations were run to determine the effect of salinity on faecal coliforms at bathing waters sites. Figure X.6 shows a scatterplot of faecal coliforms against salinity and the results of Pearson's correlations between the two.



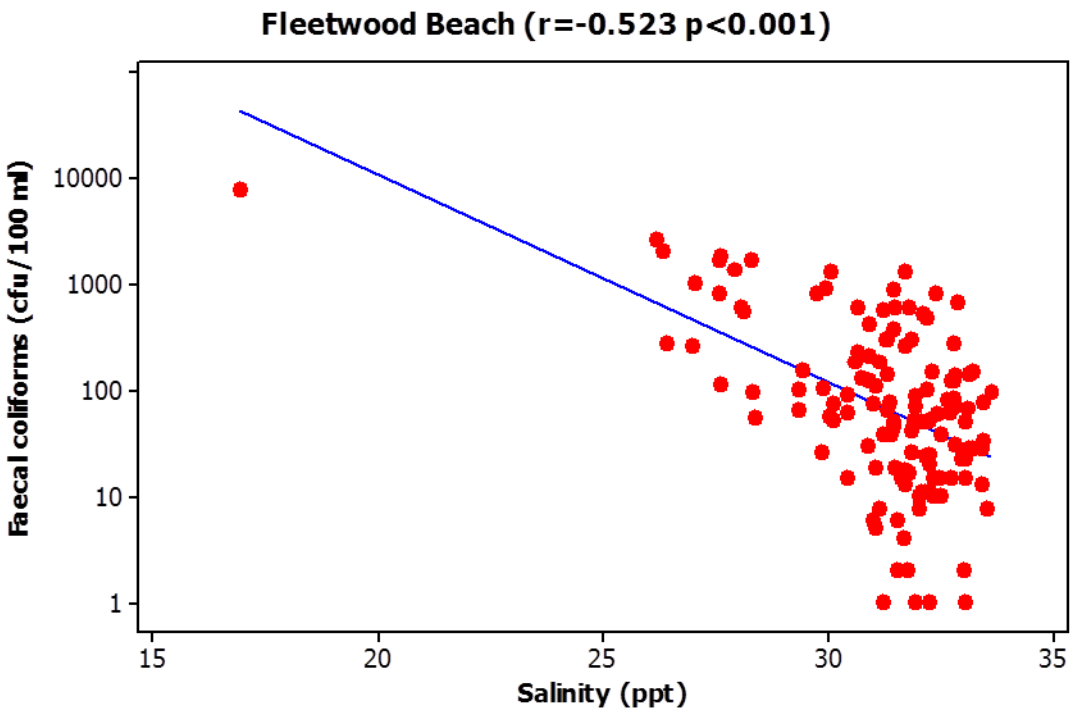


Figure X.6: Scatterplot of salinity against faecal coliform results
Data from the Environment Agency

A strong negative correlation between salinity and faecal coliform levels was observed at both bathing waters monitoring points suggesting that runoff borne contamination is a major influence.

X.2. Microbiological Data: Shellfish Flesh Shellfish Waters

Summary statistics and geographical variation

There are three shellfish waters sites designated under Directive 2006/113/EC (European Communities, 2006) around the Lune. Figure X.7 shows the location of these sites. Table X.4 presents summary statistics for bacteriological monitoring results and Figure X.8 presents a boxplot of faecal coliforms levels from the monitoring point.

Figure X.7: Location of monitoring points around the Lune.

Table X.4: 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
Plover Scar	49	22/01/2003	30/04/2013	22.0	<2	1,146	24.5	2.0
Broadfleet	49	22/01/2003	30/04/2013	21.5	<2	290	18.4	0.0
Number 16 Buoy	47	23/01/2003	20/06/2013	46.7	4	5,900	31.9	12.8

Datya from the Environment Agency

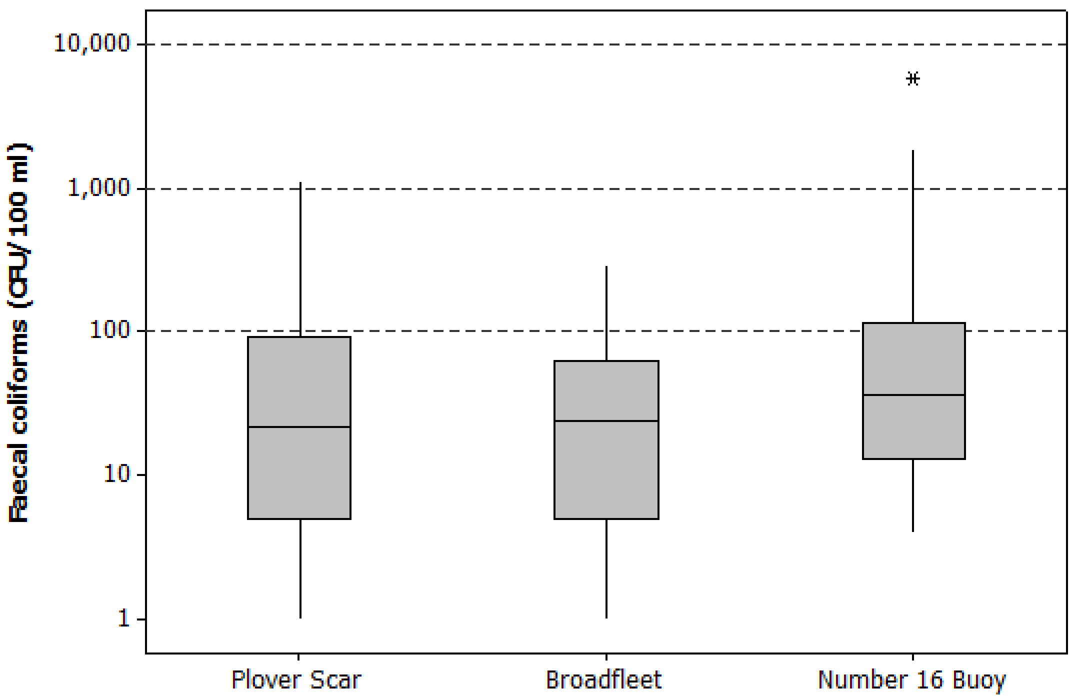


Figure X.8: Box-and-whisker plots of all faecal coliforms results
Data from the Environment Agency

Statistical comparisons (one-way ANOVA) showed that there were significant differences in faecal coliforms between the sites. However, post ANOVA Tukey tests did not reveal where this difference lay.

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. There was a strong correlation (p=0.000) between Plover Scar and Broadfleet, suggesting that these sites are influenced by similar sources. There was insufficient data for any comparisons with Number 16 Buoy.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at bathing water sites is shown in Figure X.9.

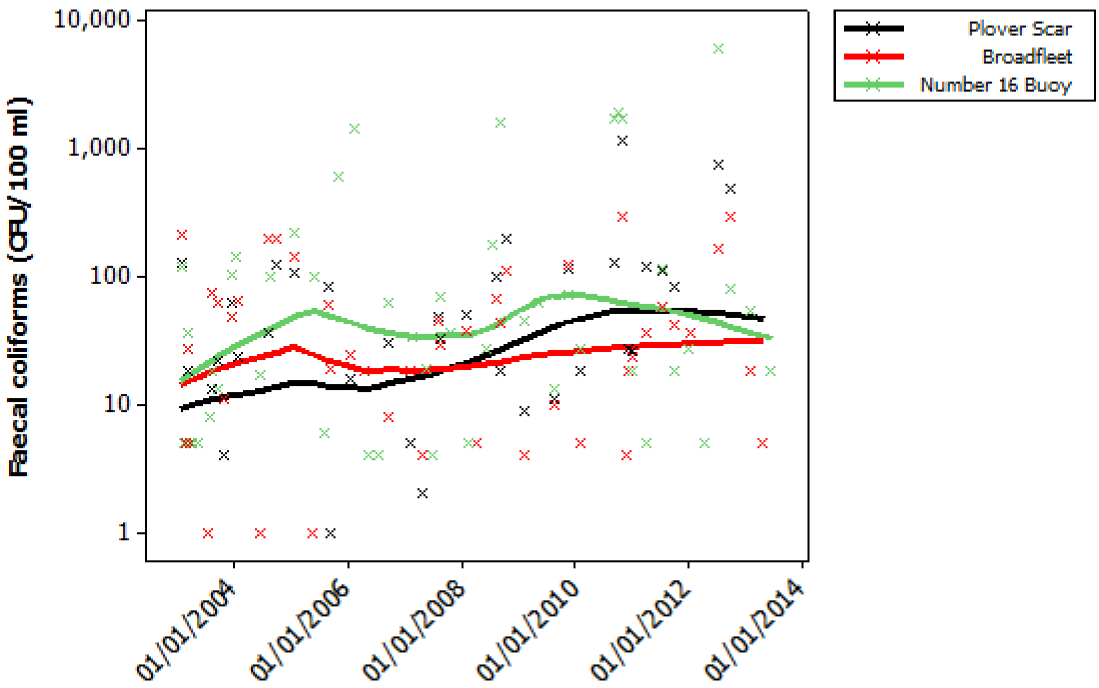


Figure X.9: Scatterplot of faecal coliform results by date, overlaid with loess lines
Data from the Environment Agency

Figure X.9 shows that faecal coliform levels at Broadfleet and Number 16 Buoy have remained stable overall since 2003. However, at Number 16 Buoy there was an increase in faecal coliform levels from 2003 to 2006 and from 2009 to 2010. Faecal coliform levels at Plover Scar increased steadily from 2003 to 2011.

Seasonal patterns of results

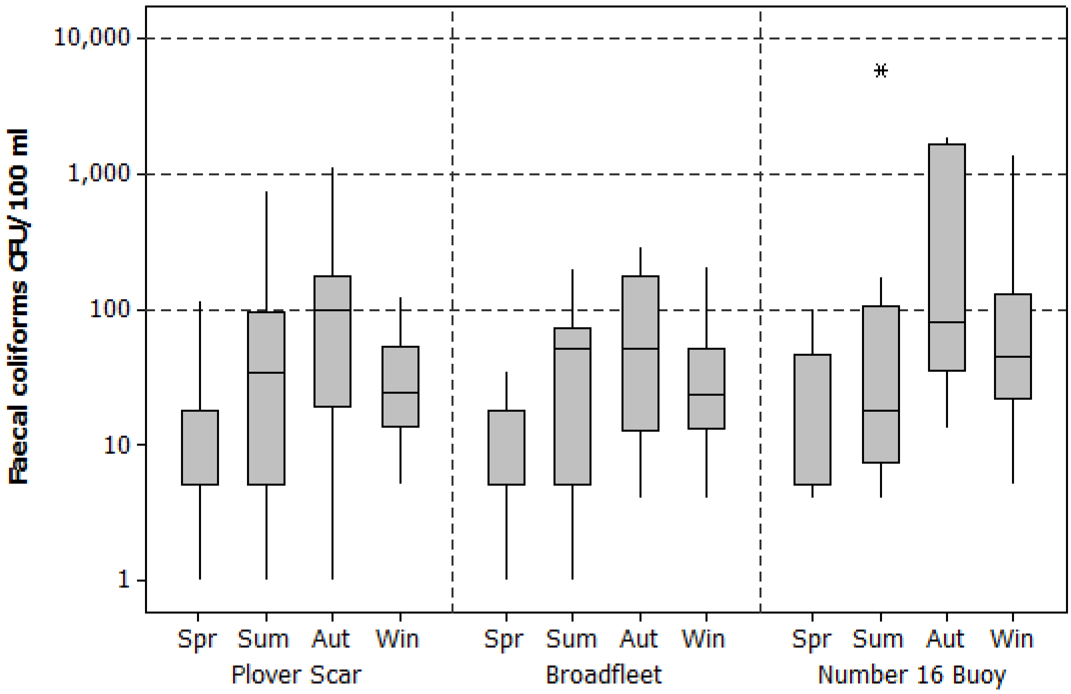


Figure X.10: Boxplot of faecal coliform results by site and season
Data from the Environment Agency

Comparisons (One-way ANOVA) of faecal coliform levels revealed that there were a significant difference between seasons at all three sites (p = 0.026, 0.013 and 0.009 at Plover Scar, Broadfleet and Number 16 Buoy respectively). Post ANOVA Tukey tests showed that at all three sites, faecal coliforms were higher in autumn than in spring.

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.5, with statistically significant ($p < 0.05$) 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**
Plover Scar	0.096	0.656	0.194	0.177
Broadfleet	0.129	0.463	0.040	0.929
Number 16 Buoy	0.519	<0.001	0.075	0.780

Data from the Environment Agency

Figure X.11presents a polar plot of $\log_{10}$ faecal coliform results against tidal state on the high/low cycle for Number 16 Buoy. High water at Glasson Dock is at 0° and low water is at 180°. Results of 100 faecal coliforms/100 ml 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.

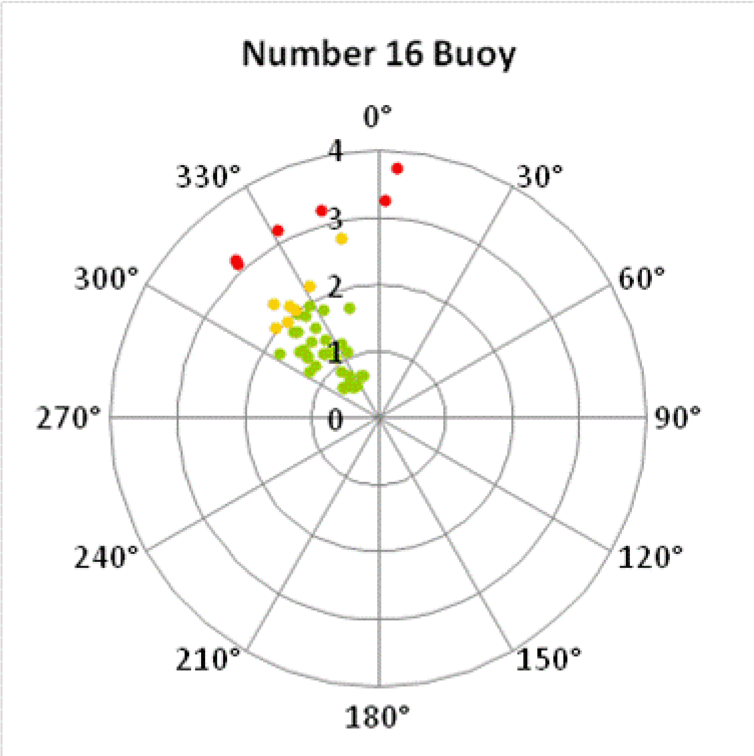


Figure X.11: Polar plots of log10 faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

Sampling at Number 16 Buoy was conducted around high tide. Samples taken towards the end of this window, when the tide had presumably begun to ebb appear much higher on average. This suggests that contamination from the Wyre estuary is a major influence here.

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 Stodday weather station (Appendix II for details) over various periods running up to sample collection and faecal coliform 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 coliform results against recent rainfall

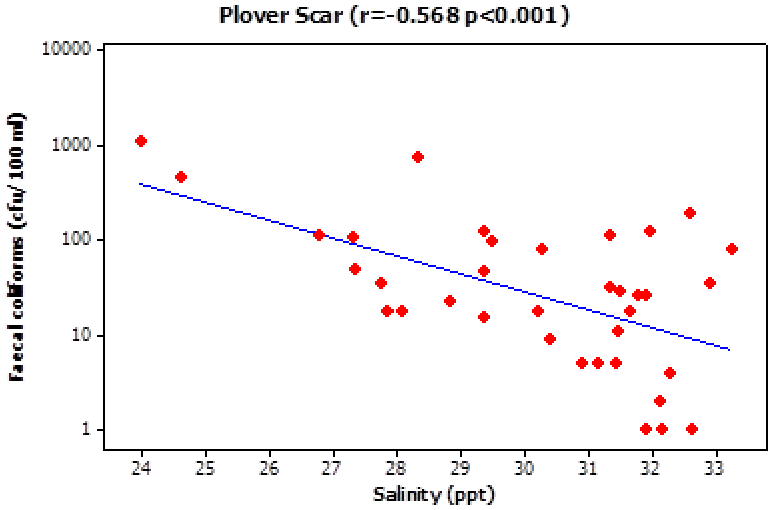
	Site	Plover Scar	Broadfleet	Number 16 Buoy
	n	47	47	45
24 hour periods prior to sampling	1 day	0.219	0.221	0.312
	2 days	0.547	0.481	0.329
	3 days	0.359	0.421	0.358
	4 days	0.512	0.363	0.086
	5 days	0.432	0.416	0.204
	6 days	0.434	0.462	0.173
	7 days	0.391	0.381	0.117
Total prior to sampling over	2 days	0.396	0.415	0.346
	3 days	0.484	0.525	0.417
	4 days	0.528	0.495	0.348
	5 days	0.600	0.577	0.375
	6 days	0.657	0.623	0.363
	7 days	0.692	0.656	0.357

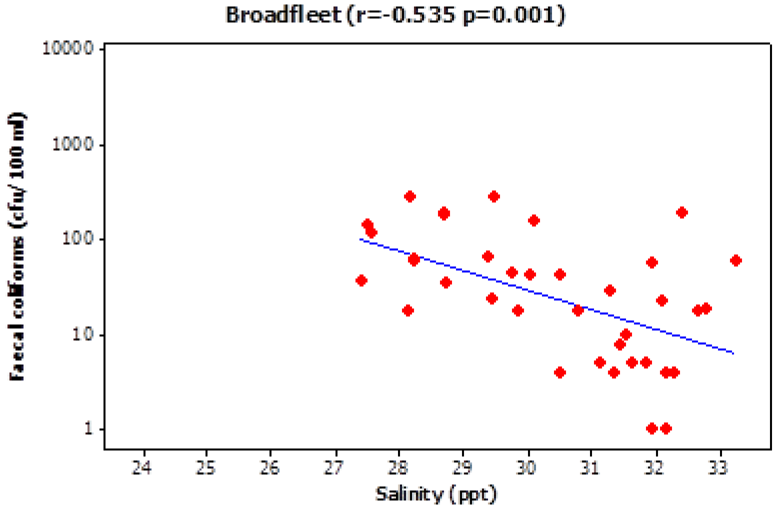
Data from the Environment Agency

Rainfall had a rapid effect on faecal coliform levels at all three sites. At Number 16 Buoy, rainfall increased faecal coliform levels within 24 hours, but rainfall that occurred more than 3 days before sampling had no influence on faecal coliform levels. This difference may be explained by Plover Scar and Broadfleet being under the influence of the Lune estuary, whilst the Number 16 Buoy is under the influence of the Wyre estuary.

Influence of salinity

Pearson's correlations were run to determine the effect of salinity on faecal coliforms at shellfish waters sites.





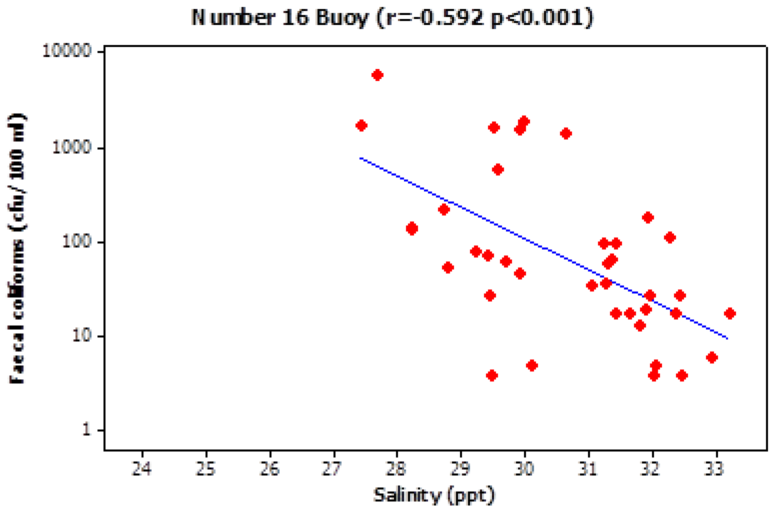


Figure X.12 shows a scatterplot of faecal coliforms against salinity and the results of Pearson's correlations between the two.

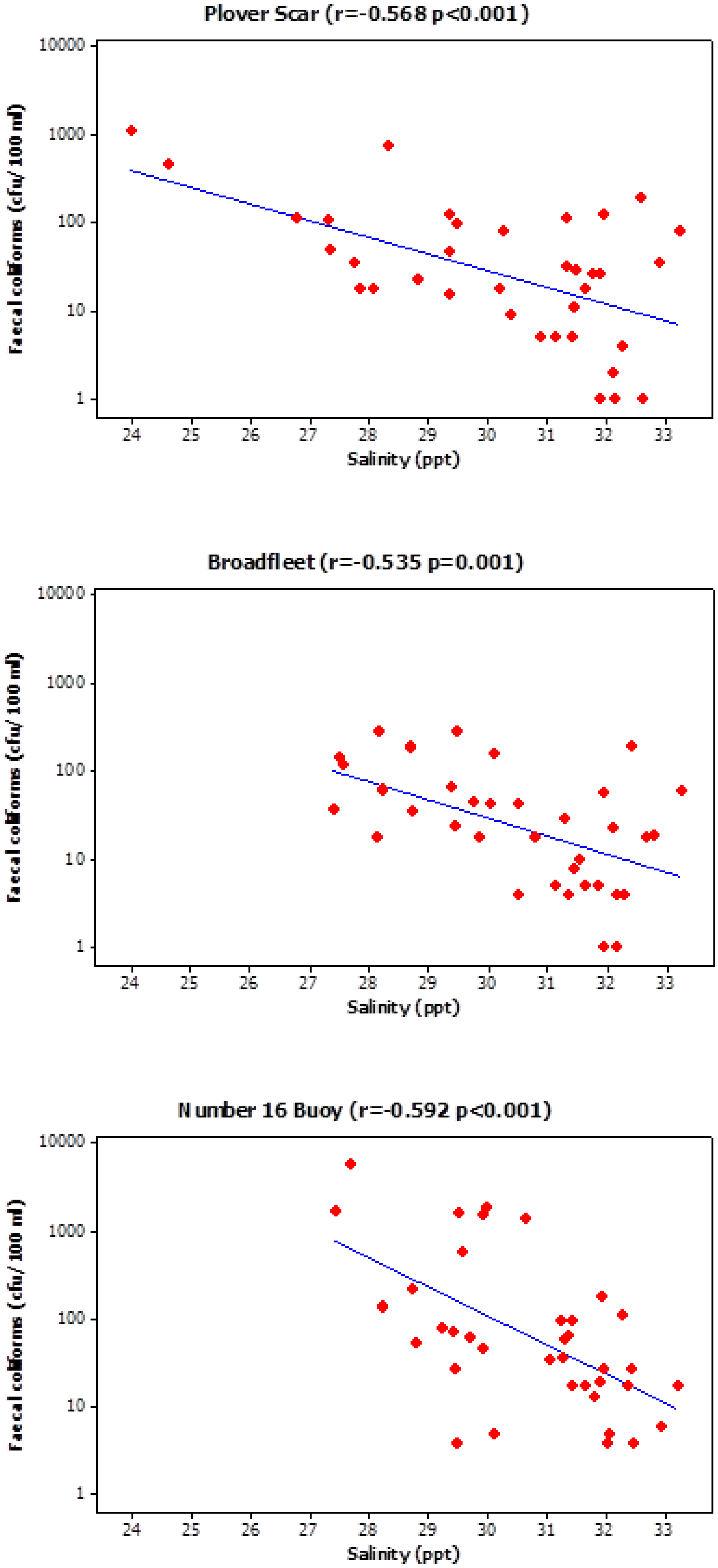


Figure X.12: Scatterplot of salinity against faecal coliform results
Data from the Environment Agency

A strong negative correlation between salinity and faecal coliform levels was observed at all three monitoring points suggesting that runoff borne contamination is a major influence throughout the area.

Appendix XI. Microbiological Data: Shellfish Flesh

XI.1. Summary statistics and geographical variation

There are a total of 12 RMPs in the Lune production area that have been sampled between 2003 and 2013. The geometric mean results of shellfish flesh monitoring from all RMPs sampled from 2003 onwards are presented in Figure XI.1. Summary statistics are presented in Table X.1 and boxplots for sites are shown in Figure XI.2 and Figure XI.3.

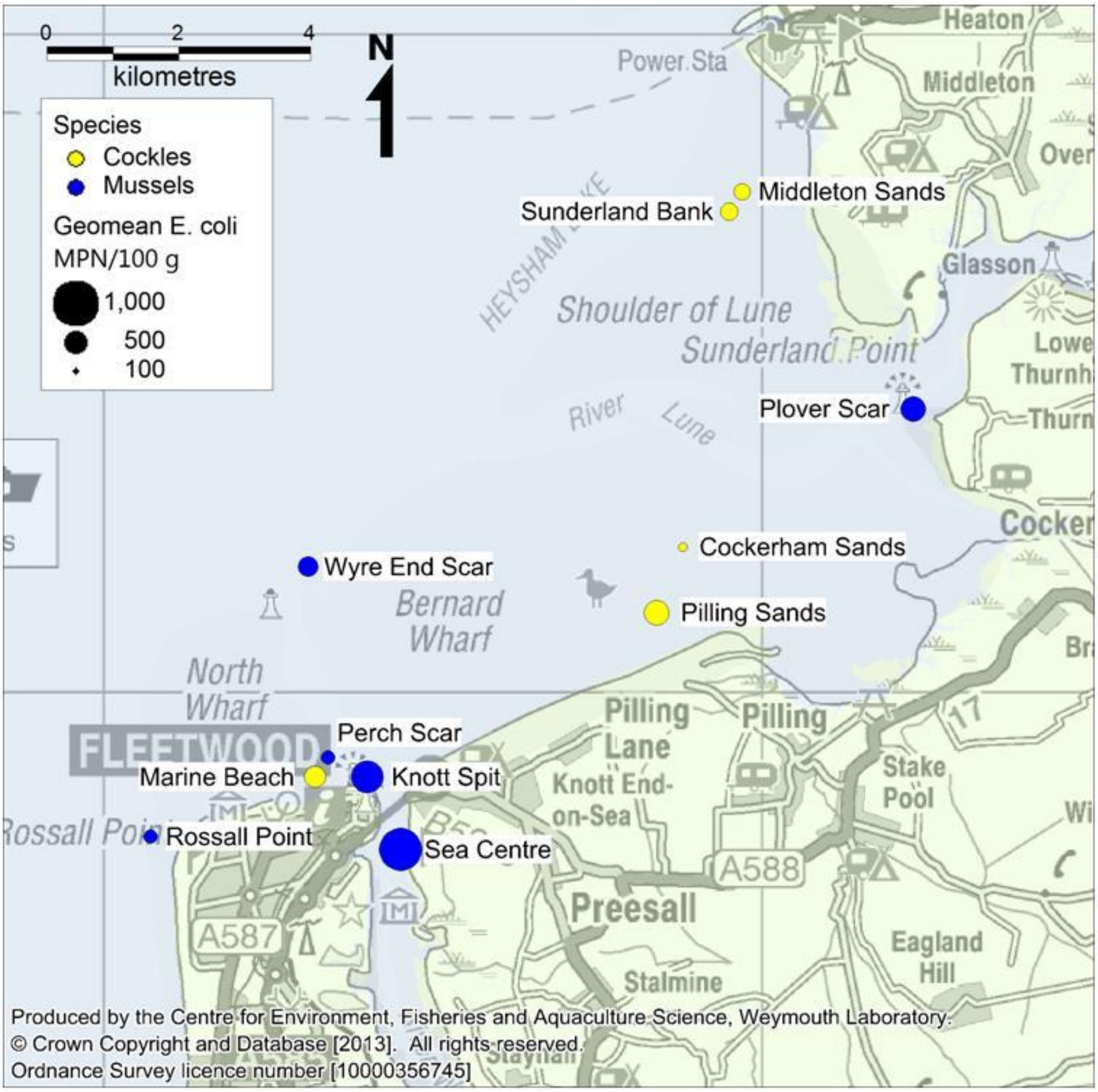


Figure XI.1: Bivalve RMPs active since 2003

(Marine Beach mussels not shown - only one sample see Table X1.1)

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

Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600	% over 46,000
Middleton Sands	Cockle	66	06/10/2005	05/03/2013	351.1	<20	35000	59.1	12.1	0.0
Sunderland Bank	Cockle	19	22/01/2003	21/11/2005	385.1	<20	24000	57.9	5.3	0.0
Cockerham Sands	Cockle	20	22/01/2003	02/03/2005	202.0	<20	750	50.0	0.0	0.0
Pilling Sands	Cockle	78	06/10/2005	15/07/2013	560.0	<20	16000	78.2	3.8	0.0
Marine Beach	Cockle	23	20/02/2003	23/05/2006	466.9	20	>180000	56.5	8.7	4.3
Plover Scar	Mussel	94	17/06/2003	16/01/2013	568.9	20	24000	72.3	10.6	0.0
Sea Centre	Mussel	101	22/01/2003	09/09/2013	952.8	70	54000	91.1	12.9	1.0
Knott Spit	Mussel	99	22/01/2003	18/03/2013	711.8	40	35000	79.8	11.1	0.0
Perch Scar	Mussel	2	26/09/2006	26/09/2006	301.7	70	1300	50.0	0.0	0.0
Marine Beach	Mussel	1	21/05/2003	21/05/2003	1100.0	1100	1100	100.0	0.0	0.0
Wyre End Scar	Mussel	23	22/01/2003	03/10/2005	451.5	40	3500	65.2	0.0	0.0
Rossall Point	Mussel	68	20/02/2003	11/08/2009	311.2	20	54000	58.8	2.9	1.5

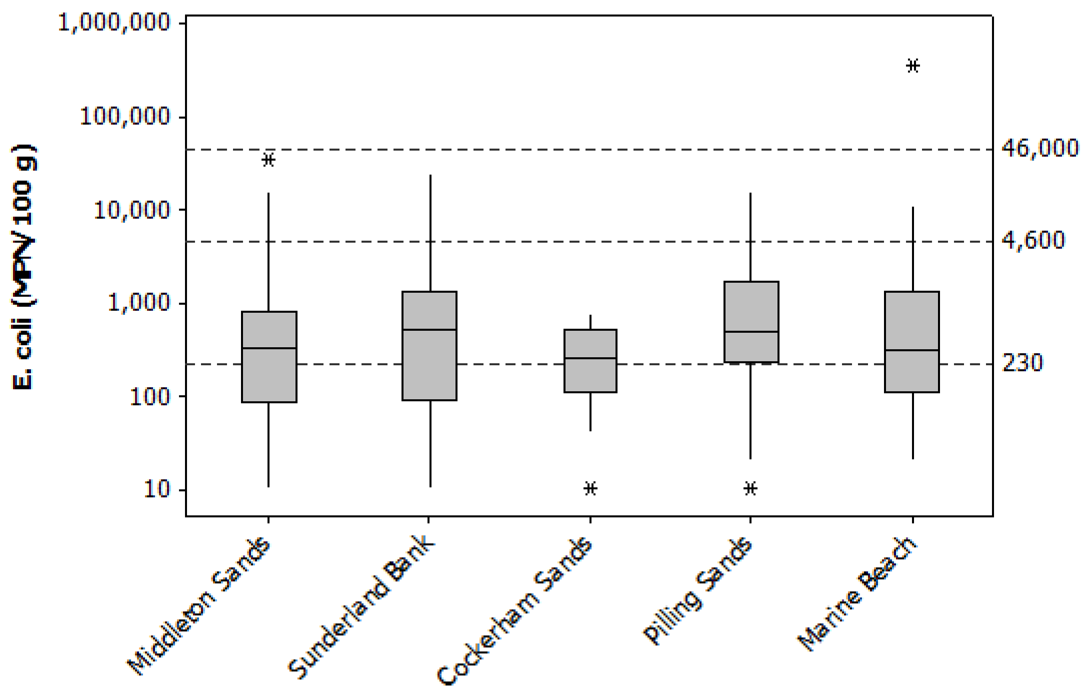


Figure XI.2: Boxplots of *E. coli* results from cockle RMPs from 2003 onwards.

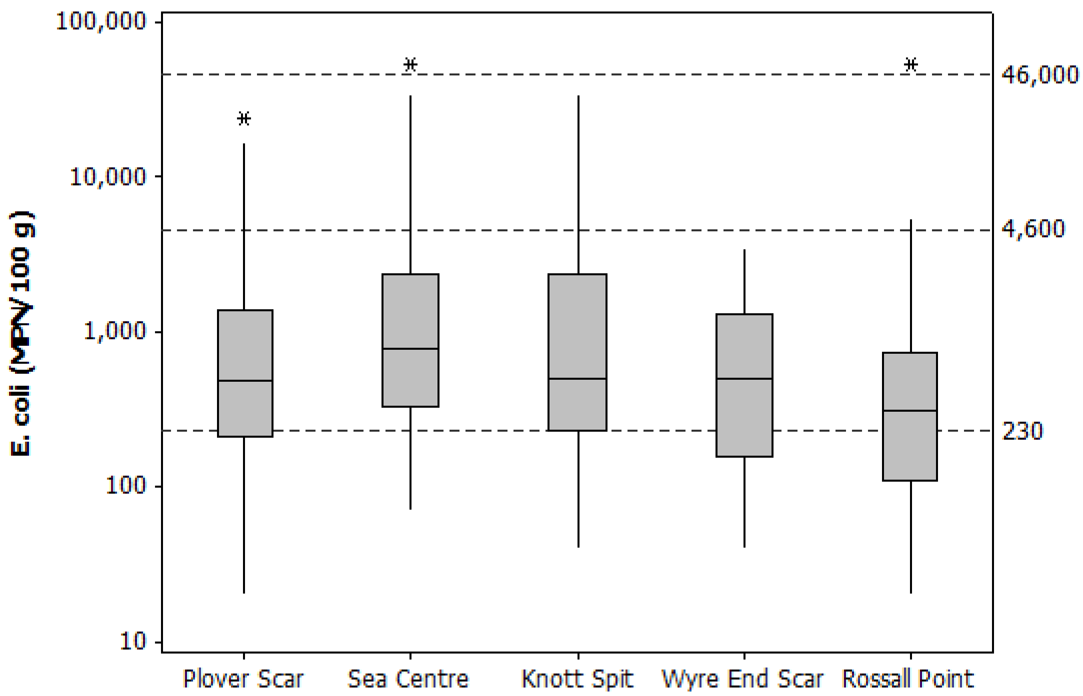


Figure XI.3: Boxplots of *E. coli* results from mussel RMPs from 2003 onwards.

Marine Beach and Perch Scar mussel RMPs were only sampled one and two times respectively and so will not be considered further. Of the remaining sites, only Cockerham Sands cockles and Wyre End Scar mussels did not have any results exceeding 4,600 *E. coli* MPN/100g. Marine Beach cockles and Sea Centre and

Rossall Point mussels had results exceeding 46,000 *E. coli* MPN/100g on one occasion.

Statistical comparisons (One-way ANOVA) of cockle RMPs showed that there was no significant differences between sites (p = 0.132). Similar comparisons for mussel RMPs revealed significant differences (p < 0.001). Post ANOVA Tukey tests showed that the *E. coli* results at Sea centre and Knott Spit were significantly higher than at Rossall Point.

Comparisons of RMPs 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. None of the cockle RMPs shared 20 or more sampling dates. At mussel RMPs correlation tests of Knott Spit vs Sea Centre, Wyre End Scar and Rossall Point were found to be significant (p < 0.05). There was also a significant correlation between Sea Centre and Rossall Point. This indicates that these RMPs probably share similar contamination sources.

XI.2. Overall temporal pattern in results

Figure XI.4 and Figure XI.5 show the overall temporal patterns in *E. coli* levels in cockles and mussels respectively.

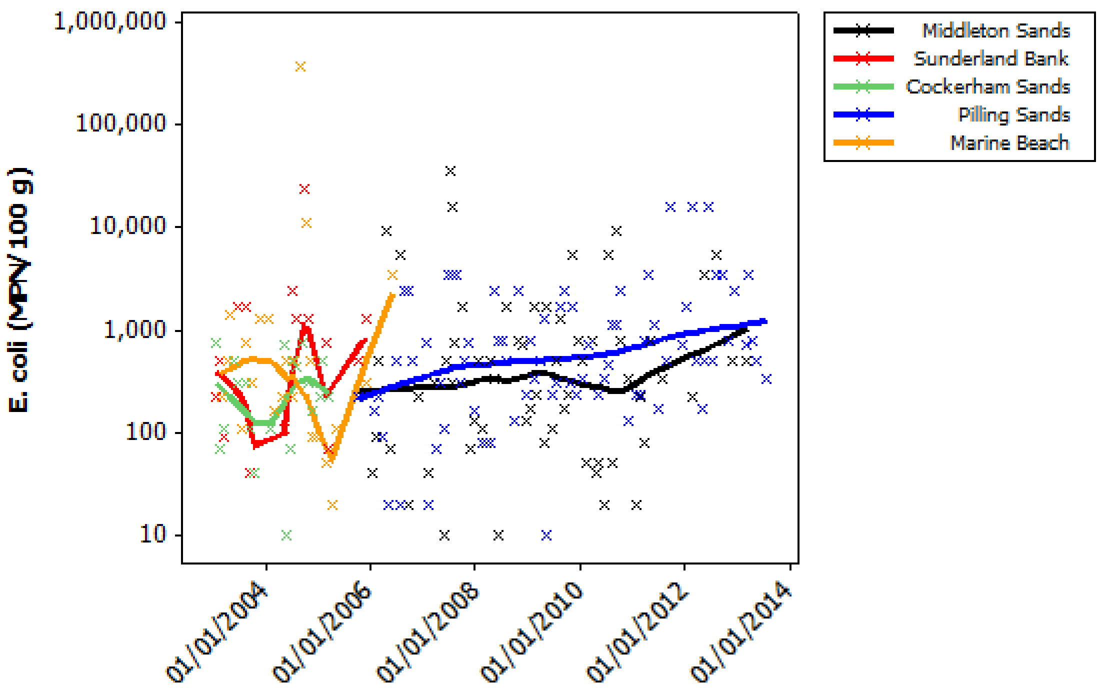


Figure XI.4: Scatterplot of *E. coli* results for cockles in the Lune production area overlaid with loess lines.

At the cockle RMPs *E. coli* levels at Sunderland bank, Cockerham Sands and Marine Beach were variable before sampling stopped. At Pilling Sands, overall *E. coli* levels have been increasing since the start of sampling in 2005. At Middleton Sands, *E. coli* levels were fairly stable from 2005 to 2011, but have increased to be similar to Pilling Sands from 2011 to 2013.

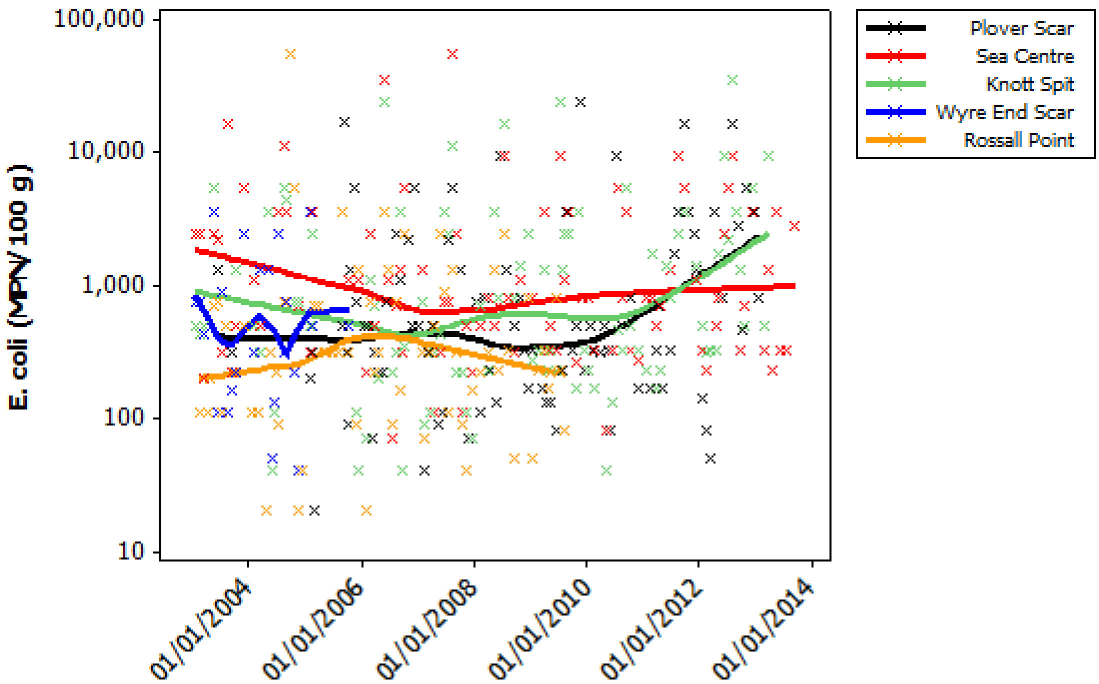


Figure XI.5: Scatterplot of *E. coli* results for mussels in the Lune production area overlaid with loess lines.

At mussel RMPs, *E. coli* levels at Wyre End Scar were variable before sampling stopped in 2005. At Rossall Point, *E. coli* levels increased slightly between 2003 and 2006 before returning to 2003 levels in 2009 when sampling stopped. At Sea Centre, *E. coli* levels have remained relatively stable since 2003, with a slight decrease from 2003 to 2007. At both Plover Scar and Knott Spit, *E. coli* levels remained stable from 2003 before entering a period of increasing *E coli* levels in 2010 to present.

XI.3. Seasonal patterns of results

Figure XI.6 and Figure XI.7 show the seasonal patterns in *E. coli* levels at cockle and mussel RMPs respectively.

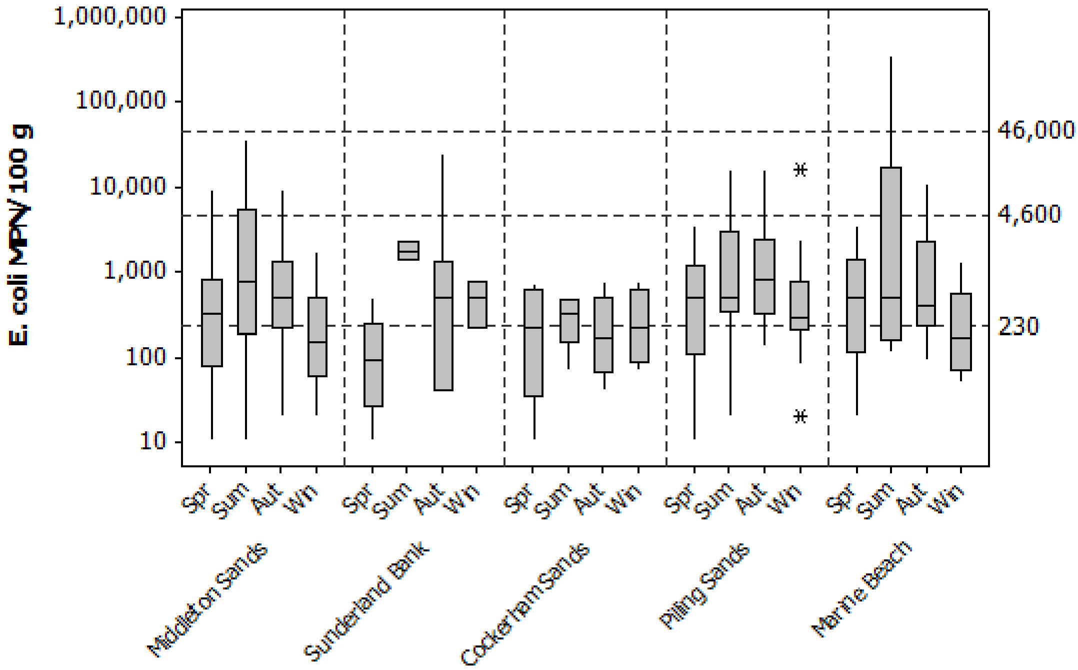


Figure XI.6: Boxplot of *E. coli* results in cockles by RMP and season.

A general tendency for higher results in the summer and autumn can be seen at all sites except for Cockerham Sands. One-way ANOVA tests revealed that while there was a significant difference in overall cockle *E. coli* levels between seasons (p = 0.001), there were no significant differences between seasons at individual sites (p = 0.081 to 0.872).

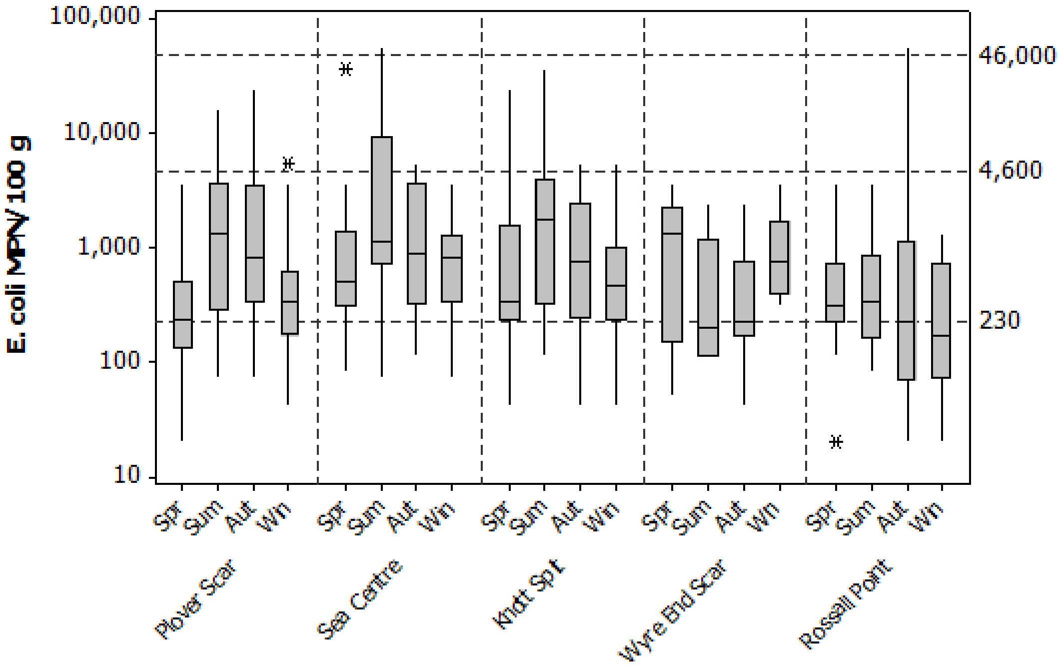


Figure XI.7: Boxplot of *E. coli* results in mussels by RMP and season.

A general tendency for higher results in the summer and autumn can be seen at most sites, with the exception of Wyre and Scar and Rosall Point. One-way ANOVA tests showed that there were significant differences in *E. coli* levels between seasons at Plover Scar ($p<0.001$), Sea Centre ($p = 0.032$) and Knott Spit ($p=0.034$). At Plover Scar, post ANOVA Tukey tests revealed that there were higher levels of *E. coli* during summer and autumn than during spring, and there were higher levels in autumn that in winter. At Sea Centre *E. coli* levels were higher in summer than in spring. At Knott Spit *E. coli* levels were higher in summer than in winter.

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 where more than 30 samples had been taken. Results of these correlations are summarised in Table XI.2, and significant results are highlighted in yellow.

Table XI.2: Circular linear correlation coefficients (r) and associated p values for *E. coli* results against the high/low and spring/neap tidal cycles

		High/low tides		Spring/neap tides	
Site Name	**Species**	**r**	**p**	**r**	**p**
Middleton Sands	Cockle	0.037	0.916	0.193	0.096
Pilling Sands	Cockle	0.200	0.050	0.102	0.460
Plover Scar	Mussel	0.135	0.191	0.058	0.737
Sea Centre	Mussel	0.174	0.052	0.163	0.073
Knott Spit	Mussel	0.186	0.036	0.196	0.025
Rossall Point	Mussel	0.119	0.396	0.048	0.862

Data from the Environment Agency

Figure XI.8 presents a polar plot of $\log_{10}$ *E. coli* results against tidal state on the high/low cycle for Knott Spit. High water at Glasson Dock 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 4600 are plotted in yellow, and those exceeding 4600 are plotted in red.

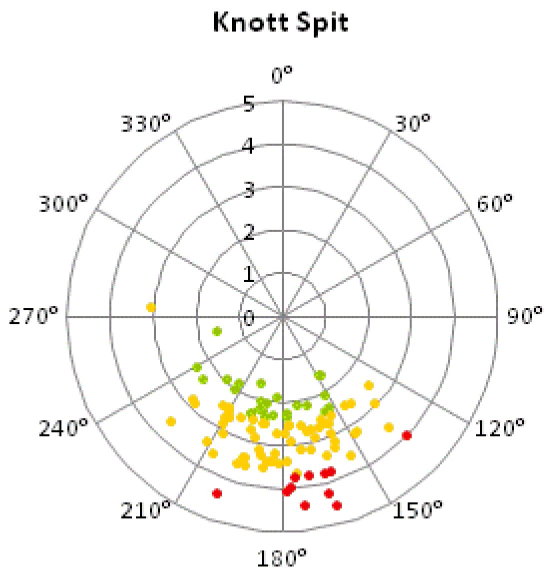


Figure XI.8: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) at Knott Spit mussel RMP against high/low tidal state

At Knott Spit, higher *E. coli* results tended to occur during the ebb tide.

Figure XI.9 presents a polar plot of $\log_{10}$ *E. coli* results against the spring neap tidal cycle for Knott Spit. 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 or less are plotted in green, those from 231 to 4600 are plotted in yellow, and those exceeding 4600 are plotted in red.

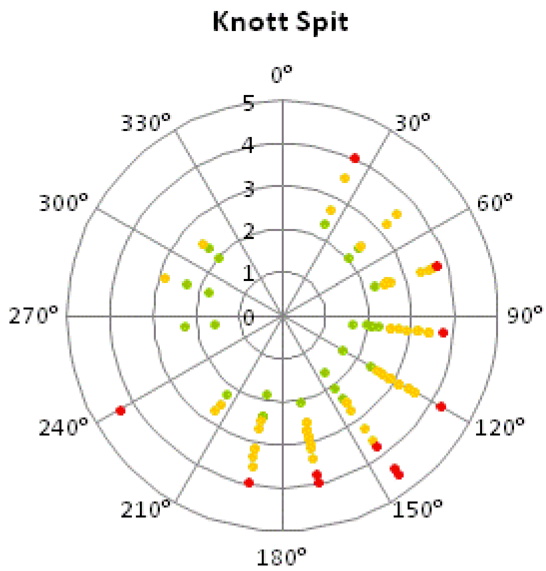


Figure XI.9: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) at Knott Spit mussel RMP against spring/neap tidal state

At Knott Spit, results were lower on average as tide size increased from springs to neaps, but few samples were taken during this period.

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 Stodday weather station (Appendix II for details) over various periods running up to sample collection. These are presented in Table XI.3, and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table XI.3: Spearman's Rank correlations between rainfall recorded at Stodday and shellfish hygiene results

	Site	Middleton Sands	Sunderland Bank	Cockerham Sands	Pilling Sands	Marine Beach	Plover Scar	Sea Centre	Knott Spit	Wyre End Scar	Rossall Point
	Species	Cockle					Mussel				
	n	65	19	20	73	23	93	94	97	23	68
24 hour periods prior to sampling	1 day	0.187	0.398	0.124	0.212	0.101	0.132	0.258	0.269	-0.160	0.024
	2 days	0.093	0.155	0.356	0.272	0.361	0.238	0.270	0.269	-0.006	0.013
	3 days	0.230	0.213	0.360	0.258	0.301	0.266	0.506	0.434	0.268	0.197
	4 days	0.313	0.383	0.180	0.172	0.457	0.350	0.313	0.236	0.128	0.346
	5 days	0.217	0.431	0.504	0.380	0.495	0.355	0.369	0.379	0.373	0.178
	6 days	0.254	0.307	0.456	0.211	0.512	0.200	0.280	0.303	0.226	0.178
	7 days	0.183	0.009	0.078	-0.129	0.209	0.224	0.272	0.193	0.019	0.028
Total prior to sampling over	2 days	0.268	0.248	0.268	0.309	0.250	0.201	0.338	0.373	-0.048	0.043
	3 days	0.276	0.355	0.393	0.341	0.260	0.279	0.432	0.442	-0.083	0.099
	4 days	0.305	0.394	0.351	0.331	0.226	0.371	0.470	0.459	-0.077	0.210
	5 days	0.337	0.488	0.589	0.398	0.300	0.431	0.536	0.540	0.070	0.261
	6 days	0.349	0.526	0.581	0.388	0.444	0.410	0.522	0.535	0.113	0.278
	7 days	0.349	0.455	0.436	0.337	0.418	0.425	0.532	0.548	0.123	0.275

All sites showed some influence of recent rainfall. The degree of influence was broadly similar across all the cockle RMPs. Across the mussel RMPs, three showed a strong and consistent influence of rainfall (Plover Scar, Sea Centre and Knott Spit) whereas at the other two, which are much more distant from the main estuary mouths, the influence of rainfall was much weaker (Wyre End Scar and Rossall Point).

Appendix XII. Shoreline Survey Report

Date (time):

10th September 2013 (0830-15:30)

11th September 2013 (0830-15:30)

12th September 2013 (0830-15:30)

Cefas Officers:

Rachel Parks (10th & 12th September 2013) and Louise Rae (10th, 11th & 12th September 2013)

Local Enforcement Authority Officers:

Neil Greenwood (Head of Environmental Health and Community Safety, Wyre Council) (11th September 2013)

Area surveyed:

Perimeter of Lune survey area (Figure XII.1).

Weather:

10th September 2013, sunny, wind 308°, 8.1 mph, air temp 16.2°C

11th September 2013, rain1.0 mm/hr, wind 246°, 4.0 mph, air temp 13.7°C

12th September 2013, overcast/sunny, wind 192°, 4.9 mph, air temp 17.1°C

Tides:

Admiralty Totaltide predictions for Fleetwood (53°56'N 3°00'W). All times in this report are BST.

10/09/2013	11/09/2013	12/09/2013
High 02:25 9.4 m	High 03:09 9.1 m	High 04:01 8.5 m
High 14:51 9.1 m	High 15:37 8.7 m	High 16:34 8.2 m
Low 09:04 1.6 m	Low 09:45 1.9 m	Low 10:37 2.4 m
Low 21:18 1.7 m	Low 22:06 2.1 m	Low 23:08 2.5 m

XII.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 and find out more information about the fishery. A full list of recorded observations is presented in Table XII.1 and the locations of these observations are mapped in Figure XII.1. Photographs are presented in Figure XII.3-Figure XII.30. The shoreline survey was undertaken over three days by foot. Every effort was made to ensure the entire shoreline was surveyed, although there were some short stretches where the shoreline could not be accessed.

XII.2. Description of Fishery

Mussels and cockle harvesting occurs within the Lune survey area. Middleton Sands North of the Lune River has recently been declassified due to insufficient stocks. Mussels are present on the Fleetwood sands and in the entrance to the River Wyre however their numbers are dwindling possibly due to a shifting sand flats. Cockle fishing is currently closed in the area. Shells of dead cockles were observed on the Middleton sand flats south of the Power Station.

XII.3. Sources of contamination

Sewage discharges

Two intermittent discharges were confirmed around the perimeter of the Lune survey area both were not flowing at the time of survey, observation 43 Pilling Lane PS Intermittent and Observation 76 Adj Manor Inn Car Park SSO. Possible storm overflows were observed adjacent to the Power Station on the western shore; these also were not flowing at the time of the survey (observation 30 and 31). Private Discharges were confirmed on the River Lune (observations 12, 14 and 15). One pipe was dripping at the time of the survey a water sample recorded 4,300 *E. coli* CFU/100ml (observation 14, sample L4).

Freshwater inputs

Numerous streams were observed flowing through the marshes (observation 1, 3, 6, 37 and 81) and surface drainage pipes mainly in the built up areas (observations 2, 38, 46 -61). A flowing stream was sighted adjacent to the caravan sight on the Middleton Sands Shore in the North of the survey area (observation 23). Underneath the possible storm overflow on the sea wall next to the Power Station there was a flow of water, its source was unknown and could not be accessed to identify (observation 30). A series of drainage ditches run parallel to the sea wall on the south shore, on the the marshland between Pilling and Cockerham marshes (observation 67, 68, 70). At intervals a series of sluices discharge into the marshes these include Mill House Outfall (observation 70) Cocker Bridge Outfall Penstock (observation 75), Pattys Barn Hasty Beck Tidal Flap (observation 78) and Bank End Tidal Flap (observation 82). Two fast flowing outfalls from the Power Station were observed but could not be sampled as they were covered by the tide and fenced off (observation 32 and 33).

Boats and Shipping

The Glasson Docks Marina and Fleetwood Marina were observed on the survey. Boats moored on the mudflats were observed at Sunderland (observation 5) in the River Wyre and at Glasson Docks Marina.

Livestock

Livestock were observed at regular intervals along the eastern side of the survey area. Cattle and sheep were observed grazing on salt marsh (observations 1, 20, 21, 35 and 81) and/or on fenced fields adjacent to the shoreline (observations 68, 69, 71, 72, 73, 85 and 87). Larger aggregations of sheep were recorded than cows. The largest herd of cattle, over 50 was observed in a field north of Overton (observation 21) and over 1000 sheep were recorded on the Cockerham marshes (observation 81). A few horses were also sighted grazing in fields and on the shore (observations 39 and 85).

Wildlife

Significant flocks of birds were observed throughout the survey, in particular on the intertidal rocks adjacent to the Power Station (observation 29), on the mudflats on the River Lune (observation 66) and south of the mouth of the River Lune (Observations 84 and 87). Smaller flocks of birds were also observed at observations 7, 13, 26, and 39 in the east. Dog walkers and dog excrement were frequently observed along the coastal paths.

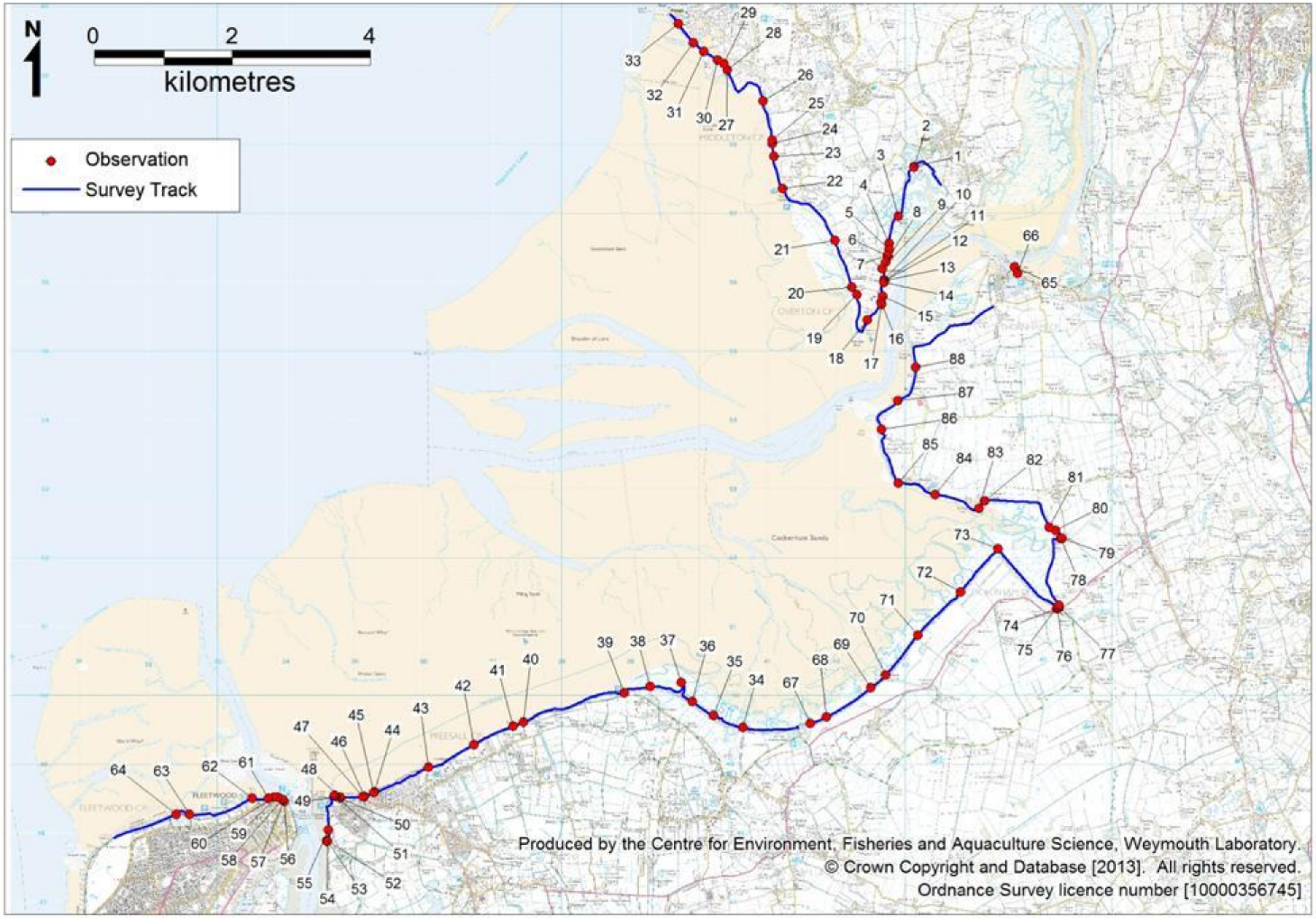


Figure XII.1: Locations of Shoreline Observations (see Table XII.1 for details)

Table XII.1: Details of Shoreline Observations

Observation No.	Date	Time	Position	Observation	Figure
1	10/09/2013	08:21	SD4311657673	Fast Flowing stream from marsh. Water sample 1. Not possible to access to measure. Cows grazing on marsh ~ 30	**Error! Reference source not found.**
2	10/09/2013	08:28	SD4311657666	Pipe with flap (possibly land drainage). Water sample 2. Not possible to access to measure	Figure XII.4
3	10/09/2013	08:55	SD4289056956	Fast Flowing stream from marsh. Water sample 3. Not possible to access to measure.	Figure XII.5
4	10/09/2013	09:04	SD4275856562	Multiple drainage channels flowing. Diverted under road by concrete pipes	
5	10/09/2013	09:07	SD4275756469	Boats moored on flats ~40	
6	10/09/2013	09:08	SD4274156377	Drainage channels flowing under road via pipes	
7	10/09/2013	09:09	SD4273756382	~50 birds on the mudflats	
8	10/09/2013	09:11	SD4270656288	Drainage pipes under road	
9	10/09/2013	09:20	SD4265656195	Public toilets with septic tank	Figure XII.6
10	10/09/2013	09:24	SD4268656026	2 pipes with flaps - dripping	
11	10/09/2013	09:25	SD4268956019	Pipe with flap - not flowing	
12	10/09/2013	09:27	SD4269256013	Large concrete structure with drain access (no visible pipe)	
13	10/09/2013	09:27	SD4269256013	~40 birds on the mudflats	
14	10/09/2013	09:29	SD4268055989	4 pipes - 1 with flap (10 ml iron pipe) dribbling. Water sample 4. Too small to measure.	Figure XII.7
15	10/09/2013	09:37	SD4266355788	Pipe on beach dripping. Birds on mudflats	
16	10/09/2013	09:43	SD4264255706	Pipeline crossing sign	
17	10/09/2013	09:45	SD4264755670	Pipe on beach flowing. Water sample 5. 2cmx13cmx0.738m/s.	Figure XII.8
18	10/09/2013	09:58	SD4243755449	Rabbit droppings	
19	10/09/2013	10:15	SD4229055817	All along HW mark - cotton wool buds	
20	10/09/2013	10:19	SD4221555925	Herd of cows ~50	Figure XII.9
21	10/09/2013	10:34	SD4197356602	>50 cows grazing on the marsh	
22	10/09/2013	11:03	SD4120757355	caravan park	

Observation No.	Date	Time	Position	Observation	Figure
23	10/09/2013	11:14	SD4108257825	End of caravan park. Discharge/stream 5cmx40cmx0.22m/s. Water sample 6.	Figure XII.10**Error! Reference source not found.**
24	10/09/2013	11:44	SD4106058009	Disused/broken pipe	
25	10/09/2013	11:48	SD4106058062	Large pipe with flap flowing 3cmx42cmx0.248. Water sample 7	Figure XII.11
26	10/09/2013	12:04	SD4092258631	~ 30 gulls	
27	10/09/2013	12:33	SD4040659081	Pipe submerged by the sea	Figure XII.12
28	10/09/2013	12:34	SD4040459079	Grids in line with the pipe on land by caravan park	
29	10/09/2013	12:37	SD4035659174	Up to 1000 birds on rocks next to power station	
30	10/09/2013	12:40	SD4026659222	Raised large pipe with 10cm grid (storm overflow) - not flowing. Below flow (unsure of source)	Figure XII.13
31	10/09/2013	12:45	SD4006259350	Storm overflow with 10 cm grid - not flowing	
32	10/09/2013	12:50	SD3991559472	Outfall from power station	
33	10/09/2013	12:56	SD3969259749	Outfall from power station	Figure XII.14
34	11/09/2013	08:16	SD4063649529	Broadfleet Outfall - channel through mud. Water sample 8. Too large to safely measure	Figure XII.15
35	11/09/2013	08:33	SD4020949707	Sheep grazing on marsh >500	
36	11/09/2013	08:41	SD3989849907	Drain in field - flowing channel 25cmx100cmx0.396m/s. Water sample 9	Figure XII.16
37	11/09/2013	09:01	SD3974150185	Drainage channel over marsh 2cmx25cmx0.223m/s. Water sample 10	
38	11/09/2013	09:21	SD3928650127	Field drain flap - not flowing 300mm diameter	
39	11/09/2013	09:35	SD3891250032	Horse and rider on sand and 200 gulls and dog walkers	
40	11/09/2013	10:09	SD3744349606	Preesall PS - 1 minute surge occurred whilst watching. EA advise sudden deep water surges.may occur Water sample 11 from behind.	Figure XII.17
41	11/09/2013	10:24	SD3729149551	Sheep droppings	
42	11/09/2013	10:37	SD3672749279	Sheep carcass	
43	11/09/2013	10:55	SD3606848957	Large pipe (1 metre wide) screened - rags noted	Figure XII.18
44	11/09/2013	11:21	SD3527948593	ceramic pipe - no flow	

Observation No.	Date	Time	Position	Observation	Figure
45	11/09/2013	11:22	SD3527248590	Pipe through breakwater	
46	11/09/2013	11:29	SD3513348531	Stagnant pool being pumped across shore by Lancashire County Council (portable pumping apparatus). Ceramic pipe not flowing close to steps. Water sample 21.	Figure XII.19
47	11/09/2013	11:38	SD3511148526	Start of series of Iron pipes - possibly surface water drainage	
48	11/09/2013	11:53	SD3478748508	End of series of Iron pipes - possibly surface water drainage	
49	11/09/2013	11:55	SD3477348521	Multiple drainage pipes off Promenade - dog droppings noted	
50	11/09/2013	11:58	SD3472148525	2 pipes under patio/deck of cafe/restuarant - no flow	
51	11/09/2013	12:02	SD3470348545	Drainage from behind nre concrete walls	
52	11/09/2013	13:03	SD3459347892	Pipes from holiday homes	
53	11/09/2013	13:04	SD3459347893	Wyre estuary seawater sample 13	
54	11/09/2013	13:07	SD3459547873	Drainage pipes from holiday homes. Water sample 14, too small to measure	
55	11/09/2013	13:14	SD3461248045	Drainage pipes from holiday homes	
56	11/09/2013	14:01	SD3396248462	Pipe under promenade behind sand dune flowing 15cmx2cmx1.072m/s. Water sample 15.	Figure XII.20
57	11/09/2013	14:06	SD3396148463	Pipe under promenade behind sand dune flowing	
58	11/09/2013	14:08	SD3394248485	Pipe under promenade behind sand dune flowing	
59	11/09/2013	14:11	SD3387548521	Pipe under promenade behind sand dune flowing	
60	11/09/2013	14:13	SD3381948522	Pipe disappears into sand from structure and draiange pipe	
61	11/09/2013	14:17	SD3374148504	Pipe under promenade behind sand dune flowing	
62	11/09/2013	14:22	SD3350248506	Drainage all along promenade - flowing	
63	11/09/2013	14:38	SD3259448265	Boating Lake - Nb. Dredged 4 years ago	
64	11/09/2013	14:44	SD3239648268	Pumping station from boating lake- pipe runs into sea for input/output	
65	12/09/2013	07:43	SD4458556215	.Over 800 birds on the mudflats. Seawater sample 16.	Figure XII.21
66	12/09/2013	07:50	SD4462456128	Victoria Hotel Pumping Station	
67	12/09/2013	09:04	SD4161049587	Pond with drainage ditch running parallel behind sea embankment	
68	12/09/2013	09:09	SD4185049680	~400 sheep behind sea defence. Land drainage to ditch	
69	12/09/2013	09:21	SD4248850106	~50 cows in field behind embankment	

Observation No.	Date	Time	Position	Observation	Figure
70	12/09/2013	09:25	SD4270850293	Mill House Outfall - sluice gate from drainage ditch behind. Water sample 17. Not possible to access to measure. Large manure pile located next to drainage channel	Figure XII.22
71	12/09/2013	09:42	SD4317350875	~100 sheep on field drainage ditch behind sea defence	
72	12/09/2013	10:05	SD4379351500	~200 sheep ~80 cows	
73	12/09/2013	10:21	SD4433752125	River Cocker over 500 sheep in nearby field. Water sample 18. Channel too large to measure	Figure XII.23
74	12/09/2013	10:52	SD4519351259	Manhole cover in field	
75	12/09/2013	10:53	SD4522551262	Cocker Bridge Outfall Peristock	
76	12/09/2013	10:56	SD4520451284	Iron Pipe with flap into Cocker Channel	
77	12/09/2013	10:57	SD4522851307	Pipe and channel which had recently been dredged 38cmx5cmx0.302m/s. Water sample 19.	Figure XII.24
78	12/09/2013	11:46	SD4525252276	Pattys Barn Hasty Beck Tidal Flap Stream. Water sample 20, not possible to access to measure.	Figure XII.25
79	12/09/2013	12:04	SD4527052281	Black Knights Parachute Centre Toilets Holiday Cottages and farm - query private discharge?	
80	12/09/2013	12:08	SD4518052391	Possible pipe under road overgrown ditch, no discharge	
81	12/09/2013	12:10	SD4508452436	~1000 sheep grazing on marsh fields with drainage channels meandering through	Figure XII.26
82	12/09/2013	12:33	SD4415152822	Bank End Tidal Flap. Water sample 21. Not possible to access to measure.	Figure XII.27
83	12/09/2013	12:40	SD4406352712	Banks End Farm/Caravan Park concrete with manhole covers possibly septic tank	
84	12/09/2013	12:53	SD4342852909	~800 birds on mudflats	Figure XII.28
85	12/09/2013	13:04	SD4289353084	Horses and cows in field behind breakwater	
86	12/09/2013	13:20	SD4264653858	Muck spreading on the fields	Figure XII.29
87	12/09/2013	13:32	SD4288854276	~1000 flock of gulls	Figure XII.30
88	12/09/2013	13:44	SD4314754766	~80 cows in field	

Sample Results

Freshwater inputs were sampled and spot discharge measurements taken, where possible to give spot estimates of their *E. coli* (CFU/100ml) loadings (Table XII.2 and Figure XII.2). Most of the larger watercourses were considered inaccessible by survey staff and could not be measured, but all were sampled. Seawater samples were taken from both of the major estuaries. The River Wyre sample was taken on a flood tide and 1,300 *E. coli* CFU/100ml was recorded. The River Lune sample was taken on an ebb tide and 3,100 *E. coli* CFU/100ml was recorded. Due to the extensive microbiological monitoring history of the area no shellfish sampling was considered necessary.

Table XII.2: Water sample *E. coli* results, spot flow gauging results and estimated stream loadings

Obs. No.	Sample no.	Description	Type	Discharge (m^3/day)	*E.coli* concentration (cfu/100ml)	*E. coli* loading (cfu/day)
1	1	Stream	Freshwater	Inaccessible	8900	
2	2	Stream	Freshwater	Inaccessible	>20000	
3	3	Stream	Freshwater	Inaccessible	>20000	
14	4	Pipe	Freshwater	Insufficient flow	4300	
17	5	Pipe	Freshwater	63763	>20000	$6.63x10^{10}$
23	6	Stream/discharge	Freshwater	19008	8900	$3.38x10^{10}$
25	7	Large pipe	Freshwater	21427	420	$1.13x10^{9}$
34	8	Broadfleet Outfall	Freshwater	Inaccessible	870	
36	9	Tidal Flap	Freshwater	34214	3400	$2.91x10^{11}$
37	10	Drainage channel	Freshwater	19267	75	$7.23x10^{7}$
40	11	Presall Pumping Station	Freshwater	Not pumping	2400	
46	12	Stagnant pool being pumped into marsh	Freshwater	Inaccessible	830	
53	13	River Wyre Seawater Sample	Seawater		1300	
54	14	Drainage pipes	Freshwater	Insufficient flow	3100	
56	15	Land drainage	Freshwater	92621	13000	$3.61x10^{10}$
65	16	River Lune Seawater Sample	Seawater		7000	
70	17	Mill House Outfall - Sluice	Freshwater	Inaccessible	1500	
73	18	River Cocker – Sluice gates	Freshwater	Inaccessible	10000	
77	19	Pipe	Freshwater	26093	3500	$1.74x10^{10}$

78	20	Hasty Beck Tidal Flap - Sluice	Freshwater	Inaccessible	>10000
82	21	Bank End Tidal Flap - Sluice	Freshwater	Inaccessible	14000

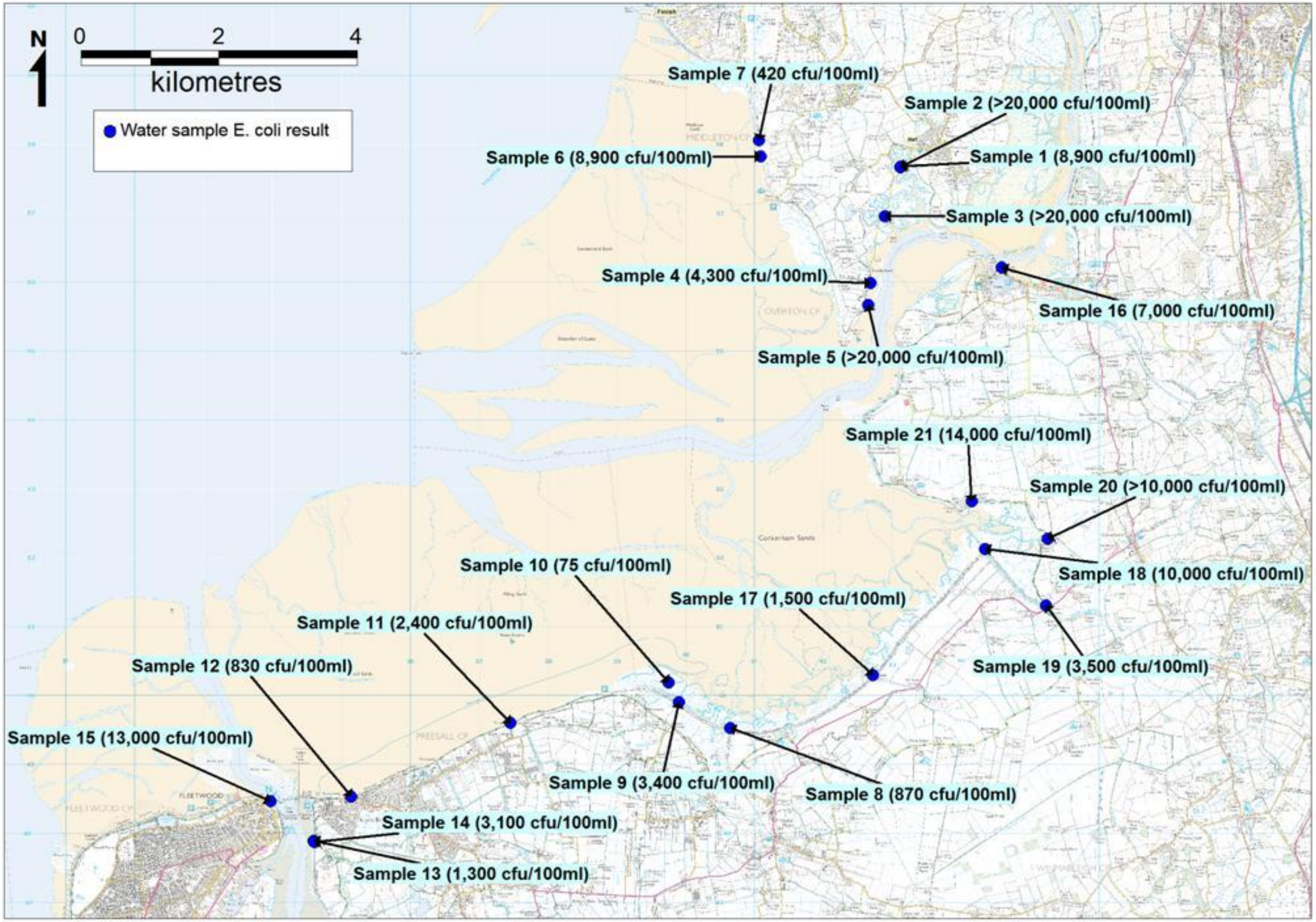


Figure XII.2: Locations of water samples taken from the Lune estuary

Figure XII.3

Figure XII.4

Figure XII.5

Figure XII.6

Figure XII.7

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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
NW IFCA	North Western Inshore Fisheries and Conservation 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
TACs	Total Allowable Catches
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”.

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