Centre for Environment Fisheries & Aquaculture Science

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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Morecambe Bay

December 2014

Food Standards Agency

Cover photo: Walney Meetings

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Statement of use

This report provides a sanitary survey relevant to bivalve mollusc beds within Morecambe Bay, 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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2	Draft for client/consultee comment	Andrew Younger	07/01/2015
3	2nd draft for IFCA comment	Simon Kershaw	02/04/2015
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Consultation

Consultee	Date of consultation	Date of response
Barrow in Furness Borough Council	21/01/2015	-
South Lakeland District Council	21/01/2015	-
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North Western IFCA	21/01/2015	04/02/2015
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Dissemination

Food Standards Agency, Barrow in Furness Borough Council, South Lakeland District Council, Lancaster City Council.

Recommended Bibliographic Reference

Cefas, 2014. Sanitary survey of Morecambe Bay. 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. 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 bivalve mollusc production areas (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 the faeces of warm-blooded animals 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.), cockles (*Cerastoderma edule*) and Pacific oysters (*Crassostrea gigas*) within Morecambe Bay. It covers three 'production areas' (Morecambe Bay East, Morecambe Bay Roosebeck and Morecambe Bay Barrow). Instead of presenting these as two surveys and a review of a previous survey as originally scheduled, it was decided that the whole area should be considered in one survey in the interests of coherency and efficiency.

1.2. Area Description

Morecambe Bay is the second largest embayment in the UK, after The Wash. It is located on the Cumbria Lancashire Border, in north west England (Figure 1.1).

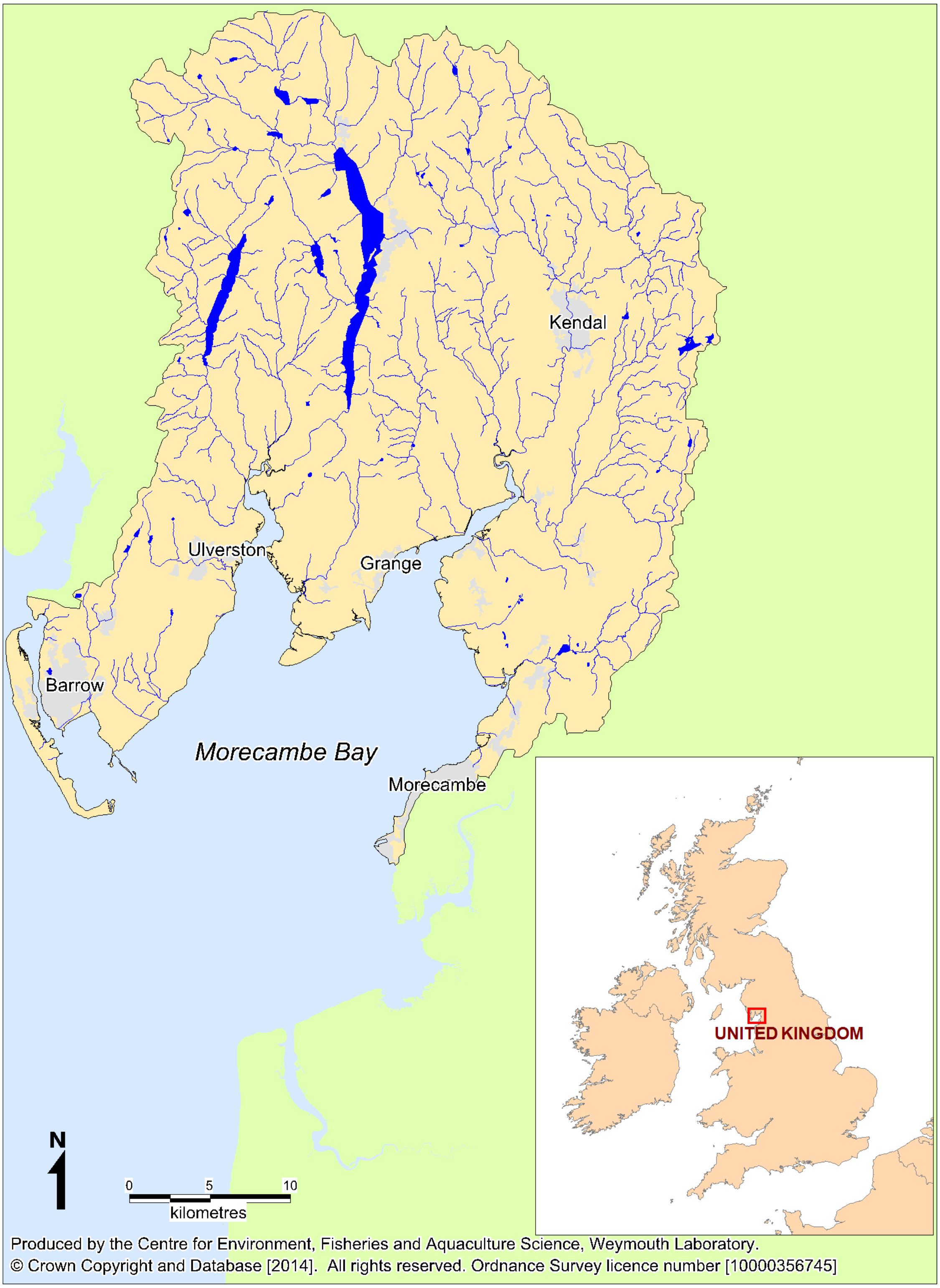

Figure 1.1: Location of Morecambe Bay

The estuaries of several significant rivers drain to the Bay, and at low tide large areas of intertidal sand flats are exposed. The survey area also includes the Walney Channel, which lies in the lee of Walney Island and connects Morecambe Bay to the neighbouring Duddon estuary at high tide. The area addressed in this survey does not include the southernmost part of the bay, where the Lune and Wyre estuaries are located, as this was covered in a separate report (Cefas, 2013). The two main coastal towns are Morecambe/Heysham and Barrow, which lie opposite one another in the outer reaches of the survey area. The economy is based around industry, agriculture, and tourism. Morecambe Bay also supports important shellfisheries, including a Pacific oyster hatchery and trestle farm, significant mussel stocks which are taken as both 'size'[1] and 'undersize'[2], as well as sporadic but sometimes very large settlements of cockles.

1.3. Catchment

Figure 1.2 illustrates land cover within the hydrological catchment which covers an area of approximately 1,268 km². The principle land cover type is pasture. There are also a few small pockets of arable land in the lower catchment. Significant wooded areas are present, mainly in the middle reaches of the western half of the catchment. Natural grassland and moor/heathland cover most of the higher elevations in the northernmost reaches of the catchment. The extent of urbanised areas is limited, and a large proportion of these lie on the coast.

[1] Size mussels refers to mussels above the minimum landing size (45 mm shell length) marketed directly for human consumption, following any required post harvest treatment.
[2] Undersize refers to mussels of less than 45 mm (either part grown or seed) which are taken for transplanting and ongrowing elsewhere. The undersize fishery does not require a hygiene classification.

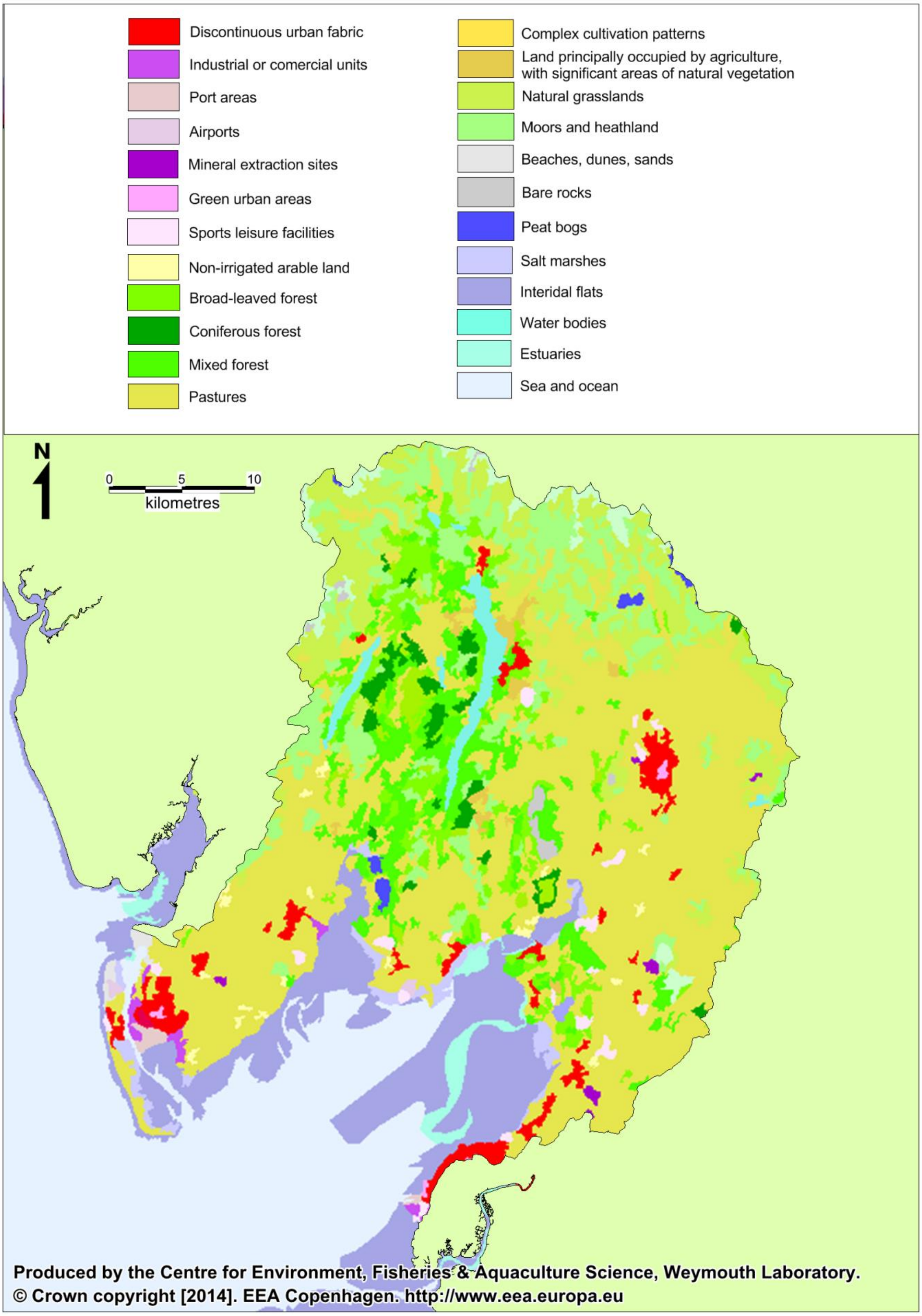

Figure 1.2: Landcover in the Morecambe Bay catchment

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 the contributions from which increase up to 100 fold.

The hydrogeology varies from very low permeability throughout most of the more inland areas to moderate permeability throughout most coastal areas, and areas of high permeability at Barrow and Roosebeck (NERC, 2012). Elevations in the upper catchment reach almost 900 m. A rapid response to rainfall and high runoff rates are anticipated for watercourses in the upper catchment, but a slower response is anticipated from the smaller, lower lying coastal streams draining directly to the bay.

2. Recommendations

It is recognised that shifting stock distributions may result in changes to the exact location of some RMPs. The constantly changing bathymetry within the bay, coupled with the large uncertainties over the future extent of any commercial cockle settlements make it impossible to provide a definitive, fully geographically referenced sampling plan for this species which would be applicable to all scenarios. Where needs be, RMP locations (and possibly even zone boundaries) may require adjustment. Any changes to RMP locations (or zone boundaries) should follow the principles identified in these recommendations to ensure they are best protective of public health. Any proposed changes to boundaries and/or RMPs should be discussed and agreed in advance with Cefas and the FSA. Most of these sampling plans will not require immediate implementation as they cover shellfish resources which are not currently being harvested.

2.1. Cockles

The cockle fishery is currently closed as stocks are considered to be below safe biological limits. The earliest a fishery could open is September 2016, if the IFCA identify a significant settlement during summer 2015 surveys which subsequently survives to maturity. This would provide a notice period of about a year during which classifications will need to be re-established. The following nine zones are proposed, not all of which will necessarily require classification in the event of a settlement. The IFCA will continue sampling on a quarterly basis within four of these (Newbiggin, Ulverston, Central East and Central West) to maintain their 'temporarily declassified' status.

Snab Sands

This area may in the future support minor settlements of cockles. A part of Snab Sands lie within a protected seagrass zone where gathering is not permitted. This protected area should therefore be excluded from any future classified zone. There is little in the way of sources discharging to this zone. There is some grazed saltmarsh and a sizeable private discharge from a caravan park. Other sources of possible influence include numerous moorings and intermittent discharges in the vicinity of the Jubilee Bridge, Mill Beck, and a small sewage works at Roa Island but these are relatively remote. It is therefore recommended that the cockle RMP be located as close as possible to the intertidal drainage channel to which the caravan park discharge is made, as far inshore as stocks extend.

Roosecote Sands

This area may in the future support minor settlements of cockles. A large part of Roosecote Sands lie within a protected seagrass zone where gathering is not permitted. This protected area should therefore be excluded from any future classified zone. The main source locally is the Barrow STW outfall which discharges to the eastern edge of the subtidal channel about 500 m south of the dock entrance. Contamination from this will be carried along the outer edge of Roosecote Sands on the ebbing tide. Other sources of possible influence include an intermittent discharge to the intertidal about 400 m from the northernmost corner of this zone, numerous moorings and intermittent discharges in the vicinity of the Jubilee Bridge, Mill Beck, and a small sewage works at Roa Island. It is concluded that the RMP should be located as close to the edge of the main subtidal channel and as far north as it is possible to sample.

Newbiggin

Should a significant cockle settlement occur it is likely that commercial densities will be present throughout most of this zone. There are two watercourses draining to the foreshore within this zone. The larger of these is the Deep Meadow Beck. It receives UV treated sewage from Newbiggin STW, and effluent from an intermittent discharge from this works which was active for 32.2% of the time in recent years. The smaller Sarah Beck drains to the shore about 1.5 km south of Deep Meadow Back. The Rampside Village intermittent overflow discharges to the shore at the south western end of this zone, but was only active for 0.8% of the time in recent history. There are some significant sources of contamination to the north of this zone (e.g. the River Leven and Ulverston STW) but microbiological monitoring results do not indicate a general increase in levels of contamination northwards along this shore. It is therefore recommended that the RMP is located immediately adjacent to the Deep Meadow Beck drainage channel, as far inshore as stocks extend. The IFCA indicate that there are some stocks at the recommended RMP and they will continue quarterly sampling in this zone.

Ulverston

Should a significant cockle settlement occur it is likely that commercial densities will be present in this zone, although it may be less likely that they will extend all the way to the northern boundary based on historical occurrences. There are two intermittent discharges direct to this zone, and one about 200 m to the north. Two are monitored and both hardly spilled at all in recent times (<0.2% of the time). There are two large sewage discharges of similar sizes which are located about 2.5 km to the north of this zone. Ulverston STW is a large municipal works providing UV treatment, and there is also a large discharge from the Glaxo Smith Kline Factory, both of which generally contain low concentrations of faecal coliforms. The Glaxo Smith Kline discharge is tidally phased, and operates for 45 minutes each tidal cycle starting 30 minutes after high water. There is also a cluster of intermittent discharges in the Ulverston area, which include the Ulverston STW overflow which operated for 19.8% of the time in recent history. There are no significant watercourses draining directly to the zone, but the Dragley Beck is located about 2.5 km to the north and the Leven estuary, to which a significant catchment area drains, lies further to the north. There may also be significant but more diffuse inputs from saltmarsh grazing, also to the north of the zone. Whilst it is likely that some contamination arrives from the south on the flooding tide, for example from Newbiggin STW and overflow, it is recommended that the RMP is located as far north and as close as possible to the main Leven Channel to capture contamination arriving from the north. The IFCA will continue quarterly sampling within this zone, and advise that currently, stocks are only present towards the south west corner. The co-ordinates for the recommended RMP have been adjusted to reflect this, and may require significant re-adjustment towards the target RMP location identified above, should a major increase in stock occur.

Central West

Should a significant cockle settlement occur it is likely that commercial densities will be present in this zone, although it is unlikely that they will extend as far as its northern boundary based on historical occurrences. There are no point sources discharging directly to this zone, and all significant sources are located to the north. These include the Leven estuary, large areas of grazed saltmarsh and the River Eea. The Eea receives several intermittent discharges to its lower reaches, including two at Cark which spill for significant periods of time (active for 31.9% and 27.4% of the time in recent years). Its drainage channel appears to cut through the north western corner of this zone before converging with the main Leven Channel. It is therefore recommended that the RMP is located as far north west as stocks extend, and as close to the Eea drainage channel as possible. The IFCA indicate that they will continue quarterly sampling within this zone and advise that at present the nearest stocks are about 3 km south of the Eea channel. The co-ordinates for the recommended RMP have been adjusted to reflect this, and may require significant re-adjustment towards the target RMP location identified above, should a major increase in stock occur.

Central East

Should a significant cockle settlement occur it is likely that commercial densities will be present in this zone although it is unlikely that they will extend as far as its northern boundary based on historical occurrences. All significant sources of contamination impacting on this zone are located either on its north shore or further to the north within the Kent estuary. The Grange-over-Sands STW discharges to the north shore of the zone, but provides UV treatment so should generally only be a minor influence. Its overflow only spilled for 0.6% of the time in recent years. There is also some grazed saltmarsh along the north shore. It is, however, concluded that most contamination delivered to this zone will be from the Kent estuary, so it is recommended that the RMP is located as far north and as close as possible to the main Kent channel as stocks extend. The IFCA advise that they will continue quarterly sampling here and that the nearest stocks are about 6 km south of the northern edge of this zone, and 4 km west of the Kent channel. The co-ordinates for the recommended RMP have been adjusted to reflect this, and may require significant re-adjustment towards the target RMP location identified above, should a major increase in stock occur.

Silverdale

Should a significant cockle settlement occur it is likely that commercial densities will be present in this zone although it is unlikely that they will extend as far as its northern boundary based on historical occurrences. There is a minor watercourse discharging to the shore at the southern end of Silverdale, as well as significant areas of grazed saltmarsh immediately to the south of the watercourse. The River Bela, which receives UV treated effluent from Carnforth STW in its tidal reaches lies about 2.5 km to the south of this zone. The majority of contamination delivered to this zone however is likely to be from the Kent estuary. It is therefore recommended that the RMP is located as far north and as close as possible to the main Kent channel as stocks extend.

Keer

Should a significant cockle settlement occur it is likely that commercial densities will be present throughout most of this zone. The River Bela, which receives UV treated effluent from Carnforth STW in its tidal reaches discharges to the shore towards the northern end of this zone. None of the monitored intermittents discharging to the area spilled for more than 3% of the time in recent years. The Bela drainage channel will cut through any cockle settlement on the intertidal before converging with the main Kent channel. There are large areas of grazed saltmarsh adjacent to the northern half of this zone. There is also a small but contaminated surface outfall at Hest Bank. It is recommended that the RMP is located immediately adjacent to the Bela drainage channel, as far inshore as stocks extend.

Morecambe/Heysham

If any cockle settlements do occur within this zone, they are likely to be relatively minor and localised based on historical occurrences. The Schola Green Lane pumping station discharges to the seafront to the eastern end of this zone. This asset was only active for 0.8% of the time in recent years, but when active it spills very large volumes of storm sewage. There are two other intermittent discharges to the shore within this zone, one of which is unmonitored, and the other of which (Heysham Village PS) was only active for 0.1% of the time in recent history. UV treated effluent from Morecambe

STW is discharged to deeper water to the south west, and although it will be carried in the direction of this zone on the incoming tide the effluent contains low concentrations of faecal indicators. It is therefore recommended that the RMP is located as close as possible to the Schola Green Lane PS outfall which represents the greatest risk of a significant contamination event. This location should also capture background contamination deriving from remote sources.

The following specifications apply to all cockle RMPs:

- They will only require classification if the IFCA identifies that there are sufficient stocks to open a fishery. This may only occur once a decade, but when it does a high level of effort is anticipated, so classifications must be in place before the fishery opens. The IFCA should be able to advise if such a fishery is likely to develop about a year in advance. Not all beds/zones may require classification when such an event does occur, as some areas are more likely to be colonised than others.
- The sampling interval should be monthly. The first two months of the closed season (May and June) may be omitted assuming all other 10 months are sampled and the current closed season is maintained. 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 (i.e. animals should not pass through a 20 mm square aperture).
- 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 five zones are proposed for mussels:

North Walney

This area supports a small size mussel fishery and was also the site of an unsuccessful trial of culturing transplanted seed. There is a suspected small private discharge to the area from North Scale. There is a cluster of 10 intermittent discharges to the south of the area, around the Jubilee Bridge. Most are unmonitored, but of those which are monitored the most active one operated for only 3.9% of the time in recent years. To the north there is one intermittent discharge (Palace Nook PS) but this has not spilled at all in recent years. The Barrow STW discharges to eastern edge of the subtidal channel about 500 m south of the dock entrance, and effluent from this will be carried towards the mussel area on an incoming tide. There is little in the way of freshwater inputs to the Walney Channel. The main one (Mill Beck) passes through the

Cavendish Reservoir and the Barrow docks before entering the channel. There are also a large number of moorings to the south of the area. Given that the main sources of contamination are to the south, and mainly to the mainland shore, it is recommended that the RMP be located in the south east corner of the zone.

Roa Island

This zone includes a small bed of size mussels to the west of the lifeboat slipway at Roa Island which is active at present. The main contaminating influences will be within the south Walney Channel, and include the (UV treated) Barrow STW about 3.5 km away, and the much smaller Roa Island STW which discharges to the lower intertidal immediately adjacent to the mussel bed. There are also numerous boat moorings and intermittent discharges further up the Channel around Jubilee Bridge. It is therefore recommended that the RMP is located at the south western edge of the bed, in the lower intertidal, adjacent to the Roa Island STW outfall.

Bass Pool

Formal interest has been expressed in developing this area for the bed culture of mussels. However, these plans are at an early stage and no seed has been transplanted here yet. As such, this sampling plan will not require implementation unless directed by the IFCA. It will be mainly influenced by sources to the eastern shore of Walney Island. These are limited to a caravan park discharge, and some saltmarsh grazing. There will be some influence of the multiple sources discharging to the Walney Channel (e.g. Barrow STW) at the eastern end of the zone. It is recommended that the RMP is located where the intertidal drainage channel which receives the caravan park discharge feeds into the zone as this is likely to represent the most concentrated source of contamination.

Foulney

This is a large zone containing mainly undersize mussels, with a significant amount of size mussels on the lower intertidal due south of Foulney Island. These are currently the subject of a relatively large fishery so require continued classification. There is also an area on the lower intertidal adjacent to the maintained Barrow approach channel where bed culture of mussels is being developed. There are no point sources of contamination direct to this zone. The western and eastern sides of this zone will be subject to differing sources of contamination, with the former influenced principally by sources to the Walney Channel and the latter influenced by sources to the western part of Morecambe Bay. However, the IFCA advised that splitting this zone based on these hygiene considerations would be impossible as the stocks are essentially continuous and a split classification would be unenforceable. Historical hygiene classification results were very similar at Roa Island and Foulney, although results from paired (same day) samples were not significantly correlated between the two.

The main sources to the western shore of Morecambe Bay, such as the sewage discharges off Ulverston and the River Leven are remote from the active fishery. The most significant nearby source is the Deep Meadow Beck and associated sewage discharges, about 5 km to the north. This is a minor watercourse which receives UV treated sewage from Newbiggin STW, and an intermittent discharge from this works which was active for 32.2% of the time in recent years. The Rampside Village intermittent discharge lies about 2.5 km to the north of the mussel bed, but this was only active for 0.8% of the time in recent history. Sarah Beck, a small watercourse, drains to the shore about 4 km to the north of the bed. Sources to the Walney Channel all lie to the north. They include the (UV treated) Barrow STW about 5 km away, the much smaller Roa Island STW about 2 km away, numerous intermittent discharges and yacht moorings, and some minor freshwater inputs.

It is therefore recommended that the RMP is located at the centre of the northern edge of the main active size fishery off Foulney, which will be subject to influences from both western Morecambe Bay and the Walney Channel. It must be noted however that this monitoring point is a practical compromise and may not best reflect peak levels of contamination deriving from either western Morecambe Bay or the Walney Channel.

Morecambe

This zone includes a small area of size mussels which are currently subject to some limited harvesting activity. It therefore requires ongoing classification. The mussel bed lies adjacent to a drainage channel which receives low volumes of contaminated water from a small surface water outfall at Hest Bank. This outfall also receives effluent from two intermittent discharges, one of which is unmonitored, and the other of which (Hest Bank PS) spilled for 2.1% of the time in recent years. Some small boats are moored around the mussel bed, but most if not all appear too small to have onboard toilets. The Schola Green Lane pumping station discharges to the seafront about 2 km to the west of the mussel bed. This asset was only active for 0.8% of the time in recent years, but when active spills very large volumes of storm sewage. It is recommended that the RMP be located at the eastern end of the mussel bed, immediately adjacent to the channel, at the lowest elevation possible. This would best capture contamination from the freshwater outfall, and should contamination from a spill from Schola Green Lane pumping station reach the bed, this RMP should also capture its impacts.

Heysham

This zone includes some undersize mussel beds where stocks have not historically persisted to size. However, there are indications that a fishery based on size stocks may develop here in the near future. Should this fishery materialise, the IFCA should advise the LEA that the zone will require classification. There are two intermittent discharges in close proximity to these mussel beds. The Heysham Village PS lies to the west, but was only active for 0.1% of the time in recent history. The Schola Green Lane PS lies to the east. UV treated effluent from Morecambe STW is discharged to deeper water about 5 km to the south west, and although it will be carried in the direction of mussel beds on incoming tides the effluent contains low concentrations of faecal indicators. Again, the main concern would be a spill from the Schola Green Lane PS, so it is recommended that the RMP is located on the inshore eastern end of the main mussel bed to best capture such an event. This location should also capture background contamination deriving from remote sources.

The following specifications apply to all mussel RMPs:

- Not all zones currently require classification. The IFCA will advise in advance when each zone will come into production. A notice period of at least three months will be required so the necessary 10 samples can be collected at least one week apart.
- For a full/ongoing classification, the sampling interval should be monthly, and sampling should be undertaken all year round.
- Samples should be of size mussels (>45 mm shell length).
- Samples should be hand gathered, unless harvesting is undertaken by a different method. It is possible for example that dredges may be approved for harvesting within the future mussel culture areas, in which case it would be appropriate to use them for sampling also.
- A tolerance of 50 m applies to allow repeated sampling.

2.3. Pacific oysters

The Pacific oyster farm is contained within one discrete area. It is actively harvesting so requires ongoing sampling. The Rampside Village intermittent discharge lies about 1 km to the west of the oyster farm, but this was only active for 0.8% of the time in recent history. Sarah Beck, a small watercourse drains to the shore about 1 km to the north of the farm. Deep Meadow Beck, a larger watercourse, drains to the shore about 2.5 km to the north of the farm. It receives UV treated sewage from Newbiggin STW, and an intermittent discharge from this works which was active for 32.2% of the time in recent years. More remote sources further to the north (e.g. Ulverston STW and the River Leven) may be of some impact, and such impacts are likely to be greatest on the more offshore part of the site, at lower elevations by the subtidal channel. It is recommended that the RMP is located at the northern tip of the site, to best capture contamination originating from the main sources at Newbiggin. There is some uncertainty about the path that the Deep Meadow Beck drainage channel follows across the intertidal, so if necessary the RMP location may be adjusted to ensure it lies as close to this channel as possible. Sampling should be undertaken by hand, and animals sampled should be of a market size. A tolerance of 10 m applies. The sampling frequency should be monthly all year round.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Morecambe Bay
Cefas Main Site Reference	M047, M048 and M077
Ordnance survey 1:25,000 map	Explorer OL6, OL7 and 296
Admiralty Chart Nos.	2010, 3164, 1320

Shellfishery

Species/culture	Mussels	Wild/cultured
	Cockles	Wild
	Pacific oysters	Cultured
Seasonality of harvest	Cockle fishery is currently closed due to low stock levels. Closed season for cockles runs from 1st May to 31st August (when fishery is in operation). No closed season for mussels or Pacific oysters.	

Local Enforcement Authorities

Authority	Environmental Health Department Barrow-in-Furness Borough Council Town Hall Duke Street Barrow-in-Furness Cumbria LA14 2LD
Environmental Health Officer	Richard Garnett
Telephone number ☎	01229 876547
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E-mail	rgarnett@barrowbc.gov.uk
Authority	Environmental Health Department Lancaster City Council Town Hall Morecambe Lancashire LA4 5AF
Environmental Health Officer	Joanne Alexander
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Environmental Health Officer	Jane Latham
Telephone number ☎	01539 793426
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3.2. Requirement for Review

The Guide to Good Practice for the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas (EU Working Group on the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas, 2014) indicates that sanitary assessments should be fully reviewed every 6 years, so this assessment is due a formal review in 2020. 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 Morecambe Bay

Zone	RMP	RMP name	NGR**	Latitude & Longitude (WGS84)**	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Authority	Comments
Snab Sands	TBA*	South End	SD 2203 6262	54° 03.217'N 03° 11.550'W	Cockles	Wild	Hand	Hand	100 m	Monthly	Barrow	Closed. The IFCA will provide around 12 months notice if it is likely to reopen
Roosecote Sands	TBA*	Roosecote Outer	SD 2071 6627	54° 05.173'N 03° 12.817'W	Cockles	Wild	Hand	Hand	100 m	Monthly	Barrow	Closed. The IFCA will provide around 12 months notice if it is likely to reopen.
Newbiggin	TBA*	Newbiggin Channel	SD 2714 6872	54° 06.551'N 03° 06.956'W	Cockles	Wild	Hand	Hand	100 m	Monthly	South Lakeland	Closed, but sampled quarterly. The IFCA will provide around 12 months notice if it is likely to reopen
Ulverston	TBA*	Ulverston Sands	SD 2950 7050	54° 07.530'N 03° 04.815'W	Cockles	Wild	Hand	Hand	100 m	Monthly	South Lakeland	Closed, but sampled quarterly. The IFCA will provide around 12 months notice if it is likely to reopen. If it does reopen, significant adjustment of the RMP towards the target location may be required.

Zone	RMP	RMP name	NGR**	Latitude & Longitude (WGS84)**	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Authority	Comments
Central West	TBA*	Eea Channel	SD 3300 7100	54° 07.828'N 03° 01.609'W	Cockles	Wild	Hand	Hand	100 m	Monthly	South Lakeland	Closed, but sampled quarterly. The IFCA will provide around 12 months notice if it is likely to reopen. If it does reopen, significant adjustment of the RMP towards the target location may be required.
Central East	TBA*	Humphrey Head	SD 3801 6995	54° 07.299'N 02° 56.997'W	Cockles	Wild	Hand	Hand	100 m	Monthly	South Lakeland	Closed, but sampled quarterly. The IFCA will provide around 12 months notice if it is likely to reopen. If it does reopen, significant adjustment of the RMP towards the target location may be required.
Silverdale	TBA*	Off Silverdale	SD 4180 7502	54° 10.060'N 02° 53.577'W	Cockles	Wild	Hand	Hand	100 m	Monthly	South Lakeland	Closed. The IFCA will provide around 12 months notice if it is likely to reopen

Zone	RMP	RMP name	NGR**	Latitude & Longitude (WGS84)**	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Authority	Comments
Keer	TBA*	Keer Channel	SD 4568 6953	54° 07.125'N 02° 49.952'W	Cockles	Wild	Hand	Hand	100 m	Monthly	Lancaster	Closed. The IFCA will provide around 12 months notice if it is likely to reopen
Morecambe/ Heysham	TBA*	Morecambe West End	SD 4231 6418	54° 04.218'N 02° 52.984'W	Cockles	Wild	Hand	Hand	100 m	Monthly	Lancaster	Closed. The IFCA will provide around 12 months notice if it is likely to reopen
North Walney	B077P	South of Jubilee	SD 1896 6846	54° 06.337'N 03° 14.457'W	Mussels	Wild/ bed culture	Hand	Hand	50 m	Monthly	Barrow	Actively harvested at present
Roa Island	B077Q	Roa Island	SD 2311 6464	54° 04.316'N 03° 10.591'W	Mussels	Wild	Hand	Hand	50 m	Monthly	Barrow	Actively harvested at present
Bass Pool	TBA*	Bass Pool	SD 2310 6310	54° 03.485'N 03° 10.577'W	Mussels	Bed culture	To be decided	Hand	50 m	Monthly	Barrow	No stock on site. Classification not required unless IFCA advise so.
Foulney	B077R	Foulney	SD 2491 6365	54° 03.798'N 03° 08.926'W	Mussels	Wild/bed culture	Hand	Hand	50 m	Monthly	Barrow	Actively harvested at present
Morecambe	B047R	Bare Ayre East	SD 4431 6540	54° 04.889'N 02° 51.164'W	Mussels	Wild	Hand	Hand	50 m	Monthly	Lancaster	Actively harvested at present
Heysham	TBA*	Heysham East	SD 4145 6314	54° 03.652'N 02° 53.760'W	Mussels	Wild	Hand	Hand	50 m	Monthly	Lancaster	Currently undersize only, but recent indications of size fishery developing. Classification not required unless IFCA advise so.

Zone	RMP	RMP name	NGR**	Latitude & Longitude (WGS84)**	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Authority	Comments
Roosebeck	B48AX	Roosebeck North	SD 2599 6647	54° 05.328'N 03° 07.978'W	Pacific oyster	Trestle culture	Hand	Hand	10 m	Monthly	South Lakeland	Actively harvested at present

**RMP codes not shown will be generated at the start of sampling / confirmation of locations which can be sampled (areas not currently requiring classification)*
***RMP locations are nominal and may require adjustment depending on stock distribution, and possibly other considerations as detailed in the recommendations section.*

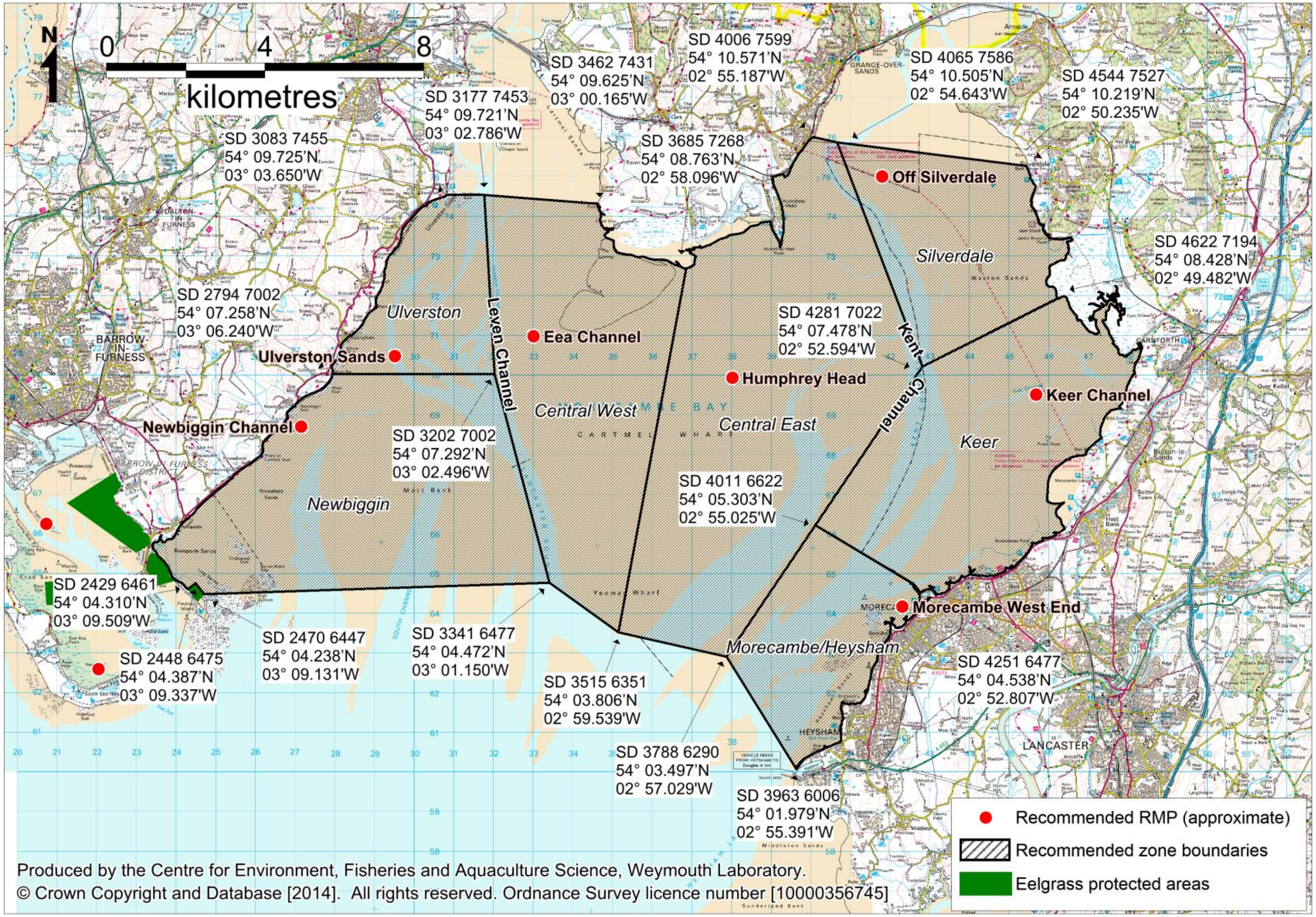


Figure 3.1: Recommended zoning and monitoring arrangements (Morecambe Bay cockles)

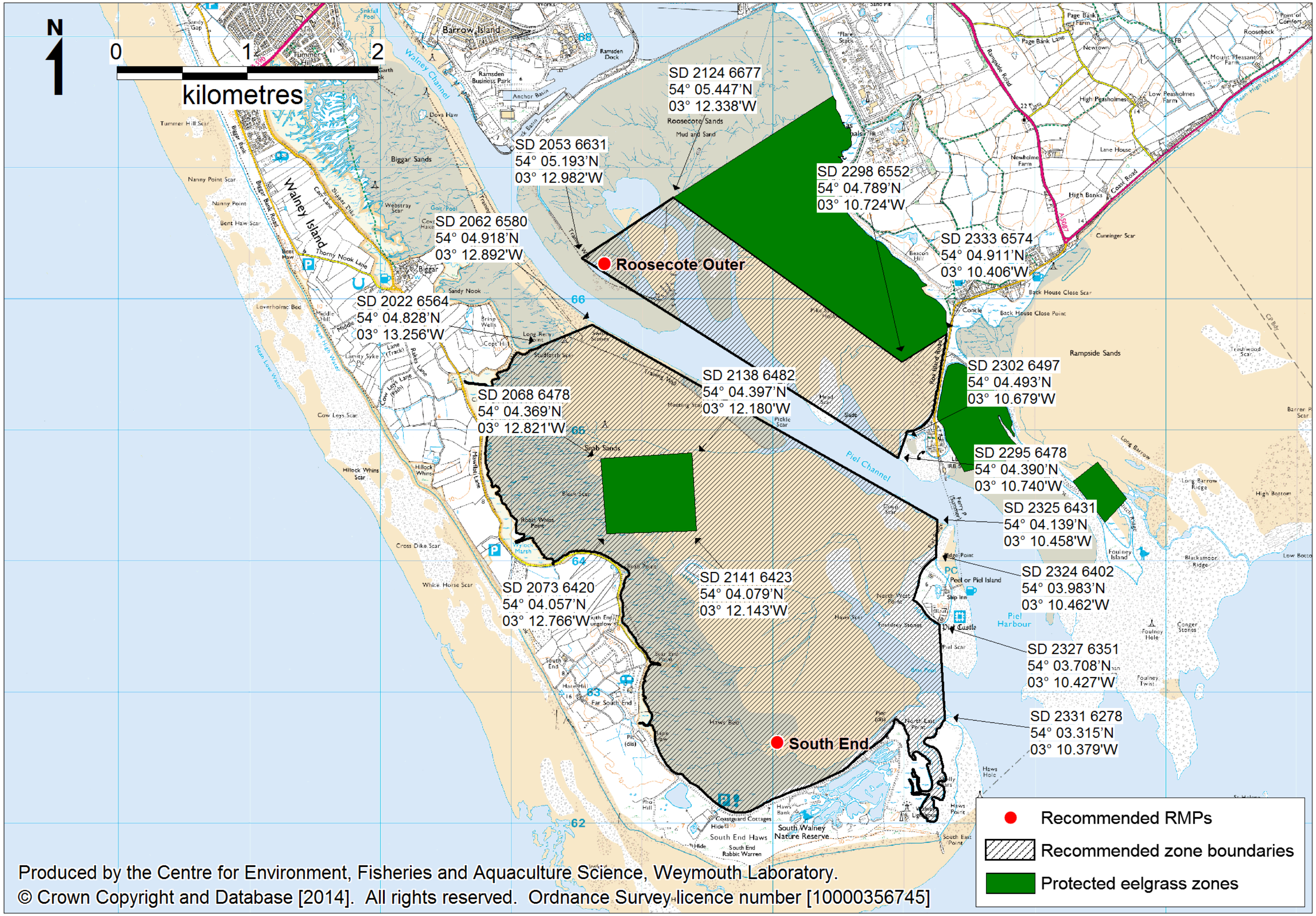


Figure 3.2: Recommended zoning and monitoring arrangements (Walney channel cockles)

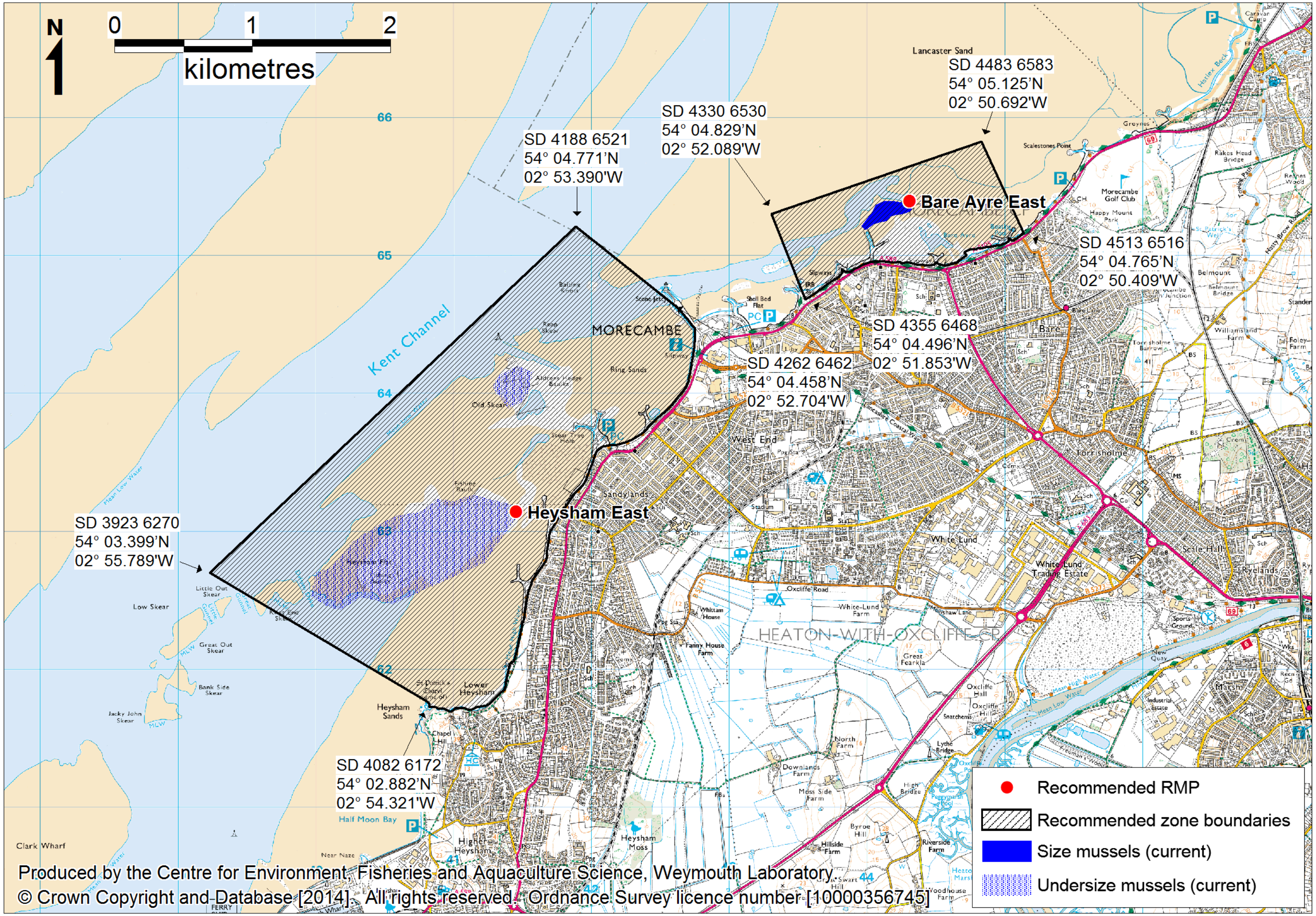


Figure 3.3: Recommended zoning and monitoring arrangements (Morecambe/Heysham mussels)

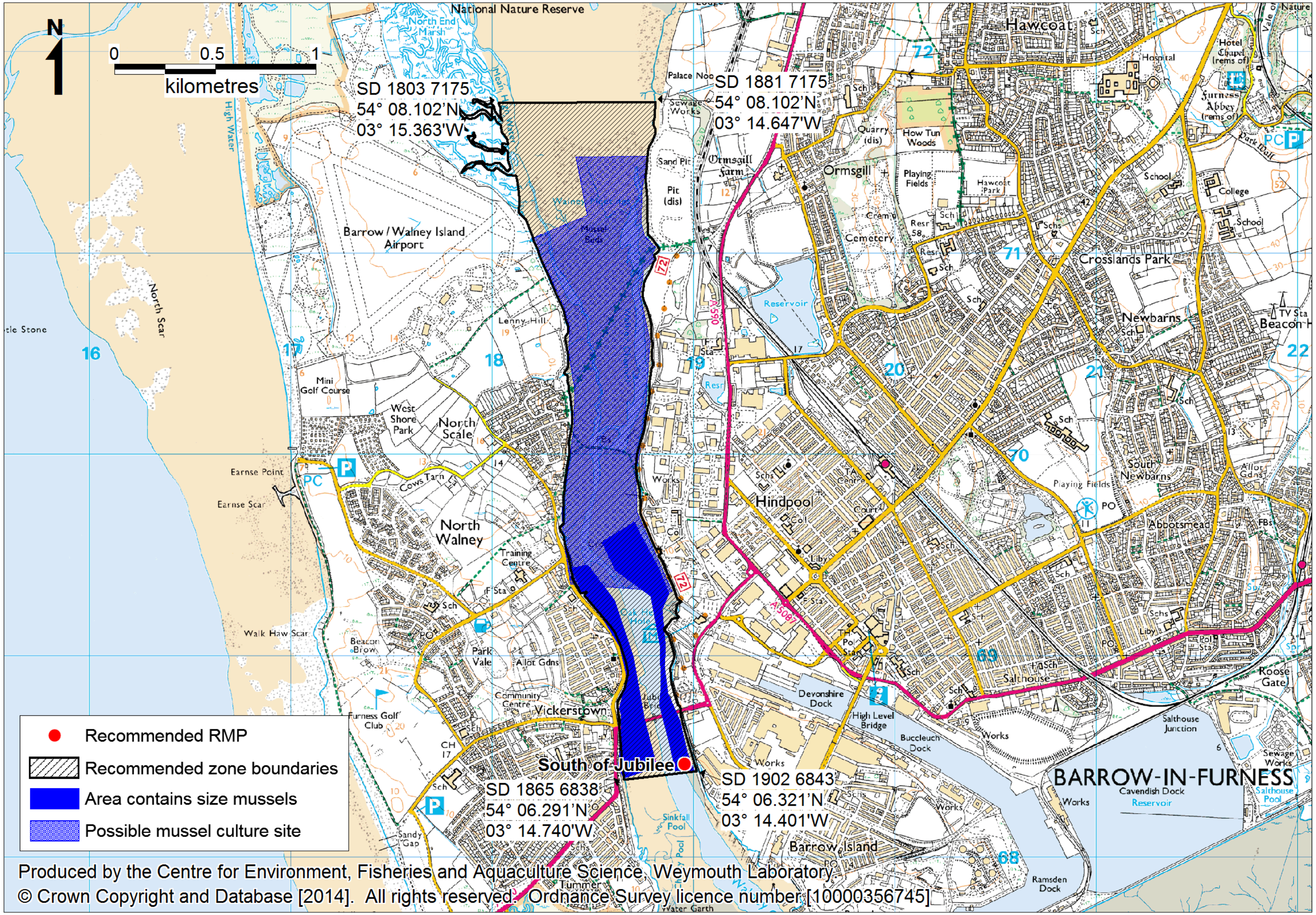


Figure 3.4: Recommended zoning and monitoring arrangements (Walney Channel mussels)

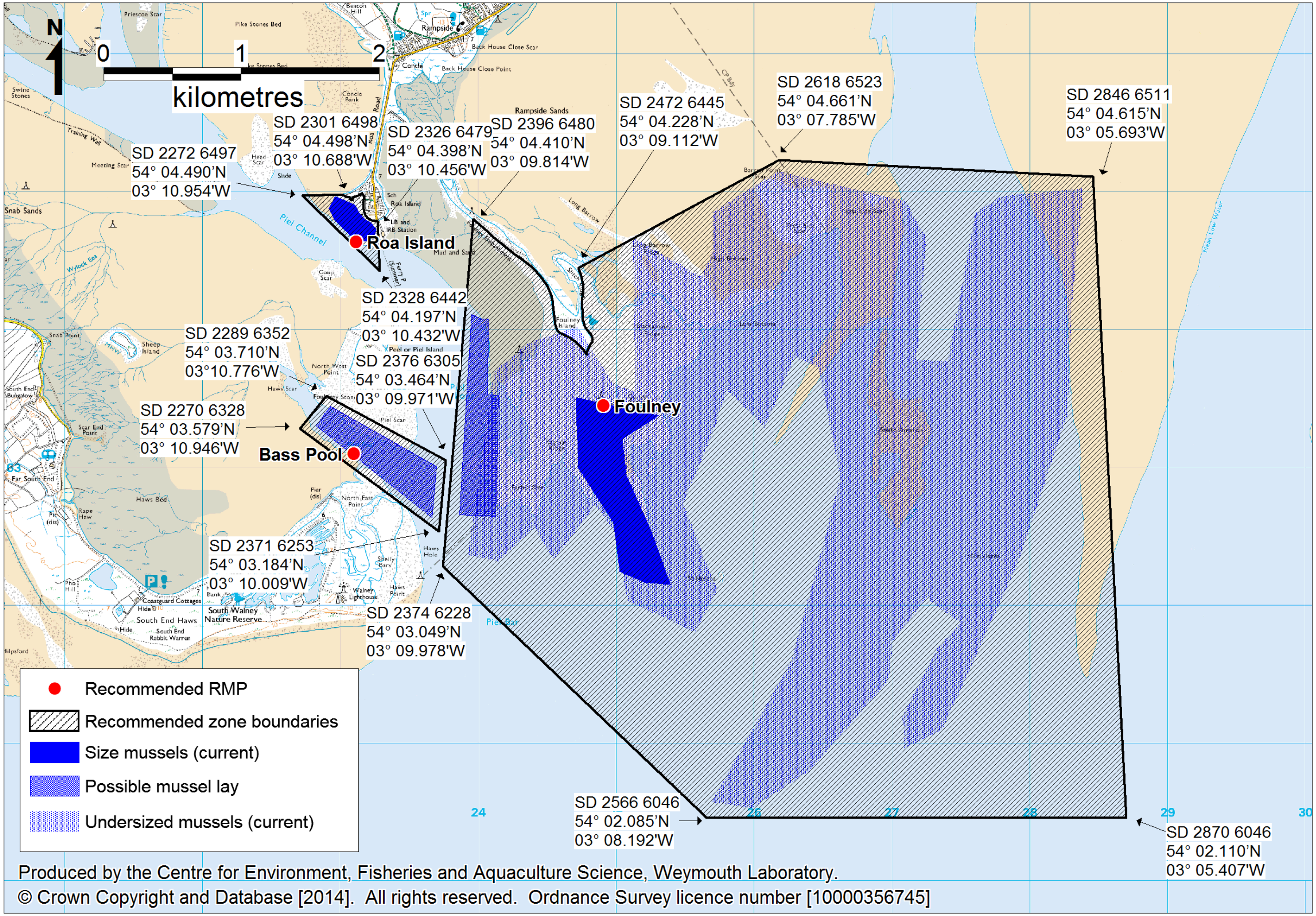


Figure 3.5: Recommended zoning and monitoring arrangements (Foulney mussels)

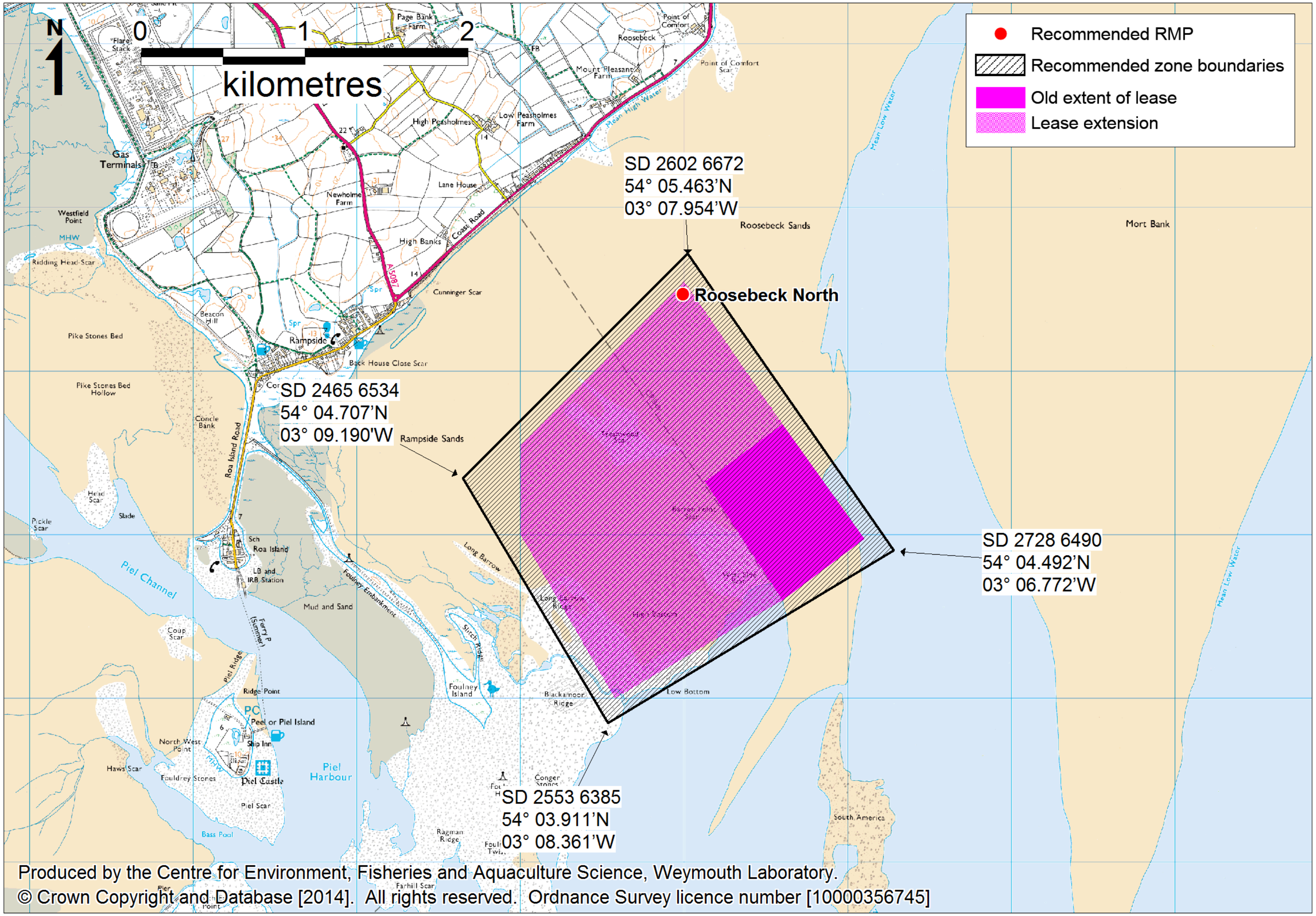


Figure 3.6: Recommended zoning and monitoring arrangements (Pacific oysters)

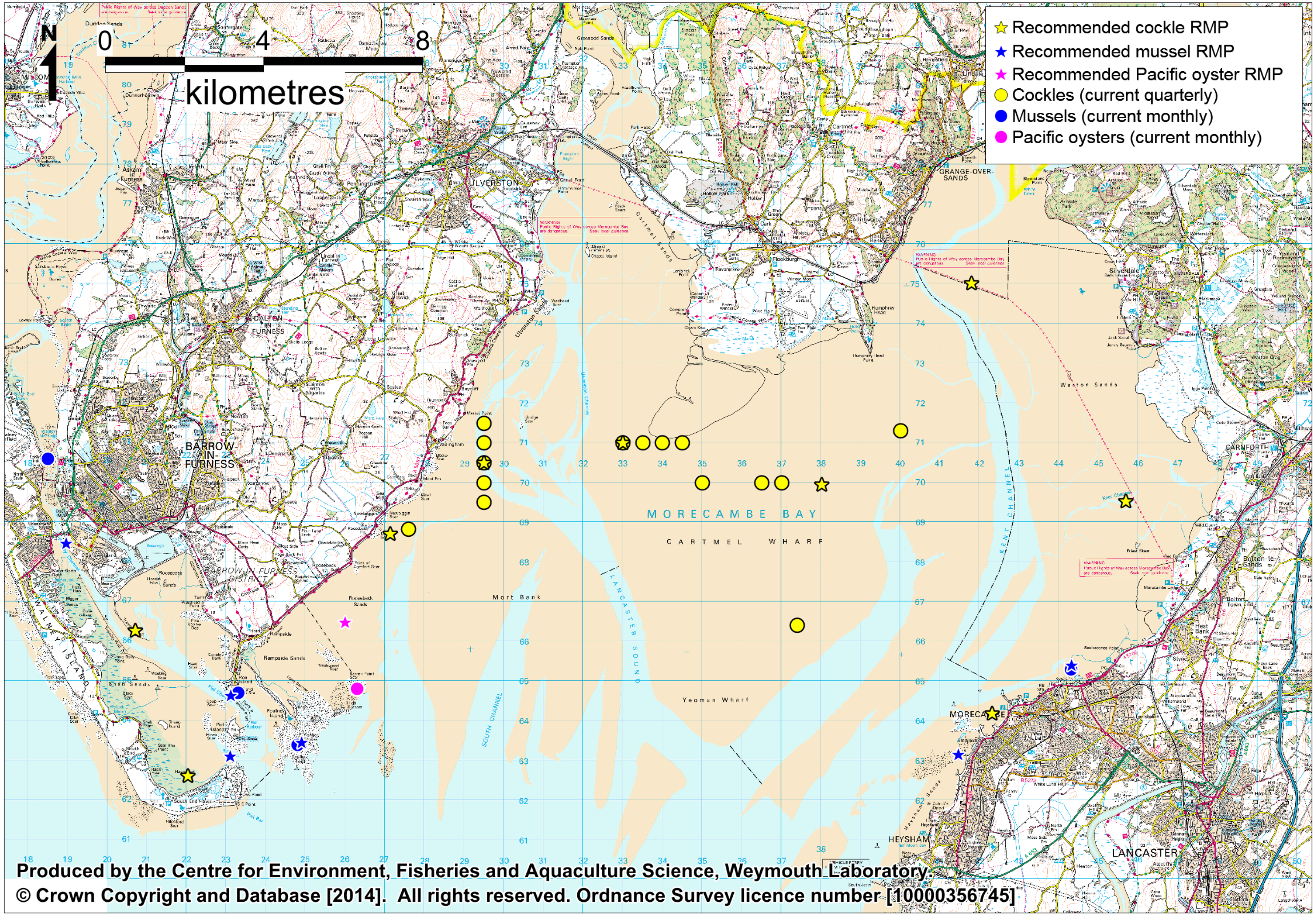


Figure 3.7: Comparison of current RMPs from against Recommended RMPs.
Some current cockle zones have multiple RMPs along a transect which may be used interchangeably to allow for variable location of stocks. Some recommended RMPs will not require monitoring at present.

4. Shellfisheries

4.1. Description of fisheries

Shellfish resources within the survey area include naturally occurring cockles and mussels. These are all managed by the North Western IFCA under their local byelaws. There is also a large Pacific oyster trestle farm.

Cockles

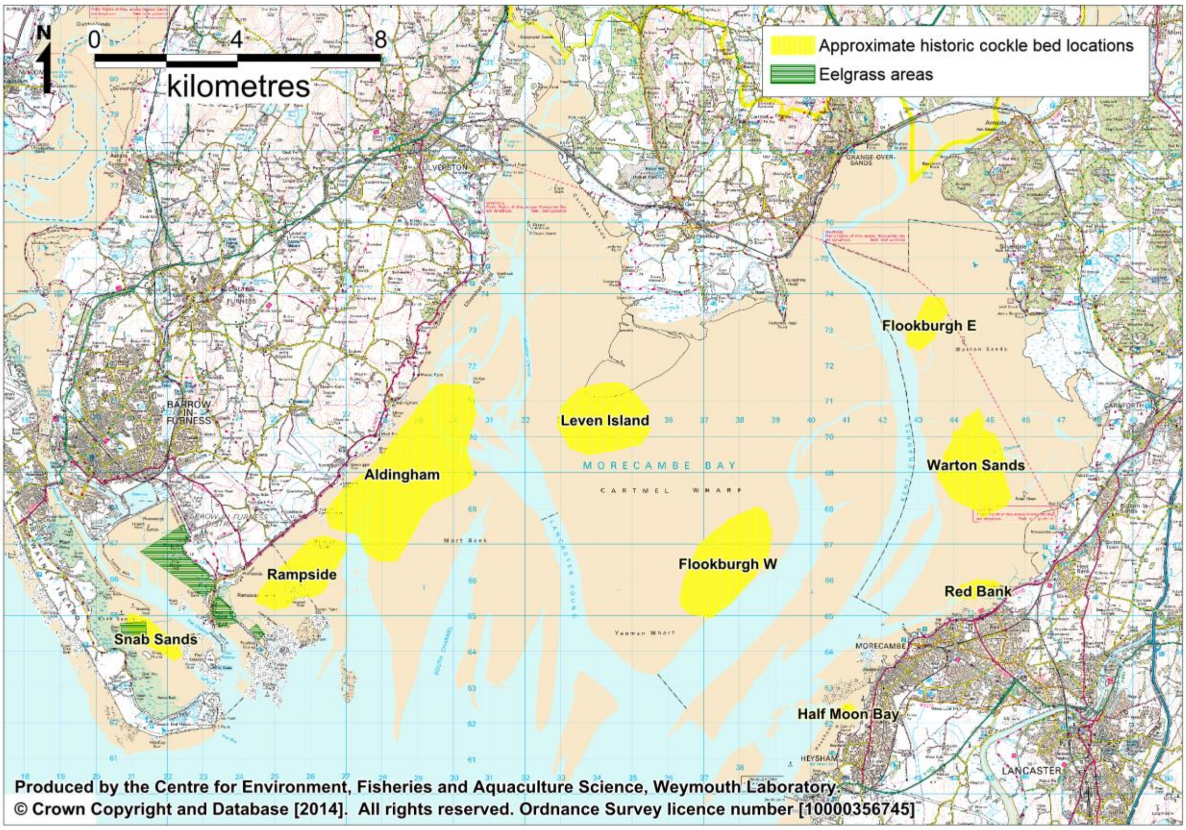


Figure 4.1: Approximate historic cockle bed locations

Historically, there have been sporadic large commercially exploitable cockle settlements in various parts of the bay. There has not been a commercial cockle fishery in the estuary since 2007/8, and although there are small numbers of cockles still present in these areas there are no beds holding commercial densities at present. Cockle stocks fluctuate significantly in their overall biomass and their distribution around the area. Success of spatfalls[3] may vary greatly between years. Storms,

[3] Spatfalls are a mass of newly settled larvae

temperature extremes, diseases, predation and of course exploitation can all affect cockle stocks and mass mortalities may occur at times. A pattern of long periods of low stock levels, with sporadic large recruitment events[4] 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.

Commercially viable cockle settlements have not historically extended north of a line drawn between Bardsea and Silverdale, but may occur on intertidal areas almost anywhere south of this line. When there are major settlements, the geographic distribution of commercial densities will vary significantly, not least due to the constantly changing bathymetry within the bay. The seabed in the area to the south of Humphrey Head is reported to have accreted and is now not sufficiently wet to support cockles as it has in the past for example. Figure 4.1 shows the very approximate areas where the main settlements have occurred historically.

Cockle stocks are regularly monitored by the IFCA, and if evidence of a significant settlement is observed, more detailed surveys are undertaken. Information on their spatial distribution would be obtained from these surveys, although distributions may change significantly over periods as short as a few months. Any significant spatfall would take around 18 months to reach a harvestable size, assuming they survive. No major spatfall was observed in summer 2014, so even if a major recruitment event occurs in 2015, the earliest a cockle fishery could be opened is in September 2016.

[4] Recruitment events refer to the addition of a new cohort to a population.

Mussels

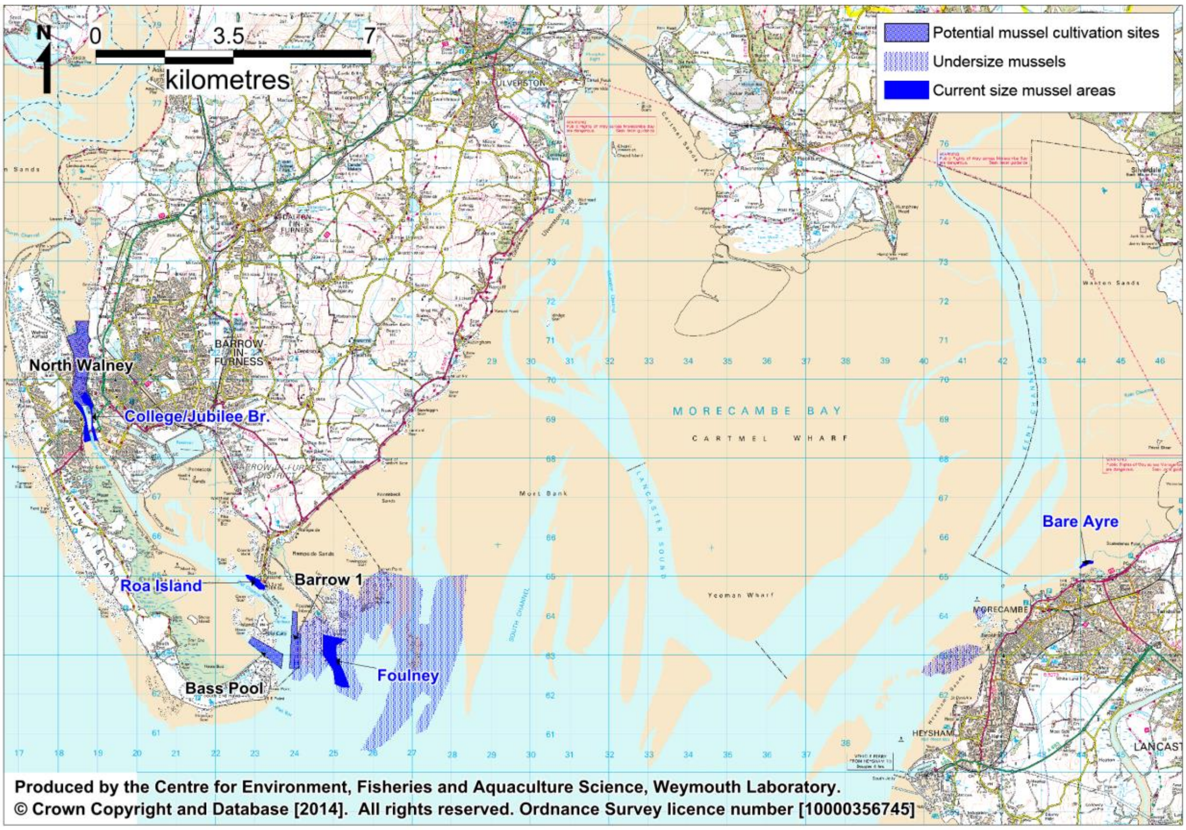


Figure 4.2: Approximate mussel bed locations

Large but variable mussel settlements occur within the bay, mainly in the area around Foulney Island, but also off Heysham and Morecambe and within the Walney Channel. They settle on areas of glacially deposited cobbles (skears) so their distribution is similar from year to year. Much of the mussel covering is ephemeral, and does not persist to size (45 mm) before it is washed away during storm events. These areas are fished for undersize stocks (seed or part grown) which are transplanted elsewhere (e.g. the Menai Strait) for ongrowing. No classification is required for part grown or seed mussels, so these resources will not be considered further in this report. Size wild mussels are harvested directly from several areas (Foulney, Bare Ayre, Roa Island, and either side of the Jubilee Bridge). The Foulney mussel bed is the most prolific, and currently attracts around 30 harvesters when tides are sufficiently large for the bed to be accessed. Stocks at Bare Ayre, Roa Island and the Jubilee Bridge are more limited and subject to much lower levels of exploitation. Most are sold to continental markets, although some go to the south west of England and a few are sold locally. The mussel bed off Heysham, which has historically only supported a fishery for undersized stock, may also support sufficient market sized mussels for commercial harvesting in the near future.

Three areas have been identified as potential mussel culture sites (Barrow 1, Bass Pool and North Walney). Formal expressions of interest in establishing several orders in these areas have been made. The general principle at these sites is to deposit locally sourced seed and grow it on to size, or alternatively it may possibly be sold on as part-grown stock for finishing elsewhere. They are in various stages of development, with trials having been undertaken at North Walney and Barrow 1. The trials at North Walney gave poor results so at present there are no further plans to transplant more seed there. No seed has been transplanted to Bass Pool. It is the intention that Barrow 1 and Bass Pool will be fully developed in the future, although the timescales for this are uncertain.

Pacific oysters

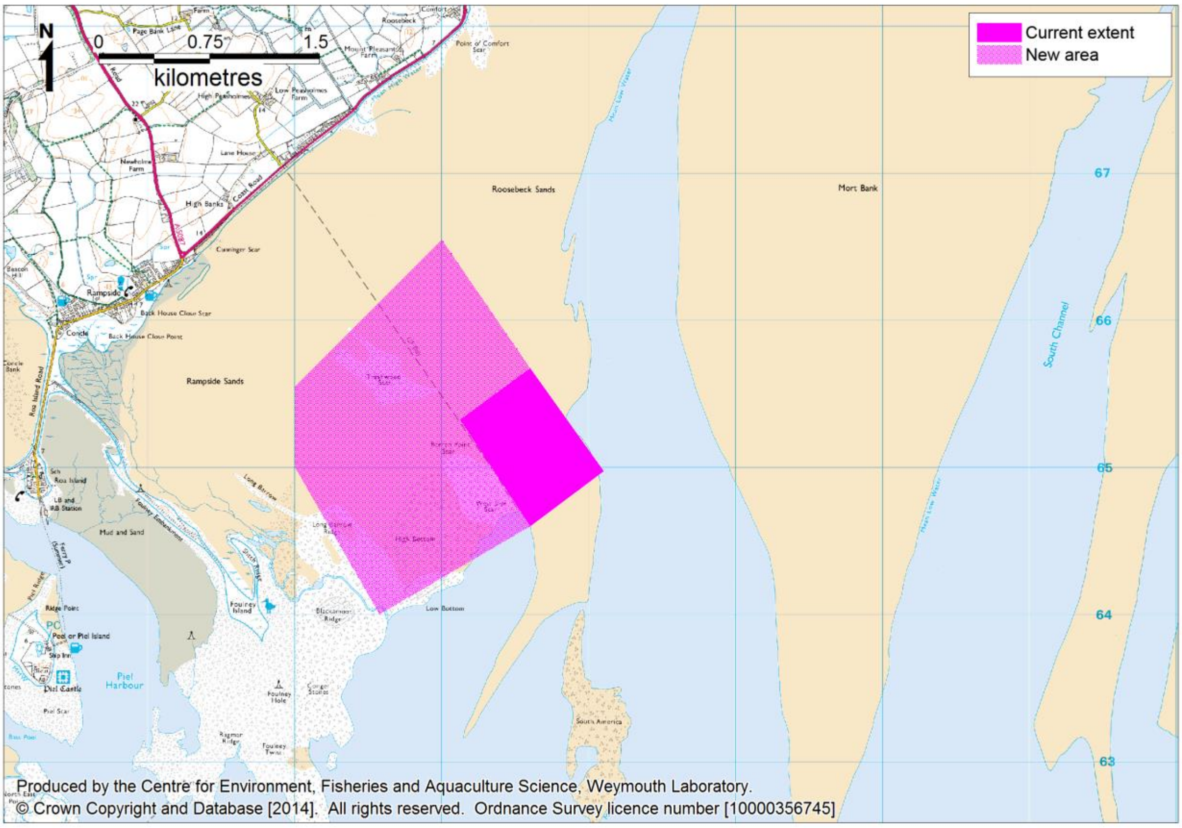


Figure 4.3: Oyster trestle farm location

The oyster farm is located on the lower intertidal area off Rampside, on an area of privately owned seabed leased from Boughton Estates. Pacific oysters are grown from seed to market size in net bags on trestles on the lower intertidal, a process that takes around 3 years. The farm is currently being extended. There is also a hatchery on the south end of Walney Island, but this only produces seed so does not require a hygiene classification and therefore will not be considered further in this report.

4.2. Fishery management

Currently, the wild cockle and mussel fisheries are managed under the NW IFCA's byelaws. 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. 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 157 permits were issued for the 2013/14 season.

The cockle fishery within the Morecambe Bay area is currently closed under NW IFCA byelaw 13a to protect remaining stocks, which are considered to be below safe biological limits for exploitation. When open a closed season operates from 1st May to 31st August to protect newly settled spat[5]. The mussel fishery is currently open, and is not subject to a closed season. Minimum landing sizes apply to cockles (must be unable to pass through a 20 mm square aperture) and mussels (45 mm shell length) under NW IFCA byelaws. Gear limitations (hand gathering only) apply to the intertidal cockle and mussel fisheries, limiting levels of exploitation and preventing the use of mechanical methods. The use of dredges for market size mussels may be authorised in exceptional circumstances, although dredges are more routinely used for the gathering of ephemeral undersized stock located subtidally or semi-subtidally. Shellfish gathering is prohibited in some areas of the southern Walney Channel under NW IFCA byelaw 6 to avoid damage to eelgrass beds. Settlements of cockles on Snab Sands may coincide with eelgrass beds, although this area rarely supports stocks of commercial interest.

If Several Orders for the mussel lays are progressed these areas will be taken out of the public fishery, and as such not all of the byelaws that apply to the public fishery will be appropriate. Each will be subject to their own individual management plan, which will include some conservation related restrictions. There is uncertainty about what form the management plans for each site would take, as they are in an early stage of development. No closed seasons or minimum landing sizes apply to the Pacific oyster farm.

Proposals to implement a multi-sectoral shellfish working group to assist in informing management of these fisheries are currently under consideration by the IFCA. Implementing a management plan for Morecambe Bay cockles and mussels would allow a ‘suite’ of adaptive management measures that are flexible to stock levels and environmental considerations. These include restricting fishing methods, 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).

[5] Spat are recently settled juvenile bivalves.

4.3. Hygiene Classification

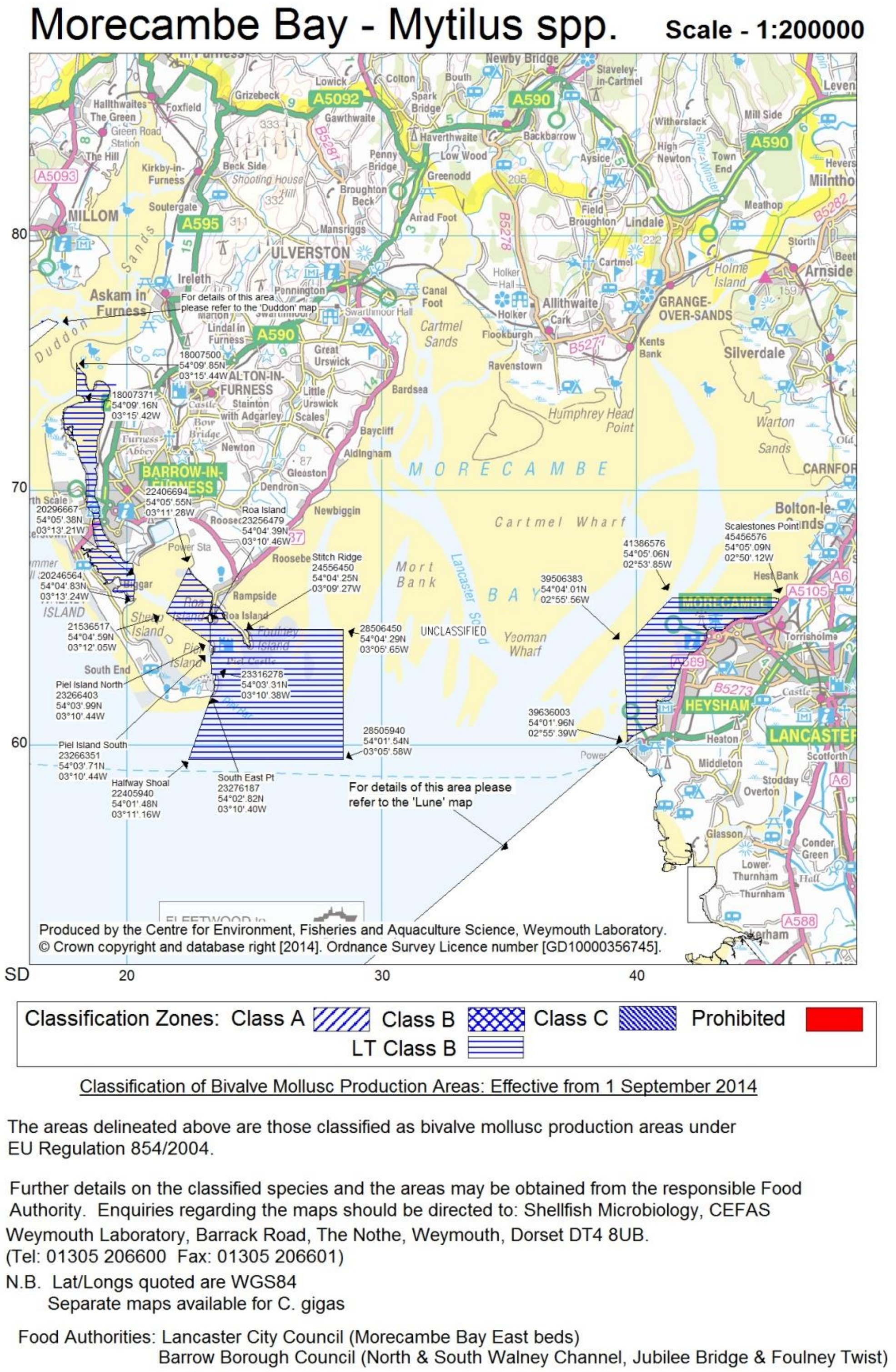
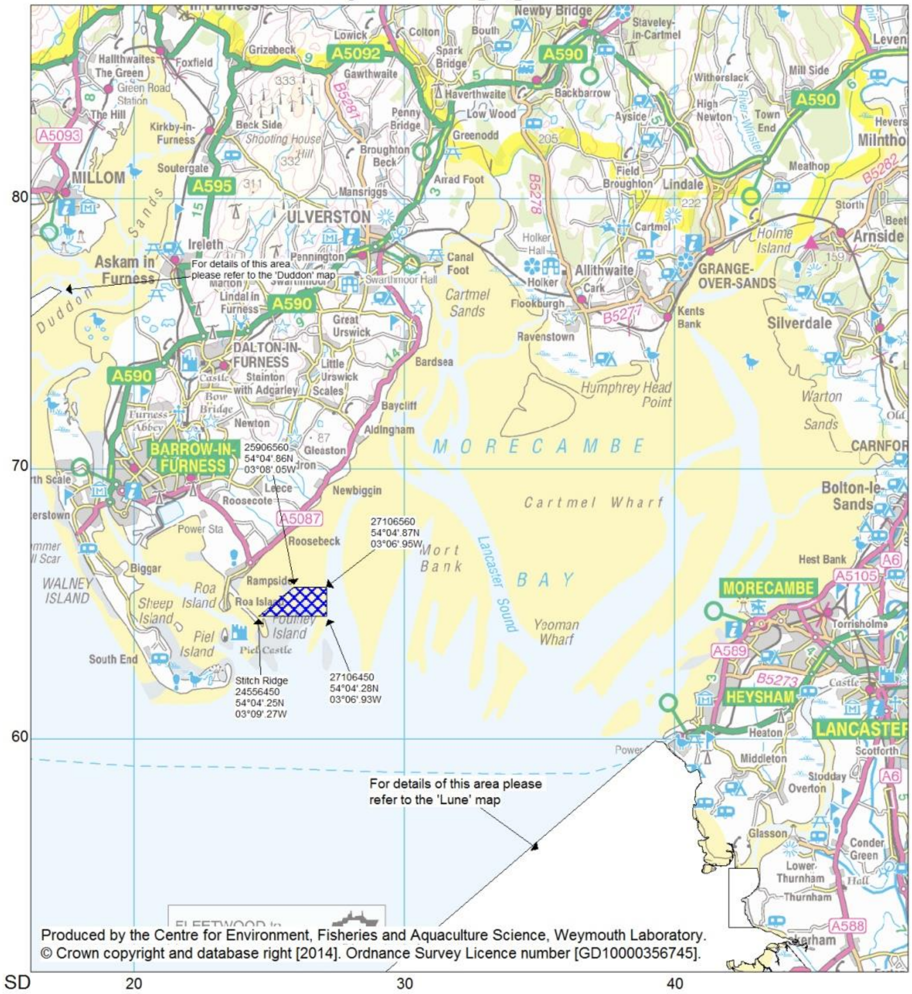


Figure 4.4: Current mussel classifications

Morecambe Bay - C. gigas

Scale - 1:200000



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

Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2014

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 maps available for Mytilus spp.

Food Authorities: Lancaster City Council (Morecambe Bay East beds)
Barrow Borough Council (North & South Walney Channel, Jubilee Bridge & Foulney Twist)

Figure 4.5: Current Pacific oyster classifications

Table 4.1: Historical hygiene classifications, 2005 to present

Bed name	Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Old Skeer	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Heysham Flat Skeer	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Bare Ayre	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Reap Skeer	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT			
Red Bank	Cockles		C	C	C	B	B				
Warton Sands	Cockles	B	C	C	C	B	B				
Roosebeck bed 1	P. oysters	B	B-LT	B-LT	B-LT	B-LT	B-LT			B	B
Foulney Twist	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Point of Comfort	Cockles	C									
Flookburgh	Cockles	B		C	C	C	C	B	B	B	
Aldingham	Cockles					B	B	B	B	B	
Leven Island	Cockles					B	B	B	B	B	
Newbiggin	Cockles					P	P	P	C	C	
Roa Island	Cockles	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT				
Roa Island	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT				B
South Walney Channel Head Scar	Cockles	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT				
Head Scar	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT				B
Sheep Island	Cockles	B-LT	B-LT	B-LT	B-LT						
Sheep Island	Mussels	B-LT	B-LT	B-LT	B-LT						
North Walney Channel Lowsey Point	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Cocken Tunnel	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Jubilee Bridge	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Rampside Flats	Cockles	C									

The principal cockle areas (Flookburgh, Aldingham, Leven Island and Newbiggin) currently hold temporarily declassified status and are sampled on a quarterly basis to maintain this. All other cockle areas are fully declassified. Most cockle areas have at some point held C classifications, and Newbiggin was prohibited for three years. Most mussel areas are currently classified, and all have held B classifications during the period presented above. The Pacific oyster farm has held a B classification throughout, apart from when it was declassified for two years as it was only being used for the ongrowing of seed through to a part grown stage, which was then sold on to other farms who brought them on to market size. The current classification zone does not cover the entire extent of the expanded lease area.

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

Morecambe Bay has historically supported very large stocks of cockles, although major settlements only tend to occur roughly once a decade. There has not been a commercial cockle fishery in the estuary since 2007/8, and although there are small numbers of cockles still present in these areas there are no beds holding commercial densities at present. As such, the cockle fishery is currently closed as stocks are believed to be below safe biological limits. The next significant settlement could result in a major fishery in the area. Cockle stocks are regularly monitored by the IFCA. Any significant spatfall would take around 18 months to reach a harvestable size assuming they survive. No major spatfall was observed in summer 2014, so even if a major recruitment event occurs in 2015, the earliest a cockle fishery could be opened is in September 2016.

Commercially viable cockle settlements have not historically extended north of a line drawn between Bardsea and Silverdale, but may occur on intertidal areas almost anywhere south of this line. They have also occurred on Snab Sands, which lies on the western side of the outer Walney Channel. The geographical extent of commercially exploitable settlements has varied significantly in the past, and it will be impossible to predict the precise extent of any future settlements. The constantly changing bathymetry within the bay, coupled with the large uncertainties over the future extent of any commercial cockle settlements make it impossible to provide a definitive, fully geographically referenced sampling plan for this species. The Leven and Kent river channels for example, which may potentially be used to delineate zones, can shift position by significant distances over relatively short periods. As various parts of the bay have not all held the same classifications in the past, zone boundaries should ideally be defined in such a way as that they may be readily enforced. The different parts of the bay are accessed from a relatively small number of fixed points by harvesters, and this may potentially be used as a basis for dividing the bay into zones. The IFCA, who undertake the cockle classification sampling on behalf of the various local authorities, are able to access most parts of the bay. Access to the sandbanks further offshore in the outer reaches of the western part of the survey area is difficult, and the Red Bank/Warton Sands area has to be accessed from the south.

The cockle fishery is managed under various IFCA byelaws. These include a permit system, which allows only permit holders to take more than 5 kg of cockles or mussels per day. A total of 157 permits were issued for the 2013/14 season. Only hand gathering is permitted. When the cockle fishery is open, a closed season operates from 1st May to 31st August to protect settling spat. Only cockles which do not pass through a 20 mm square aperture can be taken. Both Snab Sands and Roosecote Sands support protected seagrass areas, within which shellfish gathering is prohibited.

There are also significant wild mussel stocks within the survey area. These settle on discrete areas of glacially deposited cobbles (skears) so although their biomass and stock structure varies, their geographic distribution is very similar from year to year. The main area is located around Foulney Island, and there are smaller but significant patches in the intertidal off Morecambe and Heysham. Much of the mussel covering is ephemeral, and does not survive to size before it is washed away during storm events. These areas are fished for undersize stocks which are transplanted elsewhere (e.g. Menai Strait) for ongrowing, and a hygiene classification is not required for their removal. Nevertheless, sampling plans will be provided for all mussel skears, as the areas within which stocks persist to size can vary significantly from year to year. Size mussels are currently harvested from several areas (Foulney Island, Bare Ayre, Roa Island, and around Jubilee Bridge). The Foulney mussel bed is the most prolific, and attracts around 30 harvesters on suitable tides. The other beds are smaller and subject to much lower levels of exploitation. There are recent indications that the bed off Heysham, which has historically only supported an undersize fishery, may develop into a size mussel fishery in the near future.

As with the cockle fishery, the mussel fishery is managed via IFCA byelaws. The same permit system is used as for cockles. Only hand gathering of market size mussels is permitted apart from in exceptional circumstances, although dredges are regularly used for the collection of subtidal and semi-subtidal undersized stocks for ongrowing elsewhere (e.g. the Menai Strait). There is no closed season, and a minimum landing size of 45 mm applies within the size fishery.

There are three areas where formal interest in culturing mussels has been expressed (North Walney, Barrow Island and Bass Pool). The general approach is to lay seed mussels sourced locally on the sea bed and allow them to grow to market size. They are in various stages of development and if Several Orders are progressed they will be taken out of the public fishery. Their management regimes are yet to be decided. These areas will all require sampling plans which can be applied as and when required. Trials undertaken at North Walney were unsuccessful so are unlikely to be repeated.

There is a Pacific oyster farm on the lower intertidal area off Rampside which requires continuing classification. Pacific oysters are grown here from seed to market size in net bags on trestles, a process that takes around 3 years. No conservation controls such as minimum size or closed season apply to this fishery.

5.3. Pollution Sources

Freshwater Inputs

The survey area has a hydrological catchment of 1,268 km^2. A large proportion of this drains to the Leven and Kent estuaries, which are broadly similar in terms of size and catchment areas. They extend from the north-west and north-east corners of the bay respectively. The principle watercourses draining to the Leven estuary are the Leven, Crake, and Rusland Pool, and those draining to the Kent estuary are the Kent, Bela, Gilpin and Winster. Each estuary receives further freshwater inputs to its lower reaches from a number of smaller watercourses. There are also several streams and minor rivers which drain to the shore of the bay in the vicinity of the shellfish beds. Freshwater inputs to the Walney Channel are much more limited, the main one being Mill Beck which drains via the docks at Barrow.

The dominant land cover in the catchment is pasture, with some natural areas (woodland and heathland) and several built up areas, most of which are close to the coast. The catchment is quite hilly, reaching a maximum elevation of just under 900 m. The hydrogeology varies from very low permeability throughout most of the inland areas to moderate permeability throughout most coastal areas, with areas of high permeability at Barrow and Roosebeck. Rainfall increases from around 1,000 mm per year in coastal areas to more than double this over higher elevations in the upper reaches of the catchment. A rapid response to rainfall and high runoff rates are anticipated for watercourses in the upper catchment, but a slower response is anticipated from the lower lying coastal streams draining directly to the bay where gradients are lower and flows may be damped by groundwater discharge and recharge. The Rivers Crake and Leven both have large natural lakes which will have buffering effects on their discharge rates, and will also retain water from the upper catchment for significant periods. It is therefore likely that a high proportion of bacterial contamination delivered to these lakes from upstream sources dies off before it drains from their outlets.

Flow gauging records were available for stations on the Crake, Leven, Kent, Bela and Keer. Average discharge rates (2004-14) were 4.6, 15.7, 10.4, 3.9 and 0.6 m^3/sec respectively. Gauging records show significant day to day variability in flows in all these watercourses, including the Crake and Leven. Flows were higher on average during the colder months. 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. As such, the bacterial loadings they deliver are likely to fluctuate significantly in response to rainfall. Whether the increased winter average discharge rates translate to increased bacterial loadings is uncertain.

There are several potentially significant watercourses draining directly to the bay and Walney Channel in close proximity to some of the shellfish resources. These are of importance to the assessment as they may create hotspots of contamination within shellfish beds where their intertidal drainage channels cut through them. Most were sampled and/or measured during the shoreline survey.

The largest watercourse draining to the eastern shore of the bay is the River Bela, the drainage channels from which cut through Warton Sands. The bacterial concentration it was carrying at the time of survey was low, so the bacterial loading it was carrying was not particularly large (2.4×10^{11} *E. coli*/day). Nevertheless, it was carrying the largest measured bacterial loading to the east shore, and is likely to be of local significance. Also of potential significance along this shore was a small freshwater outfall at Hest Bank carrying a very high concentration of *E. coli* (>20,000 cfu/100ml). The discharge rate was low so the loading it was delivering was $>5.31 \times 10^{10}$ *E. coli*/day.

The main watercourse draining from the central Furness peninsula is the River Eea. The flow and dimensions of this watercourse was not measured, but was carrying a bacterial concentration of 2,900 *E. coli* cfu/100ml. It is therefore likely to deliver a significant bacterial loading. A smaller marsh drain also feeds into the drainage channel it follows across the intertidal. This channel appears to join the main Leven channel north of where cockle beds tend to form, so is therefore not a major consideration for the sampling plan.

Along the west shore between Rampside and Ulverston, the main two freshwater inputs are the Deep Meadow Beck and Dragley Beck. Deep Meadow Beck receives effluent from Newbiggin STW and associated overflows just upstream from its outfall. It was carrying a very high concentration of *E. coli* at the time of shoreline survey, so the bacterial loading it was delivering was about two orders of magnitude higher and possibly more ($>2.90 \times 10^{12}$ *E. coli*/day) than the adjacent, smaller Sarah Beck (3.7×10^{10} *E. coli*/day). The drainage channels from both of these cut through an area where cockle beds have formed historically. Dragley Beck was neither sampled nor measured during the shoreline survey, but its drainage channel appears to converge with the main Leven channel several km to the north of areas where cockle beds tend to form off Aldingham.

The main freshwater input to the Walney Channel is Mill Beck (or Poaka Beck). This drains to the Walney channel via the Cavendish Reservoir and then the docks at Barrow. A large proportion of indicator bacteria are likely to die off whilst retained within the reservoir and docks. This watercourse was not sampled or measured during the shoreline survey. There are several small freshwater outfalls draining to the northern end of the Walney Channel from the mainland but none was of much significance either in terms of volumes discharged or concentrations of bacterial indicators. There are two further minor freshwater inputs to the Roosecote Sands area. Only one freshwater input to the channel from Walney Island was observed and whilst the discharge volume was very low, high levels of contamination (and sewage related debris) were observed within it during the shoreline survey.

It is therefore concluded that the majority of land runoff delivered to the bay is via the two main estuaries, both of which lie to the north of all shellfisheries. A general principle of locating RMPs at the northern end of their respective zones and as close to the two main river drainage channels would best capture contamination originating from the wider inland catchment. Some hotspots of contamination created by minor watercourses draining in the vicinity of historic cockle beds are anticipated, namely in the vicinity of the drainage channels from the River Bela and from Deep Meadow Beck. There is no evidence of any significant land runoff related contamination hotspots within the Walney Channel. There are however numerous very small freshwater inputs at various locations which will cumulatively contribute to levels of faecal indicator organisms in the water column but will only be of very minor and localised impacts.

Human Population

Total resident population within census areas contained within or partially within the catchment area was 229,614 at the time of the last census in 2011. Coastal areas are generally more heavily populated, with several significant towns including Barrow-in-Furness, Morecambe and Ulverston. Kendal is the largest inland urban area. The remaining inland and coastal areas are more sparsely populated, with a number of small towns and villages scattered throughout. Morecambe is a seaside resort, and there are numerous holiday parks around the bay. The catchment extends into the Lake District National Park, which attracts large numbers of tourists. It is therefore concluded that most of the catchment will have a higher population during the summer months due to influxes of holidaymakers.

Sewage Discharges

There are 52 continuous water company sewage works discharging within the survey area, eight of which discharge to saline waters. The largest of these is Barrow STW, which discharges to the eastern edge of the subtidal Barrow Dock approach channel, about 500 m south of the dock entrance. It provides UV treatment so the average bacterial loading it produces is not particularly large (estimated at 1.3×10^{12} faecal coliforms/day). There is also a much smaller works to the south Walney Channel (Roa Island STW) which discharges to the intertidal just south of Roa Island. The estimated bacterial loading from this works is only 1.3×10^{11} faecal coliforms/day, so its impacts will be relatively minor and localised.

There are two sewage works discharging to the Leven estuary, to the north of the cockle beds. Ulverston is the largest of these and is also furthest south, but as it provides UV disinfection the estimated average bacterial loading it generates is not particularly large (estimated at 1.1×10^{12} faecal coliforms/day). Haverthwaite STW discharges much further up the estuary, and provides secondary treatment only but does not have any discharge volumes indicated on the EA permit database. There are also two sewage treatment works discharging to the Kent estuary. Grange-over-Sands is the larger and more southerly of the two, but provides effective UV disinfection so will usually generate only a very minor bacterial loading (estimated at 4.8×10^{9} faecal coliforms/day). Milnthorpe STW is slightly smaller and further up estuary, but only provides secondary treatment so will produce a much larger bacterial loading (estimated at 6.8×10^{12} faecal coliforms/day).

Carnforth STW discharges to the Keer estuary, and provides UV disinfection so only generates a small bacterial loading (estimated at 1.5×10^{10} faecal coliforms/day). Finally, Morecambe STW discharges to the subtidal about 2 km to the south west of Heysham. This is the second largest discharge in the area, but provides effective UV treatment so only generates a small bacterial loading (estimated at 5.1×10^{10} faecal coliforms/day).

The rest of the water company works discharge to watercourses, with the exception of Staveley-in-Cartmel STW which discharges to soakaway. Most are small works serving the scattered rural communities. The majority discharge to watercourses which drain to either the Kent or the Leven estuary to the north of any shellfish resources. Their relative impacts will depend on the distance they are from the coast and the bacterial loading they generate at the point of discharge. For those further inland, significant bacterial die-off is anticipated during transit to coastal waters. Those discharging to watercourses upstream of, or directly to, lakes such as Windermere or Coniston will have little impact due to the lengthy transit times through these lakes.

Two discharge to the upper reaches of Mill Beck (Poaka Beck) (Marton and Marton Lake Ends STWs), which drains to the Walney Channel via Barrow Docks. The combined loading they generate is relatively small (estimated at 1.7×10^{11} faecal coliforms/day), and most contamination from these is likely to die off before reaching coastal water as it has to pass through the Cavendish Reservoir and Barrow Docks first. The Newbiggin STW discharges to the very lower reaches of Deep Meadows Beck, which drains to the shore at Newbiggin. It provides UV treatment so only generates a small bacterial loading (estimated at 4.7×10^{9} faecal coliforms /day) but the Deep Meadows Beck drainage channel does cut directly through the Aldingham cockle bed. High concentrations of *E. coli* (>20,000 cfu/100ml) were found in a water sample taken from this watercourse during the shoreline survey. On the other side of the bay the River Keer receives effluent from two minor secondary works (Over Kellet and Nether Kellet STWs). The estimated combined bacterial loading that these two works generate at their points of discharge is 1.3×10^{12} faecal coliforms/day.

For the works providing UV disinfection, the maximum concentrations of faecal coliforms recorded in the effluents were between two and four orders of magnitude greater than the average. This indicates that at times their impacts may be significantly higher than the estimates made on the basis of the average faecal indicator concentrations in their effluents. It must also be noted that UV disinfection is less effective at eliminating viruses than bacteria.

There are 126 intermittent (overflow) discharges associated with the sewerage networks potentially impacting the survey area. These may discharge either when the sewer is inundated following a heavy rainfall event, or in an emergency such as a power cut or a pump failure. The main cluster of intermittent discharges is in the Barrow area, but they are widespread all around the bay and further inland. They are generally associated with the more urbanised areas. Only 37 of these are fitted with spill event monitoring equipment. Of these, most (21 of 37) spilled for less than 1% of the time so their impacts would not generally be captured through a year of monthly monitoring. The biggest spillers (in terms of % time active) were Newbiggin STW (32.2%), Cark Tank STW (31.9%), Cartmel-in-Cark PS (27.4%), Ulverston STW (19.8%) and Hawkshead PS (14.9%). The Newbiggin STW overflow is most significant in terms of both its location and spill frequency and may have been responsible for the high concentration of *E. coli* found in the Deep Meadow Beck during the shoreline survey. The Schola Green Lane PS spilled for just under 1% of the time (January 2011-December 2013) but is reported to discharge very large volumes (~18,000 m^3/day) when active. Spills from here are therefore likely to have significant and geographically widespread impacts, but are relatively rare. For the other, unmonitored intermittent discharges it is difficult to assess their impacts aside from noting their location and potential to spill untreated sewage.

Although the majority of properties within the survey area are served by water company sewerage infrastructure, there are also 315 private sewage discharges. Where specified, these are generally small treatment works such as package plants, and the majority of these are small, serving one or a small number of properties. 146 of these discharge to soakaway, so should be of no impact on shellfisheries in Morecambe Bay assuming they are functioning correctly. The remaining 169 discharge to water. The majority discharge to watercourses which drain to either the Kent or Leven estuary to the north of any shellfisheries, although most significant watercourses receive some effluent from private discharges. A few discharge directly to saline waters. The largest of these by a considerable margin originates from the Glaxo Smith Kline industrial unit at Ulverston. It discharges to the Leven channel off Ulverston, and is tidally phased, only being active for 45 minutes starting 30 minutes after high water. The maximum permitted volume is 8,000m^3/day, although a maximum volume of 12,000m^3/day can be discharged up to 35 times a year. No details of the nature of the effluent or treatment type for this discharge was available other than being described as 'process effluent', but some bacterial concentration data was available. Recent effluent testing results (January to March 2014) show that the average faecal coliform concentration was low (185 cfu/100 ml). Other private discharges of potential relevance to the sampling plan are two to Heysham Harbour (combined volume of up to 42.3 m^3/day): the Heysham Nuclear Power Station's sewage works, which discharges off Heysham (up to 38 m^3/day) and the discharge from the South End Caravan Park from the southern end of Walney Island (up to 105 m^3/day). Those discharging to watercourses will make some contribution to the bacterial loadings they deliver to coastal waters.

Agriculture

Most agricultural land within the survey catchment is pasture, although there are numerous small pockets of arable land mainly within the lower reaches of the catchment around Barrow and the lower reaches of the River Leven. Parts of the bay are fringed with grazed saltmarsh, particularly in the inner reaches and around the Kent and Leven estuaries. During the 2013 livestock census 375,144 sheep and 70,968 cattle were recorded within the catchment. Significant impacts from grazing livestock are therefore anticipated. Sheep and cattle densities were highest in the Kent, Bela and Crake sub-catchments. Small numbers of pigs were reported (2,481) as well as potentially significant numbers of poultry (245,829) most of which were in the Keer and Kent sub-catchments.

Faecal matter from grazing livestock is either deposited directly on pastures, or collected from livestock sheds if animals are housed indoors then applied to agricultural lands as a fertilizer. Manure from pigs and poultry is typically stored and applied tactically to nearby farmland. 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. Peak fluxes of contamination from grazing livestock are likely to arise following high rainfall events, 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.

Most salt marshes in the survey area are grazed on a year round basis, mainly by sheep but also some cattle. The main grazed saltmarshes lie around the Kent, Leven and Keer estuaries. There may be considerable fluxes of faecal matter into the bay from the grazed areas of saltmarsh, as it will be washed directly into drainage creeks by tidal inundation. Highest fluxes of contamination are anticipated as the tide size increases towards spring tides, when more of the marsh is inundated, and the area inundated increases each tide.

Rainfall and river flows are generally higher during the winter months, although high rainfall events may occur at any time of the year. 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 the warmer months, livestock are likely to access watercourses more frequently to drink and cool off. 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 seasonal pattern of application of other organic fertilizers (e.g. poultry manure or sewage sludge) is uncertain.

A large proportion of the agricultural land lies within parts of the catchment drained by watercourses discharging to the Kent and Leven estuaries, but almost all significant watercourses will be affected to some extent. Therefore, a general principle of locating RMPs adjacent to the main river/stream drainage channels and as close to the point at which they drain to the bay should be applied to best capture agricultural contamination. Drainage channels from grazed saltmarsh may also carry high concentrations of faecal indicator bacteria, particularly as tide sizes increase towards spring tides.

Boats

The discharge of sewage from boats is a potential source of bacterial contamination of shellfisheries within Morecambe Bay. Barrow and Heysham are the main hubs from which boat traffic in the area operates, with a few smaller vessels also using Morecambe. Navigation of larger vessels within the bay, particularly the uncharted inner reaches, is problematic due to its shallow nature and the constantly changing bathymetry. There are no sewage pumpout facilities anywhere within the survey area.

Heysham only handles commercial shipping (mainly vehicle ferries) and is accessed via the Lune Deeps and the Heysham channel. It is therefore concluded that vessels accessing Heysham do not come in close proximity to the shellfish beds, and being merchant vessels they are not allowed to make overboard discharges within 3 nautical miles of land anyway. A much greater diversity of vessels operates from Barrow, although it is a smaller port in terms of the volume of shipping it receives. It accommodates a variety of commercial, naval and recreational marine traffic, including specialist vessels such as nuclear fuel carriers. It is accessed via the Walney Channel, which is maintained by regular dredging. Traffic to and from Barrow therefore passes near to mussel beds near Roa and Foulney Islands, and any cockles on Snab Sands. Barrow is also the main centre for yachts, of which around 200 are visible on moorings on aerial photography, mainly between the port entrance and the Jubilee Bridge. A small fishing fleet of six vessels, all but one of which are under 10 m, also operates from Barrow. There are several moorings at Morecambe, where 30 smaller open boats and two larger yachts were observed during the shoreline survey. A fleet of 10 under 10 m fishing boats operates from here, some of which are likely to form part of the 30 smaller vessels observed during the shoreline survey.

Commercial shipping should be of no influence on shellfish hygiene within Morecambe Bay. Larger fishing vessels and pleasure craft such as yachts and cabin cruisers are likely to make overboard discharges in the area. This may occur whilst they are in occupation on moorings, or whilst they are on passage. The area most vulnerable to such discharges is around the moorings in the Walney Channel, and the navigation from there out to sea. It is possible that overboard discharges are also made off Morecambe. However, outside of the Walney Channel it is likely that the impacts of overboard discharges are negligible. Recreational boating activity peaks in the summer, so any associated impacts would likely follow this seasonal pattern. Without any firm information on the numbers, timing and locations of such discharges it is difficult to draw any firmer conclusions.

Wildlife

Morecambe Bay includes the largest continuous area of intertidal sand and mudflats in the UK, as well as large areas of saltmarsh, mussel reefs, and some eelgrass beds in the Walney Channel. These and other features support significant wildlife populations.

The most significant wildlife aggregation in terms of shellfish hygiene is likely to be overwintering waterbirds (waders and wildfowl). An average total count of 214,931 waterbirds was reported over five winters up to 2012/13 for Morecambe Bay, which includes the Lune and Wyre estuaries. A wide variety of species were recorded, the majority of which were wading species. These will forage on intertidal invertebrate communities where they will deposit faeces directly in a diffuse manner. At high water, they aggregate in numerous specific locations, primarily saltmarsh, although shingle banks, seawalls and groynes are also used. Waders will therefore deposit diffuse contamination directly on the intertidal, and also in the vicinity of the many roost sites where impacts may be more concentrated. Some waterbird species (e.g. geese) are herbivorous, and will forage on eelgrass, saltmarsh and coastal grasslands. As such their faeces may be deposited directly on the intertidal on the Walney eelgrass beds, on saltmarsh areas which are only inundated on the larger tides, or on pastures which are never inundated. Their impacts will therefore either be diffuse and to the intertidal, or possibly more concentrated in runoff from pasture and tidal drainage from saltmarsh. It is therefore concluded that waterbirds may be significant contributors to levels of *E. coli* within shellfish in the area but their impacts will largely be diffuse although they may be more concentrated around roost areas and in saltmarsh drainage channels.

Whilst most waterbirds migrate elsewhere outside of the overwintering period, some will breed here and remain in the area throughout the year so they will continue to impact in a similar but much reduced manner at other times of the year. There are also significant breeding populations of seabirds (gulls, terns etc) in the area. A census in 2000 recorded a total of 31,866 pairs of breeding seabirds around the perimeter of the survey area. The vast majority of these (29,616 pairs of gulls) were nesting on the South Walney nature reserve, at the southern tip of Walney Island. A much smaller breeding colony (1,836 pairs of gulls) was recorded on the Carnforth Marshes and Leighton Moss, an area of wetland just to the north of the Keer estuary. Aside from these, only a few scattered pairs were recorded. Seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. Neither of the seabird colonies lies in close proximity to any identified shellfish resources, so they will have no influence on the sampling plan.

There is a grey seal colony at the South Walney nature reserve, where numbers average between 20 and 50, and peak at around 100. They forage widely throughout Morecambe Bay, and have been reported as far inshore as Arnside. Their impacts will be highest at their haul out site, where they lie on the sand in a relatively dense aggregation, but this is not in the immediate vicinity of any shellfish resources. Away from their haul out site they range widely and so their impacts may be considered diffuse in addition to being spatially and temporally unpredictable. As such, they will have no influence on the sampling plan. No other wildlife species of relevance to shellfish hygiene in Morecambe Bay 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 such as Morecambe and Barrow. 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												
Saltmarsh grazing												
Continuous sewage discharges												
Intermittent sewage discharges	?	?	?	?	?	?	?	?	?	?	?	?
Birds												
Boats												

Red - high risk; orange - moderate risk; yellow - lower risk. It must be noted that the magnitude of impacts from the various sources vary significantly throughout the survey area.

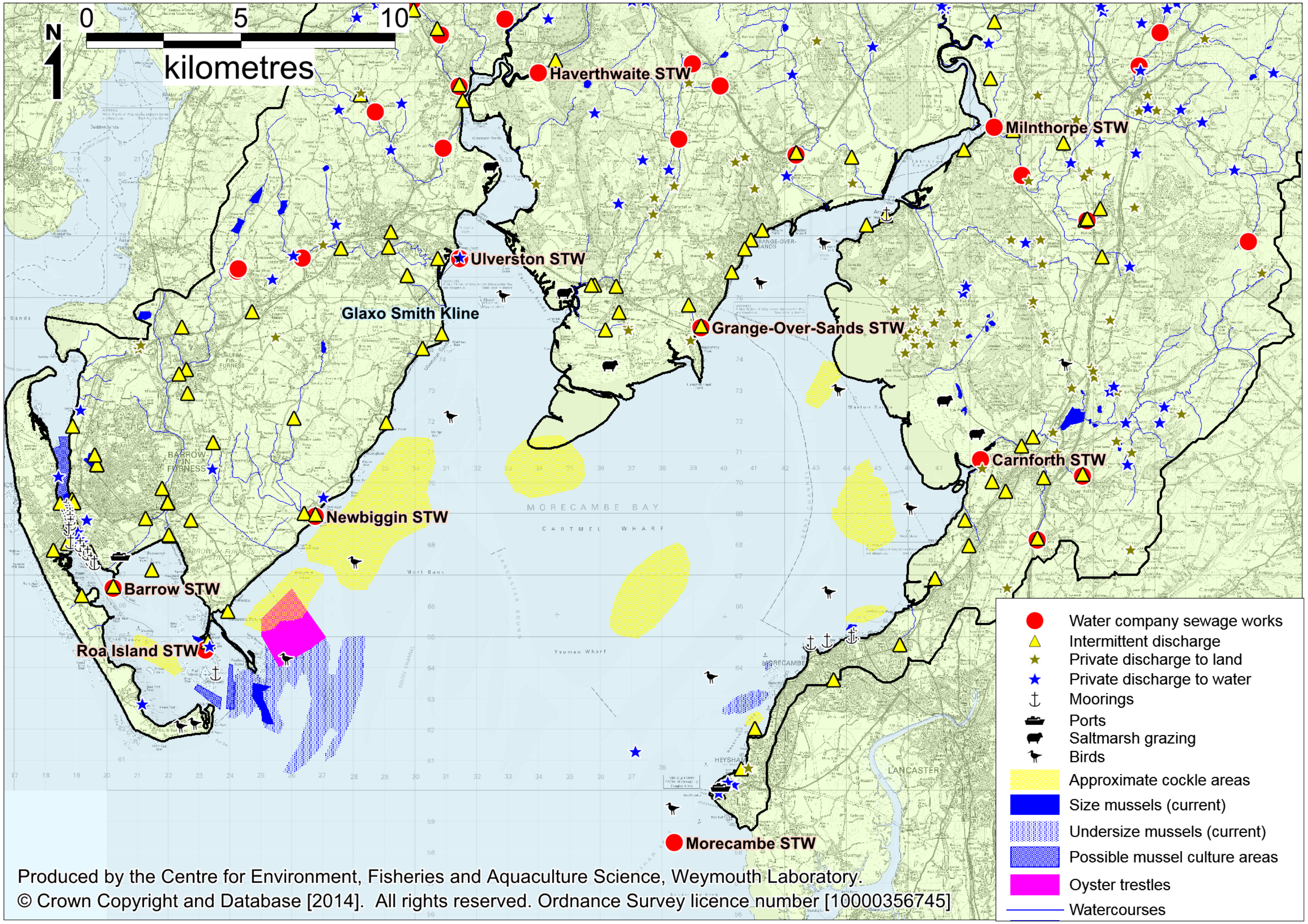


Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The survey area consists of two distinct water bodies; Morecambe Bay and the Walney Channel. Morecambe Bay consists of a vast area of constantly shifting intertidal sandflats within which there is a network of intertidal and subtidal channels. Two significant estuaries (Leven and Kent) drain to the inner reaches of the bay on the west and east sides, between which there is a central peninsula. There are significant areas of saltmarsh fringing the inner reaches of the bay and the two estuaries. The drainage channels from the two estuaries are highly mobile. They meander southwards through the bay and are braided in places. The outer reaches of the bay consist of several parallel sandbanks between which lie subtidal channels. The channels on the eastern side are deeper, including the Grange Channel where depths exceed 10 m relative to chart datum. The subtidal channels merge into the Lune Deeps to the south of the survey area. The mainly intertidal nature of the bay will mean that a large proportion of water is exchanged each tide, but the dilution potential will be more limited. Elevated concentrations of faecal indicator bacteria delivered by land runoff are likely to arise in the drainage channels at lower states of the tide.

The Walney Channel forms a connection between Morecambe Bay and the adjacent Duddon estuary to the north. At its southern end, a maintained subtidal channel connects the docks at Barrow to the Irish Sea. Either side of this dredged channel there are extensive areas of intertidal mudflats, fringed with saltmarsh in places. A network of intertidal drainage channels feed into the main subtidal channels from these areas. There is a scoured channel just south of Piel Island (Bass Pool) through which a proportion of the water flooding to and draining from Snab Sands will pass. To the north of the dock entrance the main channel narrows and shallows, becoming intertidal in the vicinity of the Jubilee Bridge. The elevation of the channel bed peaks to the north of the Jubilee Bridge around an area called the Walney Meetings, where the incoming tides from the north and south meet. The connection to the Duddon estuary will therefore be limited to higher states of the tide, and may not be made at all on the smallest neap tides so exchange of water across it will be very limited. Again, the generally shallow and intertidal nature of the Walney Channel will mean that a large proportion of water is exchanged each tide, but the dilution potential will be limited.

The tidal range is large, at 8.4 m on spring tides and 4.5 m on neap tides at Morecambe. This drives extensive water movements throughout the area. The tide floods up into Morecambe Bay from the south, through the Lune Deeps then branches out up the various subtidal and intertidal channels, from which it spreads out across the intertidal flats. The reverse occurs on the ebb. Through most parts of the bay tidal streams orientate roughly along the north-south axis. Contamination from shoreline sources will therefore generally be carried north on the flood tide, and south on the ebb tide, becoming progressively more diffuse with time and distance. At lower states of the tide, contamination from sources such as watercourses will follow drainage channels across the intertidal within which the potential for dilution is greatly reduced. In some areas the minor channels are orientated more along the east-west axis, so tidal streams across the higher parts of the intertidal zone may run more perpendicular than parallel to the shore. Such areas include Warton Sands and some areas off the central isthmus. It is difficult to be precise about the exact orientation of tidal streams on a small scale as the channels and sandbanks are highly mobile.

Tides move into the Walney Channel simultaneously from the north and south end, meeting to the north of the Jubilee Bridge towards high water. They then recede in the opposite direction on the ebb. In the southern part of the channel, the main flows will align with the maintained channel, although at higher states of the tide they may also pass just south of Piel Island. Tidal streams will spread out across Snab and Roosecote Sands from this channel. Intertidal drainage channels in these areas generally orientate perpendicular to the shore. Sources of contamination to the south of the Meetings will therefore not generally impact to the north, and vice versa. Those discharging to the narrower part of the channel to the north of Barrow docks will travel up and down the channel parallel to the shore becoming more dilute with distance. Those discharging to the shore adjacent to Roosecote and Snab Sands will be carried out via the drainage channels, where there will be little scope for dilution at lower states of the tide.

Current velocities on spring tides within the Grange, Heysham and Walney approach channels peak at just over 1 m/s and are about twice that experienced during neap tides. Very approximate estimates of tidal excursions within these channels range from 11 to 15 km on spring tides and 7-9 km on neap tides. Assuming that similar excursions apply within the two main estuaries, contamination released at the tidal limit at high water may not reach any cockle beds before the flood tide begins. This will increase the potential for bacterial die-off before contamination delivered by the rivers is flushed as far south as the cockle beds. Tidal currents will be slower in shallow intertidal areas due to the effects of friction. Tides are asymmetrical, with some areas showing flood dominance and others showing ebb dominance. While this is of great importance to longer term processes such as residual sediment transport, it is of much less relevance to the dispersal patterns of relatively short lived faecal indicator organisms.

Superimposed on tidally driven currents are the effects of freshwater inputs and wind. The flow ratio is low for Morecambe Bay as a whole indicating little possibility of density driven circulation. Such effects may arise within the upper reaches of the Kent and Leven estuaries, particularly at times of high river discharge resulting in a net seaward flow of fresher water at the surface and a corresponding return of more saline water at depth. They are unlikely to occur in the vicinity of any shellfish resources with any regularity however.

Areas of decreased average salinity are likely to represent areas of increased microbiological contamination deriving from land runoff. Repeated salinity measurements suggest that there is little freshwater influence within the Walney Channel, where salinities averaged 31.7 ppt and were usually above 30 ppt. Salinity along the Morecambe seafront was slightly lower, averaging around 30 ppt with occasional results of under 25 ppt. There was no evidence of a significant gradient in average salinity from Morecambe through to Heysham. The average salinity off Ulverston was slightly lower (28.3 ppt) and occasional measurements of less than 20 ppt were recorded. This indicates that contamination delivered by the freshwater inputs to the estuary has been well diluted with seawater before it reaches the northern part of the cockle beds. Given the similar shape and dimensions of the Kent estuary, this is also likely to apply to the opposite side of the bay.

Strong winds will modify water circulation. They drive surface currents, which in turn drive return currents either at depth or along sheltered margins. Morecambe Bay is exposed to the prevailing winds from the south west, whereas the Walney Channel is sheltered from all directions by the surrounding land. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. The prevailing south westerly winds will tend to enhance surface flood flows, and retard surface ebb flows within the bay for example. 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. Due to the large size of the embayment, strong winds from any direction will blow across a considerable distance of water, and so nowhere in the bay is particularly sheltered from an onshore wind. Incoming swells from the Irish Sea will break over the sandbanks in the outer reaches of the western side of the bay at lower states of the tide, but will travel up the deeper waters on the eastern side, which may therefore be more exposed to wave action. Whilst remobilisation of sediment entrained contamination may also occur in the Walney Channel, particularly the wider southern part, it is much more sheltered than the bay.

5.5. Summary of Existing Microbiological Data

Morecambe Bay has been subject to significant microbiological monitoring over recent years, deriving from bathing and shellfish waters monitoring and shellfish flesh monitoring for hygiene classification purposes. Figure 5.2 shows the locations of the monitoring points referred to in this assessment.

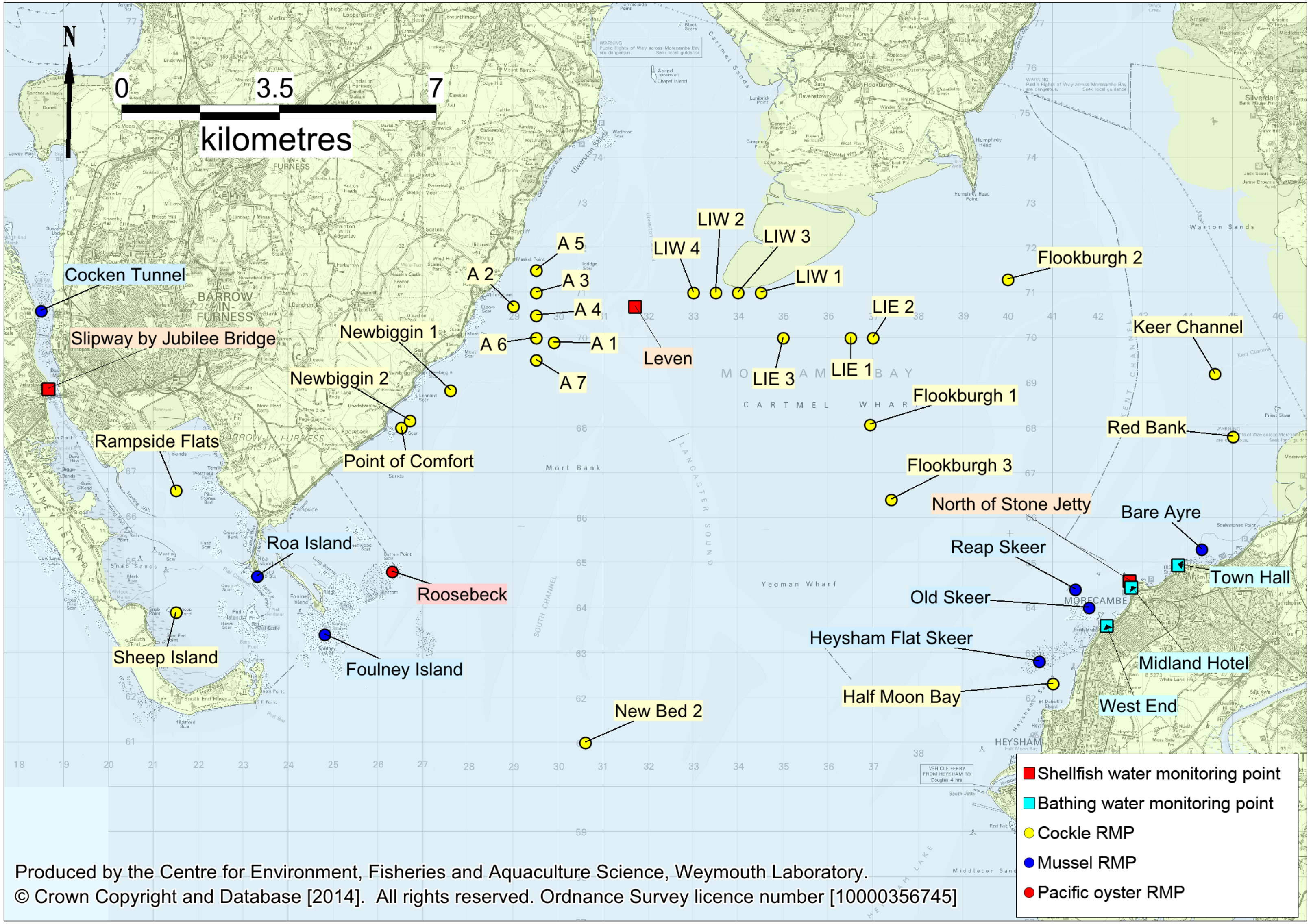


Figure 5.2: Microbiological sampling sites

Bathing Waters

Around twenty water samples were taken from each of the three bathing waters monitoring points during each bathing season (May to September) and enumerated for *E. coli*. All are located along the Morecambe seafront. Town Hall was monitored from 2009 to 2014, Midland Hotel was monitored from 2012 to 2014, and West End was only monitored in 2009. Results were highest on average at West End (95.7 *E. coli*/100ml) and very similar at Town Hall and Midland Hotel (38.4 and 42.3 *E. coli*/100ml respectively). Comparisons of paired (same day) samples indicate that *E. coli* concentrations were significantly higher at West End compared to the other two monitoring points, and that *E. coli* concentrations were strongly correlated at all three. This suggests that there is a significant source of contamination to the western end of Morecambe seafront, and that all three monitoring points are impacted by it.

A significant correlation between tidal state across the high/low tidal cycle was found for Town Hall only, but when the data was plotted it was apparent that sampling was strongly targeted to high water and no obvious patterns were apparent. No statistically significant influence of the spring/neap tidal cycle was found at any of the three sites. Significant positive correlations between *E. coli* concentrations and antecedent rainfall were found for all three monitoring points. The effect appeared to be strongest at Town Hall, and weakest at West End, suggesting the influence becomes stronger towards the eastern end of the stretch, although it must be noted that sample numbers and the period sampled varied between them. Strong negative correlations were found between salinity and *E. coli* concentrations at Town Hall and Midland Hotel, but not at West End. Although this reinforces the patterns observed with respect to rainfall, the same caveats apply.

Shellfish waters

There are three shellfish waters monitoring points within the survey area, where water samples are taken on a quarterly basis and enumerated for faecal coliforms. One of these shellfish waters (Leven) was only monitored from 2011, whereas results from the other two (Jubilee Bridge and North of Stone Jetty) from 2004 were considered in the analyses. Average faecal coliforms were highest at Jubilee Bridge (76.9 faecal coliforms/100ml) followed by North of Stone Jetty (60.2 faecal coliforms/100ml) then Leven (18.9 faecal coliform/100g). The low average result at Leven implies that there is not a major increase in levels of contamination towards the estuary. Although the mean result was markedly lower at Leven, only 11 samples were taken from here and there was no statistically significant difference in average result between the three monitoring points.

Faecal coliform concentrations have remained fairly stable at Jubilee Bridge and North of Stone Jetty since 2004. Statistically significant seasonality was observed at Jubilee Bridge, but not at North of Stone Jetty. There were insufficient numbers of results to investigate seasonality at Leven. At Jubilee Bridge results were significantly higher in the winter compared to the spring. The differing seasonal patterns suggest that the two sites are subject to different profiles of contaminating influences. A significant influence of tidal state on faecal coliform concentrations was found at Jubilee Bridge, but not at North of Stone Jetty. All but one sample from Jubilee Bridge was taken around high tide. However a tendency for higher results after high water was apparent when the data was plotted, and the sample taken at low water returned the highest individual result. This may indicate there are significant contamination sources to the north of Jubilee Bridge. A significant correlation between faecal coliform concentrations and tidal state across the spring/neap tidal cycle was found at North of Stone Jetty but not Jubilee Bridge. At North of Stone Jetty, higher results tended to occur in samples taken on larger tides. This may suggest that a more remote source or possibly tidal inundation of grazed salt marsh may be of significance in this part of the bay. No tidal correlations were undertaken for Leven due to the small number of samples.

Antecedent rainfall had a significant impact on faecal coliform levels at both Slipway by Jubilee Bridge and North of Stone Jetty, but not Leven. However, the correlation coefficient values at Leven are similar to those at the other sampling sites. It is possible therefore that Leven is significantly affected by rainfall, and that this would become apparent with further sampling. Faecal coliform concentrations showed significant negative correlations with salinity at the time of sampling at Jubilee Bridge and Leven, but not at North of Stone Jetty. At Slipway by Jubilee Bridge and Leven, faecal coliform levels correlated significantly with salinity. This indicates that land runoff is a significant contaminating influence at these locations. At North of Stone Jetty, there was no significant correlation between faecal coliform concentrations and salinity. This is perhaps surprising given the correlations with rainfall here, and the strong correlation with salinity observed at the nearby Midland Hotel bathing water site.

Shellfish Hygiene Classification Monitoring

There are a total of 34 RMPs in Morecambe Bay that have been sampled since 2005, of which 26 are for cockles, 7 are for mussels and one is for Pacific oysters. Most of these (17 of the cockle RMPs and 3 of the mussel RMPs) were sampled on less than 10 occasions so could not be considered in any of the statistical analyses.

Cockle sampling locations have varied with time across the various beds/zones, largely due to fluctuations in the geographic distribution of stocks. This complicates the interpretation of the spatial variation in levels of contamination, as the sets of results from each individual monitoring point are not directly comparable with other monitoring points as different temporal periods are represented. Results were broadly similar across the survey area as a whole, and generally aligned with a solid B classification. In the Red Bank area however, average *E. coli* levels were highest and the results were more aligned with a C classification. A less marked area of elevated contamination is also apparent in the Newbiggin/Point of Comfort area, and the Leven Island area appears to be slightly less contaminated than other areas. There is no suggestion of a consistent increase in *E. coli* levels towards the innermost reaches of the bay, although the cockle beds do not extend up into the two main river estuaries where the influence of runoff from the wider catchment would become more acute. Results were very similar at the two monitoring points in the outer Walney Channel (Rampside Flats and Sheep Island). One prohibited level result was recorded at each of Newbiggin 1, Flookburgh 2 and Red Bank. Statistical comparisons showed that average *E. coli* levels at Red Bank (503 MPN/100g) were significantly higher than Rampside Flats (176 MPN/100g), Sheep Island (148 MPN/100g), Leven Island East 2 (129 MPN/100g) and Flookburgh 3 (141 MPN/100g). Paired (same day) comparisons were possible for three RMP pairings, one on opposite sides of the Walney Channel (Rampside Flats/Sheep Island), one along the western shore (Newbiggin 1/Aldingham 4), and one off the central peninsula (Leven Island East 2/Flookburgh 3). All pairings shored strong correlations on a sample by sample basis suggesting that within these areas similar sources are an influence.

Although class B compliance was strong at all four of the main mussel RMPs, the average *E. coli* result was significantly higher at Bare Ayre (387 MPN/100g) than at Roa Island, Foulney Island and Cocken Tunnel (115, 111 and 146 MPN/100g respectively). Direct comparisons of paired (same day) sample results were only possible between the three sites on the western side of the bay (Roa Island, Foulney Island and Cocken Tunnel). *E. coli* levels were correlated on a sample by sample basis between Cocken Tunnel and Roa Island only. The reason for the lack of correlation between Roa Island and the other two RMPs is uncertain, but may be related to the presence of the Roa Island STW in close proximity to the Roa Island RMP. The sole Pacific oyster RMP (Roosebeck) complied strongly with the class B standards and had an average *E. coli* level of 91 MPN/100g.

Since 2005, results have remained stable at the RMPs which have been monitored on a long term basis. Across all nine main cockle RMPs a similar pattern of higher average results in the summer and autumn was apparent. The variation was statistically significant at most locations. Across the four main mussel RMPs differing seasonal patterns were observed. At the western RMPs (Roa Island, Foulney Island and Cocken Tunnel) results were lowest on average in the spring and highest on average in the winter, whereas on the eastern side (Bare Ayre) there was a summer/autumn peak. This suggests the two sides are subject to contamination from different seasonal profiles of sources. The variation was statistically significant at Bare Ayre only. At the Roosebeck Pacific oyster site a summer/autumn peak was observed, but the effect was not statistically significant.

Statistically significant variation in *E. coli* levels in relation to tidal cycles was detected at several RMPs. At the Sheep Island cockle RMP correlations were detected between *E. coli* levels and tidal state on both the high/low and spring/neap tidal cycles.

When the data was plotted there appeared to be a slight tendency for higher results around low tide, and no obvious pattern in relation to the spring/neap cycle. A correlation between *E. coli* results and tidal state on the high/low cycle was found for the Bare Ayre mussel RMP, but sampling was targeted towards low water and no patterns were apparent when the data was plotted. A significant correlation between results and the spring/neap tidal cycle was found for the Foulney Mussel RMP. Results were lower on average during neap tides, suggesting that more remote sources may be a significant influence here. There was a significant correlation between *E. coli* levels and the high/low tidal cycle at the Roosebeck Pacific oyster RMP, where higher results tended to occur at low water.

Rainfall had a statistically significant influence on *E. coli* levels in cockles at Newbiggin 1, Flookburgh 2 and Red Bank. These are the only three cockle monitoring points where prohibited level results have been recorded. It may therefore be speculated that these RMPs were closest to low water drainage channels carrying freshwater inputs, and that such locations are best positioned to capture peak levels of contamination. There is however no firm evidence to substantiate this supposition. *E. coli* levels in samples from all mussel RMPs except Foulney Island were significantly affected by antecedent rainfall. It appeared, however, to have no influence on levels of *E. coli* in Pacific oysters at Roosebeck.

Bacteriological survey

No bacteriological survey was undertaken as the area has sufficient historical microbiological monitoring to inform the assessment.

Appendices

Appendix I. Human Population

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

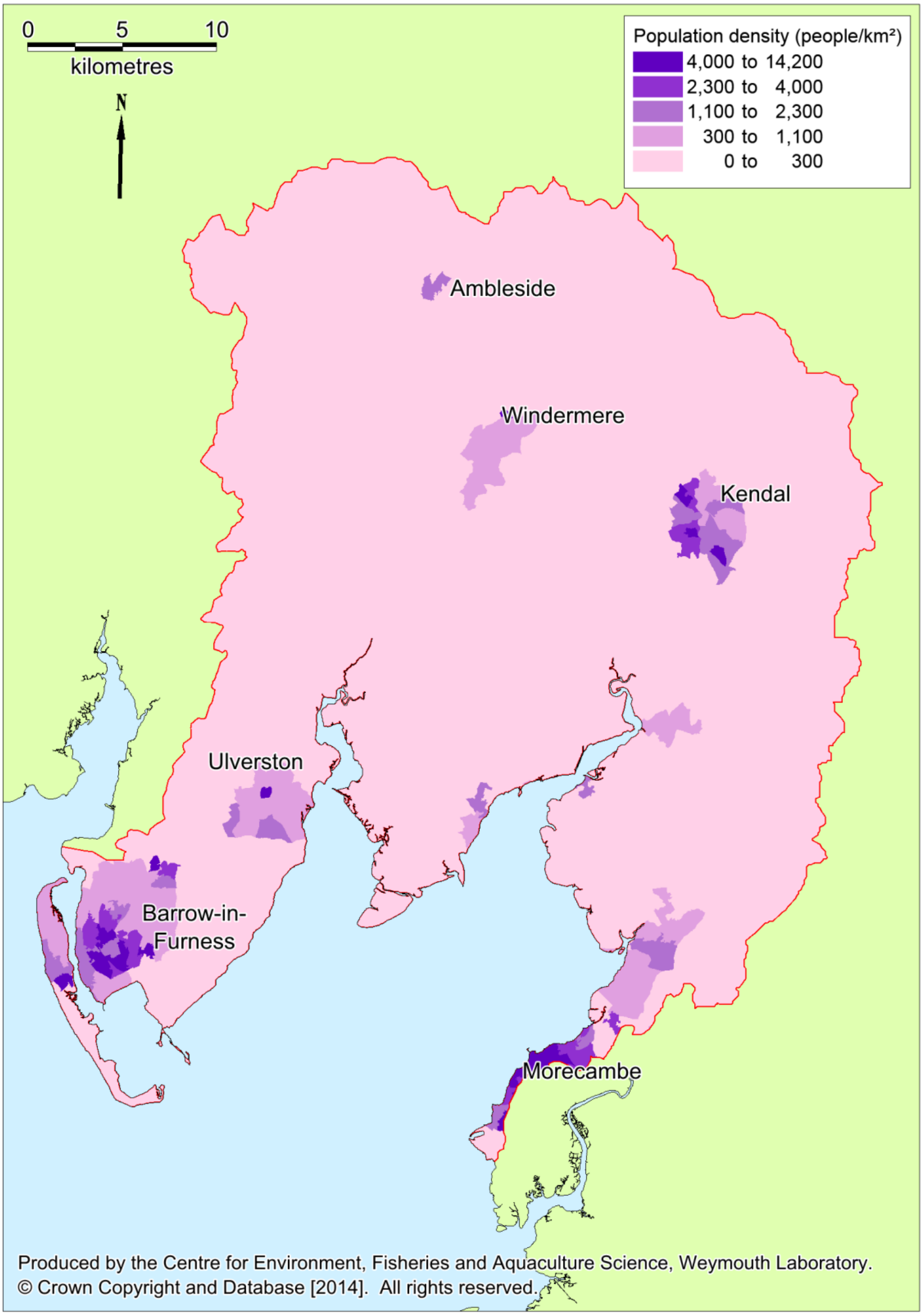


Figure I.1: Human population density in census areas in the Morecambe Bay catchment.

Total resident population within census areas contained within or partially within the catchment area was 229,614 at the time of the last census. Coastal areas are generally more heavily populated, with several significant towns including Barrow-in-Furness (population ~ 57,000), Morecambe (population ~ 45,000) and Ulverston (population ~ 12,000). Kendal is the largest inland town, with a population of around 28,000. The remaining inland and coastal areas are more sparsely populated, with a number of small towns and villages scattered throughout.

About 50% of the catchment is occupied by the Lake District National Park. In 2012 there were around 14.8 million visitors to the national park (National Parks, 2012), and so it can be expected that the population in the upper catchment will be subject to a moderate increase during the warmer months. There are also numerous static caravan holiday park sites around the bay. Morecambe is a seaside resort, although Barrow is more of an industrial town than a tourist destination. It is therefore concluded that most of the catchment will have a higher population during the summer months due to an influx of holidaymakers.

Appendix II. Sewage Discharges

Details of all consented sewage discharges within the hydrological catchment were taken from the July 2014 update of the Environment Agency national permit database. Due to the large number of discharges, the locations of these are presented over several maps. Figure II.1 shows the entire catchment but without labels, Figure II.2 shows the western coastal areas, Figure II.3 shows the eastern coastal areas, and Figure II.4 shows the inland areas.

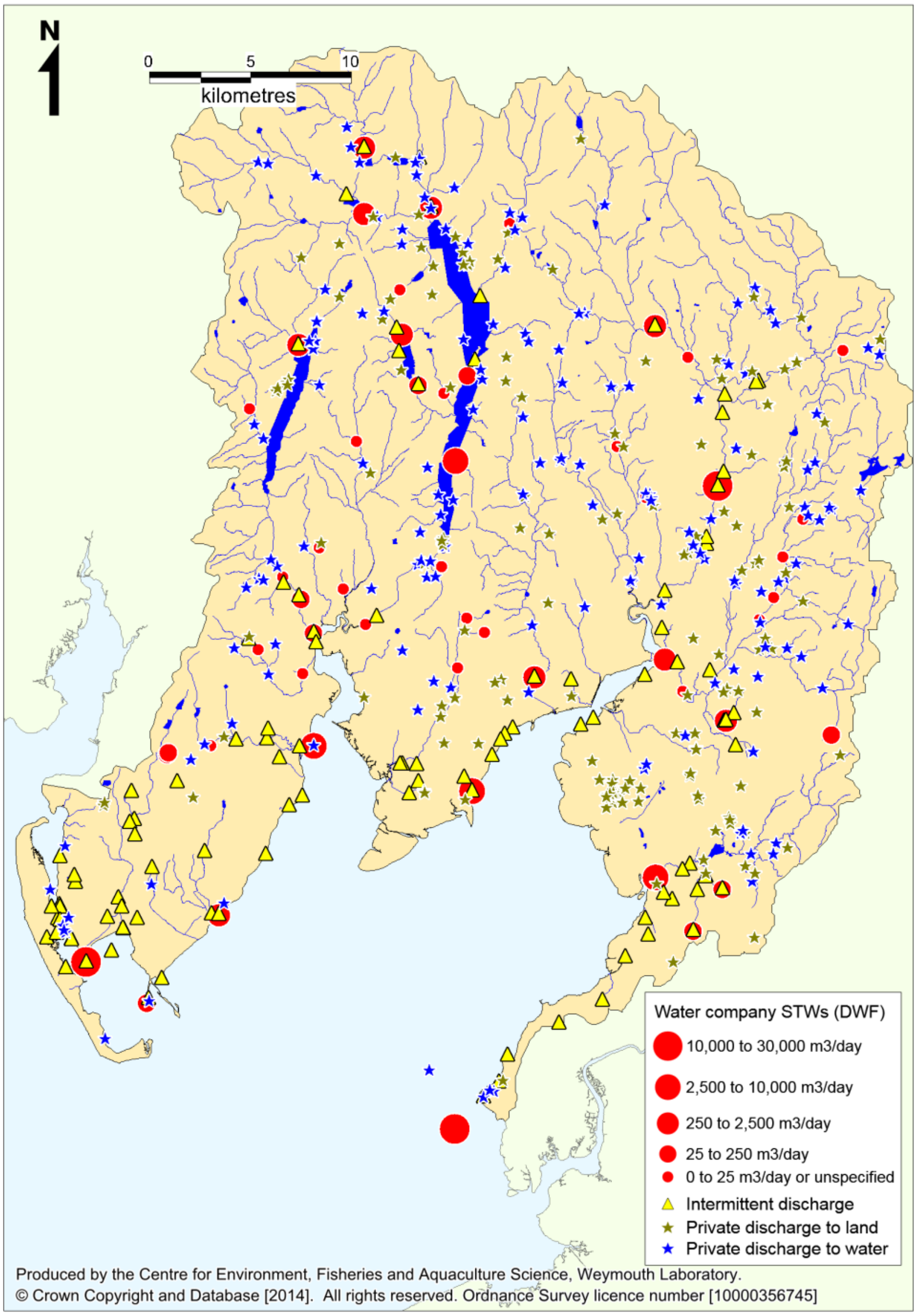


Figure II.1: All permitted sewage discharges to the Morecambe Bay catchment (labels omitted)
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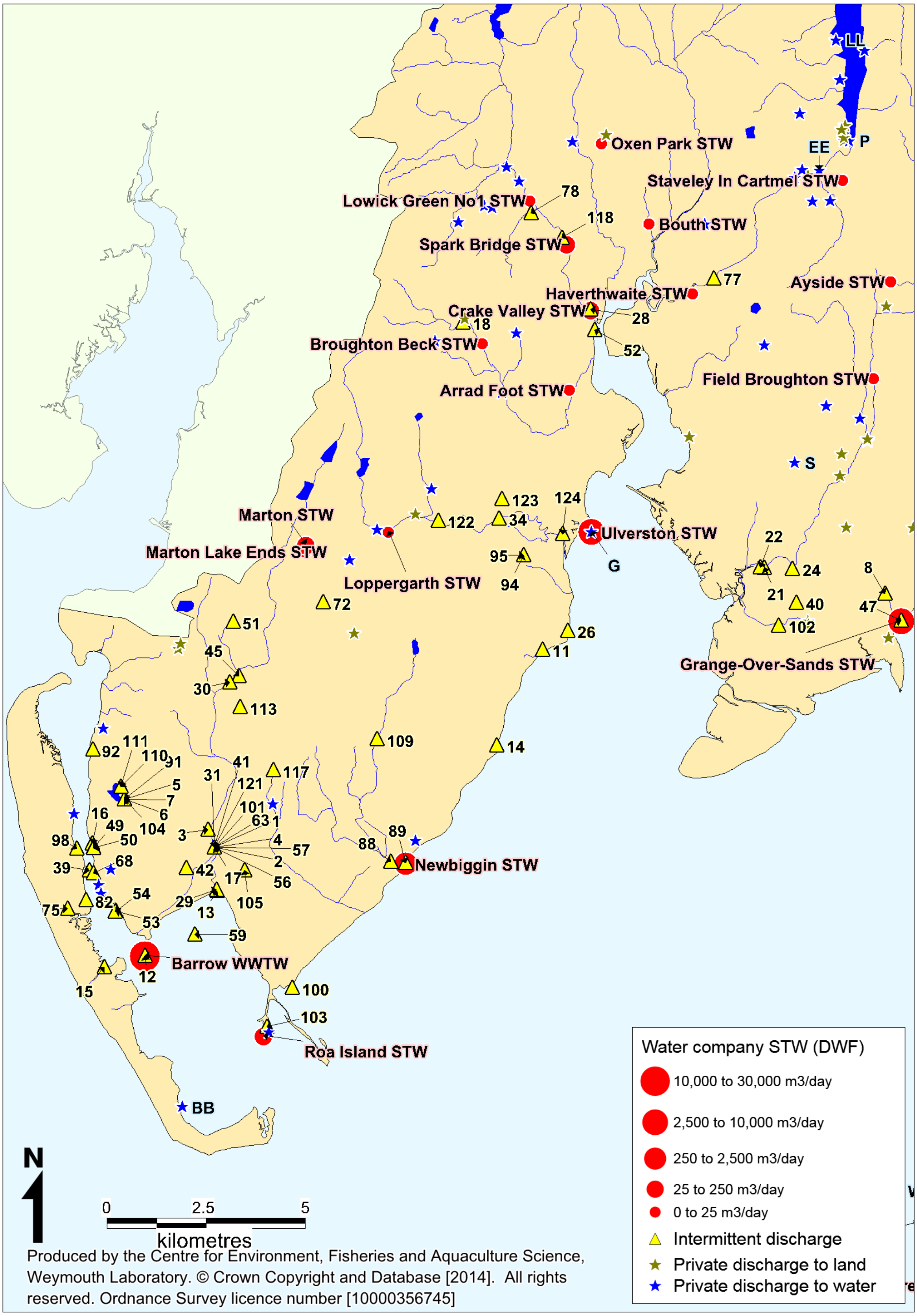

Figure II.2: All permitted sewage discharges to western coastal areas
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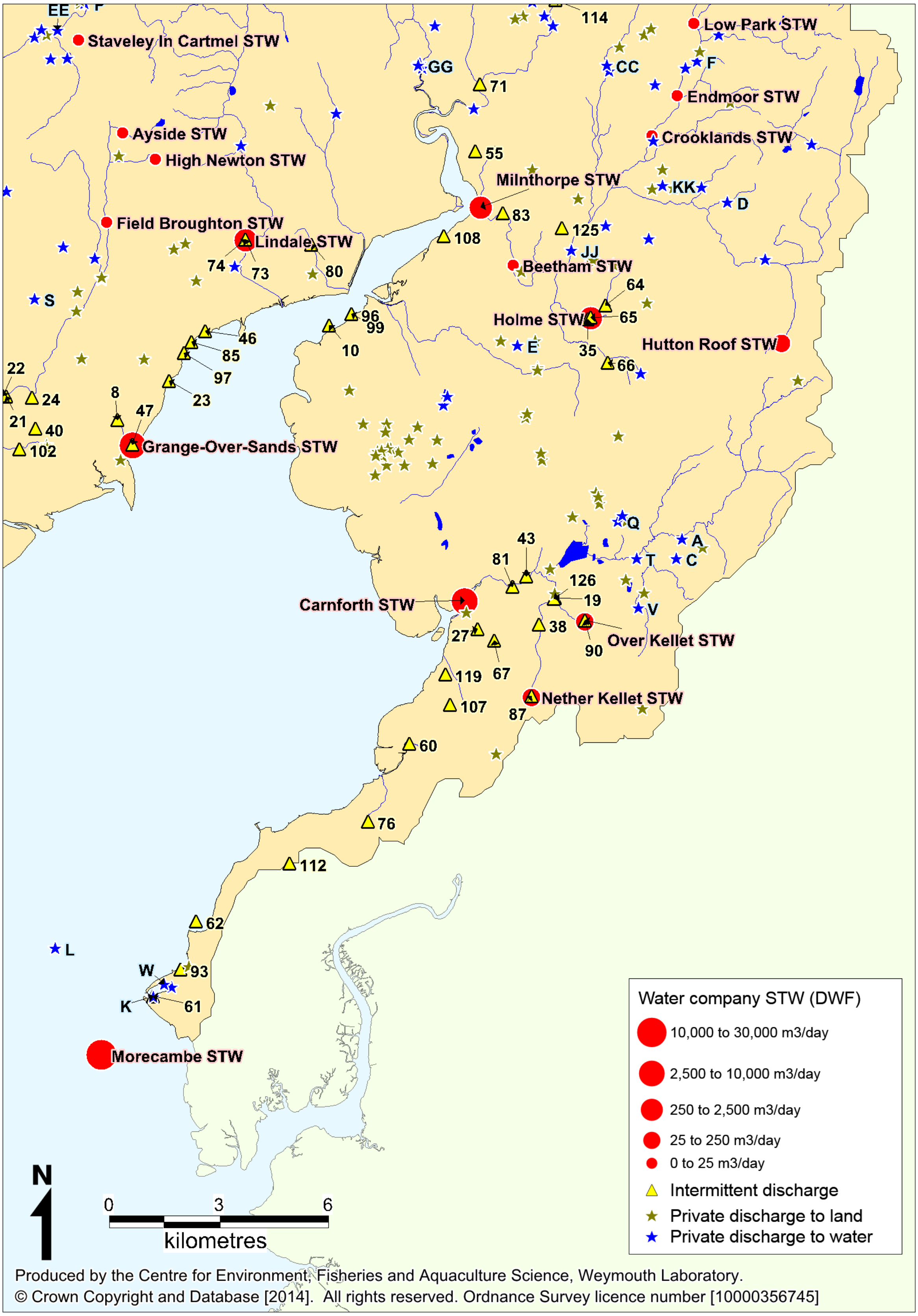

Figure II.3: All permitted sewage discharges to eastern coastal areas
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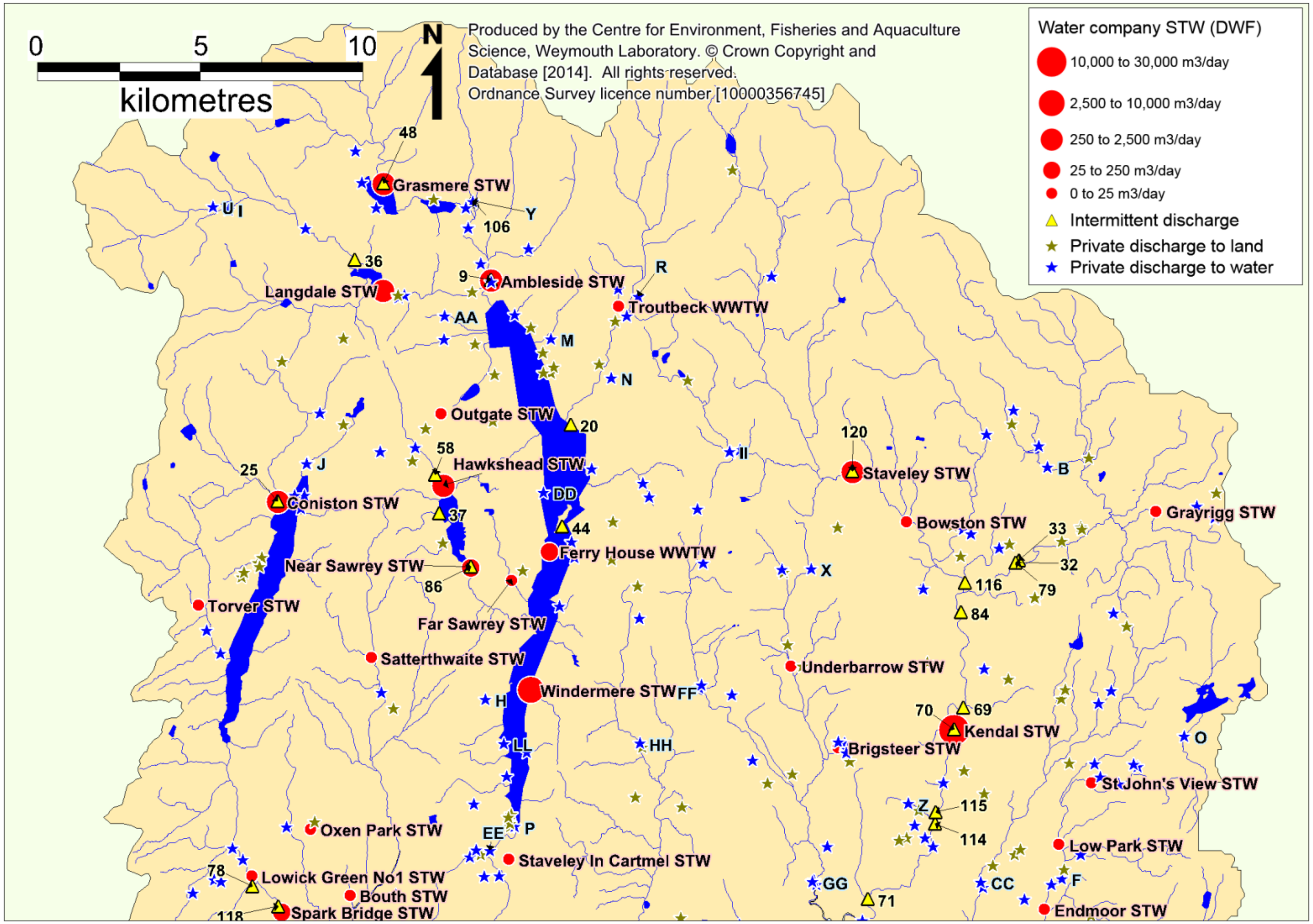

Figure II.4: All permitted sewage discharges to inland areas

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There are 52 continuous water company sewage works discharging within the survey area, details of which are presented in Table II.1.

Table II.1: Details of continuous water company sewage works within the survey area

Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)	Receiving environment
Ambleside STW Off A593	NY3722003890	UV Disinfection	1,500	$3.3x10^{8}$**	River Rothay
Arrad Foot STW	SD3089080890	Primary settlement	10.9^{+}	$1.1x10^{11}$*	Newland Beck trib.
Ayside STW	SD3899083620	Biological Filtration	11.6^{+}	$3.8x10^{10}$*	Belman Beck trib.
Barrow WWTW	SD2019066600	UV Disinfection	27,500	$1.3x10^{12}$**	Walney Channel
Beetham STW	SD4967080000	Biological Filtration	18.9^{+}	$6.2x10^{10}$*	River Bela
Bouth STW	SD3290085070	Biological Filtration	18.3^{+}	$6.0x10^{10}$*	Wear Beck
Bowston STW	SD4995096510	Biological Filtration	6.9^{+}	$2.3x10^{10}$*	River Kent
Brigsteer STW	SD4785089590	Biological Filtration	19.2^{+}	$6.3x10^{10}$*	River Pool trib.
Broughton Beck STW	SD2869082060	Biological Filtration	14.1^{+}	$4.6x10^{10}$*	Newland Beck
Carnforth STW	SD4834070780	UV Disinfection	5,260	$1.5x10^{10}$**	Keer Estuary
Coniston STW	SD3068097110	Biological Filtration	542	$1.8x10^{12}$*	Church Beck
Crake Valley STW	SD3142082890	Biological Filtration	151	$5.0x10^{11}$*	River Crake
Crooklands STW	SD5348083540	Biological Filtration	6.5^{+}	$2.2x10^{10}$*	Peasey Beck
Endmoor STW	SD5417084640	Biological Filtration	Unspecified	-	Peasey Beck
Far Sawrey STW	SD3786094720	Biological Filtration	9.9^{+}	$3.3x10^{10}$*	Wilfin Beck
Ferry House WWTW	SD3902095590	Biological Filtration	25	$8.3x10^{10}$*	Windermere
Field Broughton STW	SD3855081170	Primary settlement	8.3^{+}	$8.3x10^{10}$*	Ayside Pool
Grange-Over-Sands STW	SD3925075060	UV Disinfection	3,462	$4.8x10^{9}$**	Morecambe Bay
Grasmere STW	NY3392006840	Secondary + phosphate removal	2,470	$8.2x10^{12}$*	Grasmere
Grayrigg STW	SD5759096830	Biological Filtration	17.4^{+}	$5.8x10^{10}$*	Lambrigg Beck
Haverthwaite STW	SD3399083320	Biological Filtration	Unspecified	-	Leven Estuary
Hawkshead STW	SD3576797609	Biological Filtration	368	$1.2x10^{12}$*	Black Beck
High Newton STW	SD3988082900	Biological Filtration	22.2^{+}	$7.3x10^{10}$*	Ayside Pool trib.
Holme STW	SD5179078540	Biological Filtration	1,018	$3.4x10^{12}$*	Holme Beck
Hutton Roof STW	SD5703077860	Package Plant	27	$8.9x10^{10}$*	Sealford Beck
Kendal (New Works) STW	SD5141090120	Tertiary (disc filters)	16,000	$5.3x10^{13}$*	River Kent
Langdale STW	NY3391003580	Secondary	1,120 (max)	$3.7x10^{12}$*	River Brathay

Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)	Receiving environment
Lindale STW	SD4234080670	High Rate Biological	763	$2.5x10^{12}$*	River Winster
Loppergarth STW	SD2633077310	Biological Filtration	9.4^{+}	$3.1x10^{10}$*	Pennington Beck
Low Park STW	SD5462086630	Biological Filtration	Unspecified	-	Peasey Beck
Lowick Green No1 STW	SD2989085660	Primary settlement	8.6^{+}	$8.6x10^{10}$*	River Crake
Marton Lake Ends STW	SD2420076900	Biological Filtration	25	$8.3x10^{10}$*	Poaka Beck trib.
Marton STW	SD2425076970	Biological Filtration	25	$8.3x10^{10}$*	Poaka Beck trib.
Milnthorpe STW	SD4878081570	Activated Sludge	2,071	$6.8x10^{12}$*	Bela estuary
Morecambe STW	SD3840058350	UV Disinfection	13,820	$5.1x10^{10}$**	Morecambe Bay
Near Sawrey STW	SD3660095110	Biological Filtration	79	$2.6x10^{11}$*	Cunsey Beck
Nether Kellet STW	SD5018068160	Biological Filtration	173	$5.7x10^{11}$*	Nether Beck
Newbiggin (Leven) STW	SD2675068940	UV Disinfection	710	$4.7x10^{9}$**	Deep Meadows Beck
Outgate STW	SD3569099830	Biological Filtration	6.2^{+}	$2.1x10^{10}$*	Ford Wood Beck trib.
Over Kellet STW	SD5164070240	Biological Filtration	208	$6.9x10^{11}$*	River Keer trib.
Oxen Park STW	SD3170087100	Biological Filtration	7.5^{+}	$2.5x10^{10}$*	Colton Beck trib.
Roa Island STW	SD2318064600	Biological Filtration	38	$1.3x10^{11}$*	Piel Channel
Satterthwaite STW	SD3355092350	Biological Filtration	13.9^{+}	$4.6x10^{10}$*	Farra Grain Gill
Spark Bridge STW	SD3081084560	Biological Filtration	80	$2.6x10^{11}$*	River Crake
St John's View STW	SD5562088520	Biological Filtration	19.5^{+}	$6.4x10^{10}$*	Peasey Beck
Staveley In Cartmel STW	SD3777086170	Septic Tank And Filter	4	$4.0x10^{10}$*	Soakaway
Staveley STW	SD4830098030	Biological Filtration	754	$2.5x10^{12}$*	River Kent
Torver STW	SD2826093960	Biological Filtration	16	$5.3x10^{10}$*	Torver Beck
Troutbeck WWTW	NY4113003110	Biological Filtration	17	$5.6x10^{10}$*	Carfoot Beck/Trout Beck
Ulverston STW	SD3143077300	UV disinfection	9,315	$1.1x10^{12}$**	Morecambe Bay
Underbarrow(Hillgarth)STW	SD4642092090	Biological Filtration	2.9^{+}	$9.5x10^{9}$*	Chapel Beck
Windermere STW	SD3843091360	UV Disinfection	5,559	$5.0x10^{11}$**	Windermere

+ Calculated from population equivalent, assuming a water use of 160 l/head/day

*Faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs providing secondary treatment (Table II.2)

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

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	7.2×10^6
Primary (12)	127	1.0×10^7	14	4.6×10^6
Secondary (67)	864	3.3×10^5	184	5.0×10^5
Tertiary (UV) (8)	108	2.8×10^2	6	3.6×10^2

Data from Kay et al. (2008b).
n - number of samples.
Figures in brackets indicate the number of STWs sampled.

Eight sewage works within the survey area provide UV disinfection. Table II.3 and Figure II.5 summarise the results of bacteriological testing of their final effluents.

Table II.3: Summary statistics for final effluent testing data (faecal coliform cfu/100ml) from UV treated works, January 2009 to March 2014

Sewage works	No.	Geometric mean result (cfu/100ml)	Minimum	Maximum
Ambleside	136	22	0	230,000
Barrow	137	4,581	0	78,000,000
Carnforth	132	276	0	120,000
Grange	134	138	0	140,000
Morecambe	130	368	0	600,000
Newbiggin	135	667	0	490,000
Ulverston*	70	12,173	0	360,000
Windermere	136	9,036	0	900,000

** Data for 2013 and 2014 unavailable*

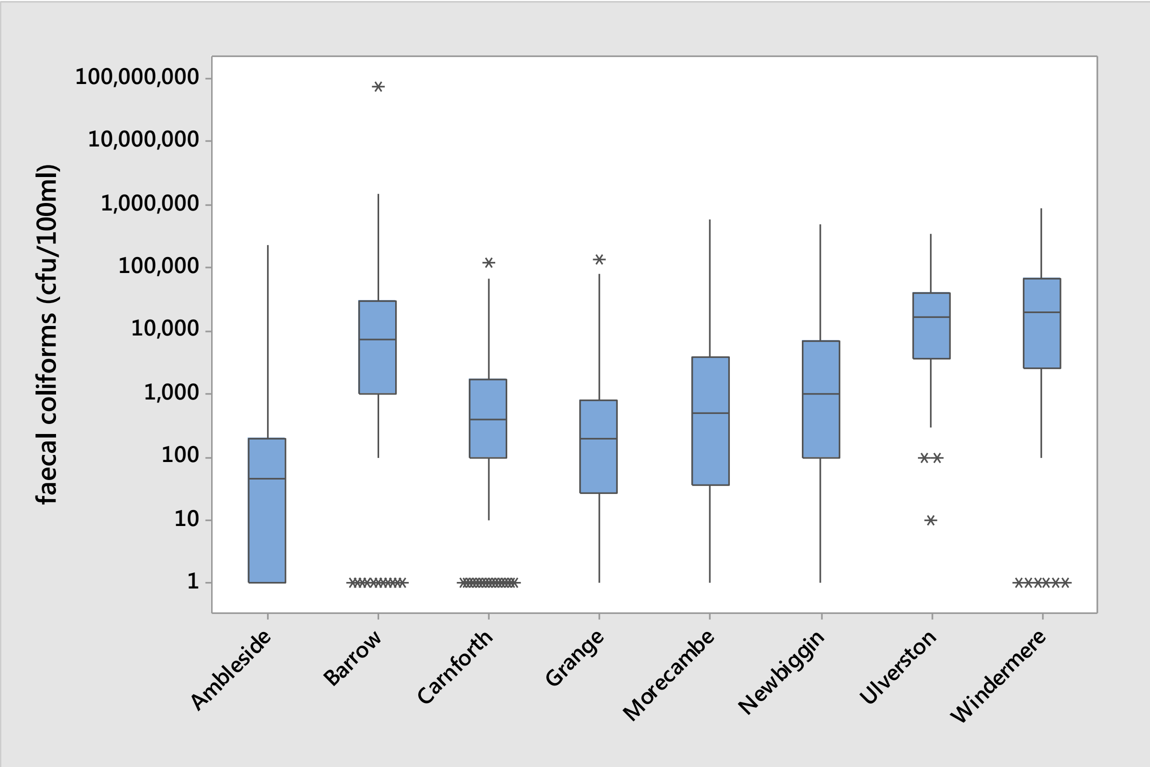

Figure II.5: Boxplot of faecal coliform concentrations in UV treated final effluents by works.
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Bacteriological testing results for the final effluent from most of these works indicates that disinfection is generally effective, and the estimated (average) bacterial loading they generate is therefore very small. As such, their impacts will usually be minor and localised. Average concentrations of faecal coliforms in the effluents from Barrow, Ulverston and Windermere STWs were markedly higher than the other works, although they were much lower than is typical of secondary works. The maximum concentrations of faecal coliforms recorded were however between two and four orders of magnitude greater than the average indicating that at times their impacts may be significantly higher. It must also be noted that UV disinfection is less effective at eliminating viruses than bacteria (e.g. Tree et al, 1997).

Of the 52 water company sewage works, eight discharge to saline waters. Barrow STW discharges to the eastern edge of the Barrow Dock approach channel, about 500 m south of the dock entrance. It is the largest discharge in the survey area, but provides UV disinfection so the average bacterial loading it generates is not particularly large. The outfall location was moved from the middle of Roosecote Sands in March 2015. There is also a much smaller works to the south of Walney Channel (Roa Island STW) which discharges to the intertidal just south of Roa Island. There are two sewage works discharging to the Leven estuary, to the north of the cockle beds. Ulverston is the largest of these and is also furthest south, and provides UV treatment, although the average bacterial indicator concentration in its effluent is relatively high for this type of works. The other (Haverthwaite STW) is a small secondary works located near the tidal limit of the Leven estuary. There are also two works discharging to the Kent estuary. Grange-over-Sands is the larger and more southerly of the two, but provides effective UV disinfection so will usually generate only a very minor bacterial loading. Milnthorpe STW is slightly smaller and further up estuary, but only provides secondary treatment so will produce a much larger bacterial loading than Grange-over-Sands STW. Carnforth STW discharges to the Keer estuary, and provides UV disinfection so only generates a small bacterial loading. The drainage channel from the Keer estuary cuts through cockle settlements at Warton Sands. Finally, Morecambe STW discharges to the subtidal about 2 km to the south west of Heysham. This is the second largest discharge in the area, but provides effective UV treatment so only generates a small bacterial loading.

The rest of the water company works discharge to watercourses, with the exception of Staveley-in-Cartmel STW which discharges to soakaway. Most of these are relatively small works serving the scattered rural communities. Two discharge to the upper reaches of Poaka Beck (Marton and Marton Lake Ends STWs), which drains to the Walney Channel via Barrow Docks. The Newbiggin STW discharges to the very lower reaches of Deep Meadows Beck, which drains to the shore at Newbiggin. It provides UV treatment and only generates a small bacterial loading, but the Deep Meadows Beck drainage channel does cut directly through the Aldingham cockle bed. On the other side of the bay the River Keer receives effluent from two minor secondary works (Over Kellet and Nether Kellet STWs). All other sewage works discharge to watercourses which drain to either the Kent or the Leven estuary to the north of any shellfish resources. Their relative impacts will depend on the distance they are from the coast and the bacterial loading they generate at the point of discharge. For those further inland, significant bacterial die-off is anticipated during transit to coastal waters. Those discharging to watercourses upstream of or directly to lakes such as Windermere or Coniston will have little if any impacts due to the lengthy transit times through these lakes.

In addition to the continuous sewage discharges, there are 126 intermittent discharges associated with the sewerage networks. Details of these are shown in Table II.4. Spill event monitoring records were available for 38 of these, which are highlighted in yellow. A large number of the unmonitored coastal intermittent discharges will be fitted with event monitoring during the period 2015-2020.

Table II.4: Intermittent discharges to the survey area

Map Ref	Name	NGR	Permit_Number	Receiving Water
1	188 Rating Lane CSO	SD2194069330	01BRW0038	Mill Beck Via Roose Bridge
2	27/29 Abbotsmead Approach	SD2194069330	01BRW0042	Mill Beck
3	31 Abbotsmead Approaches	SD2177069780	01BRW0040	Roose Brook/Millbeck
4	Abbey Rd/Hollow Lane	SD2194069330	01BRW0034	Roose Brook/Millbeck
5	Ainslie St/Harrogate St	SD1966070550	01BRW0012	Ormsgill Res
6	Ainslie St/Newport St	SD1966070550	01BRW0011	Ormsgill Res
7	Ainslie St/Oxford St	SD1966070550	01BRW0013	Ormsgill Res
8	Allithwaite STW	SD3885075730	01LAK0056	River Kent

Map Ref	Name	NGR	Permit_Number	Receiving Water
9	Ambleside STW off A593	NY3722003890	17370024	River Rothay
10	Ash Meadow PS	SD4463178321	17380414	The Kent Estuary
11	Bardsea SPS (Toilet Block)	SD3021074320	17280254	Bardsea Beck
12	Barrow WWTW	SD2019066600	17470166	Walney Channel
13	Barrow WWTW	SD2201068240	17470166	Walney Channel
14	Baycliff Overflow	SD2905071910	17370199	Morecambe Bay
15	Biggar Village PS	SD1916066320	01BRW0001	Walney Channel
16	Blake Street Outfall	SD1885069440	17380242	Walney Channel
17	Bridgegate Ave (M.H. 5)	SD2194069330	01BRW0041	Roosebridge/Millbeck
18	Broughton Beck PS	SD2820082560	17380282	Newlands Beck
19	Browfoot Close PS	SD5082070850	17390187	Nether Beck
20	Calgarth SPS	SD3966099460	17380244	Windermere
21	Cark Tank STW	SD3580076380	01LAK0076	River Eea
22	Cark Tank STW	SD3570076390	17370205	River Eea
23	Cart Lane PS	SD4025076800	17370129	Kent Channel
24	Cartmel In Cark PS	SD3651076350	17380400	River Eea
25	Coniston STW	SD3068097110	17370035	Church Beck
26	Cooper Lane SPS	SD3085074800	17280253	Leven Estuary
27	Crag Bank SPS	SD4871070000	17280249	Trib Black Dyke
28	Crake Valley WWTW	SD3142082890	EPRFP3828GS	River Crake
29	Dalton Sewer Point E	SD2199068270	01LA1659	Salthouse Pool
30	Dalton-In-Furness SSO	SD2232073490	17470006	Poaka Beck
31	Dane Ave/Wheatclose Rd	SD2194069330	01BRW0035	Roose Brook/Millbeck
32	Dodding Holme	SD5330095230	01LAK0004	Trib River Mint
33	Dodding Holme SPS	SD5340095300	17380245	Trib River Mint
34	Dragley Beck CSO	SD2911077620	17380296	Dragley Beck
35	Duke Street	SD5171078500	01LAK0044	Holme Beck
36	Elterwater	NY3305004510	01LAK0025	Great Langdale Beck
37	Esthwaite Lodge	SD3563896747	17380246	Esthwaite Water
38	Fairfield Road PS	SD5038070130	01LAN0070	Unspecified
39	Ferry PS	SD1878068750	17480342	Walney Channel
40	Field Head PS	SD3660075500	17380283	Trib Windermoor Drain
41	Flass Ln @ Bridgegate	SD2194069330	01BRW0039	Roose Brook/Millbeck
42	Frederick St PS	SD2123068810	17480412	Mill Beck/ Cavendish Dock
43	Gardner Rd	SD5003071450	01LAN0058	River Keer
44	Glebe Rd PS	SD3941196345	17370148	Windermere
45	Goose Green SPS	SD2255073650	17470001	Poaka Beck
46	Grange SPS	SD4125078160	17380194	Kent Estuary
47	Grange-Over-Sands STW	SD3925075060	17370128	Kent Channel
48	Grasmere STW	NY3392006840	17370027	Grasmere
49	Graving Dock Barrow Island	SD1889069330	17480254	Walney Channel
50	Graving Dock PS	SD1889069320	17480340	The Walney Channel
51	Greenhaume SPS	SD2241075020	17380248	Hagg Gill
52	Greenodd PS	SD3153082380	EPRFP3828XR	River Leven
53	Harbour Yard Barrow Island	SD1945067730	17480255	Walney Channel
54	Harbour Yard PS	SD1944067720	17480339	The Walney Channel

Map Ref	Name	NGR	Permit_Number	Receiving Water
55	Haversham SDW	SD4864083090	01LAK0055	Unspecified
56	Hawcoat Ln/Hartland Rd	SD2194069330	01BRW0031	Roose Brook/Millbeck
57	Hawcoat Ln/Th'Cliff Rd	SD2194069330	01BRW0032	Roose Brook/Millbeck
58	Hawkshead PS	SD3552097930	17380284	Black Beck
59	Headin Haw SPS	SD2144067140	17480257	Walney Channel
60	Hest Bank PS	SD4684066860	17290499	Hatlex Beck
61	Heysham Harbour 5th Quay	SD3982059940	17490061	Heysham Harbour (Lake)
62	Heysham Village PS	SD4100061990	17370153	Morecambe Bay
63	Hollow Ln/Old Harrel Lane	SD2194069330	01BRW0036	Mill Beck Via Roose Bridge
64	Holme	SD5221078870	01LAK0083	Holme Beck
65	Holme STW	SD5179078540	17370138	Holme Beck
66	Holme Mills SSO	SD5227077300	17370154	Ewan Mill Beck
67	Hope Tce	SD4915069690	01LAN0061	Keer Estuary
68	Jubilee Bridge SPS	SD1888068680	17480258	Walney Channel
69	Kendal (New Works) STW	SD5170090790	17370100	River Kent
70	Kendal (New Works) STW	SD5141090120	17370100	River Kent
71	Levens Pumping Station	SD4877084932	NPSWQD008205	Kent Estuary
72	Lindal In Furness SPS	SD2468075510	17370050	Clarkes Beck
73	Lindale STW	SD4234280672	17370073	River Winster
74	Lindale STW	SD4234080680	17370073	River Winster
75	Long Bank Tummerhill Mars	SD1824067790	01BRW0092	The Walney Channel
76	Low Lane PS	SD4570064720	01LAN0024	Unspecified
77	Low Wood Bridge PS	SD3453083680	17380340	River Leven
78	Lowick Green PS	SD2992085320	NPSWQD000814	Otley Beck
79	Mealbank SPS	SD5330095230	17380249	River Mint
80	Meathop PS	SD4415080530	17380417	Meathop Marsh Drain
81	Midland Tce.	SD4966071170	01LAN0059	River Keer
82	Mikasa St/Avon St	SD1870068010	01BRW0089	The Walney Channel
83	Milnthorpe Sewage PS	SD4939081400	17380339	River Bela
84	Mintsfeet Road North SPS	SD5162093710	01LAK0067	River Kent
85	Morecambe CSO	SD4087077860	01LAK0071	Kent Channel
86	Near Sawrey STW	SD3660095110	17370030	Cunsey Beck
87	Nether Kellet STW	SD5018068160	17370074	Nether Beck, Trib River Keer
88	Newbiggin (Leven) STW	SD2638068970	17370051	Deep Meadows Beck
89	Newbiggin (Leven) STW	SD2675168941	17370051	Deep Meadows Beck
90	Over Kellet STW	SD5164070240	17370075	Trib River Keer
91	Oxford Street SSO	SD1966070550	17480304	Ormsgill Reservoir
92	Palace Nook SPS	SD1887071800	17480314	Walney Channel
93	Port Of Heysham PS	SD4057060680	17370211	Trib Of Heysham Lake
94	Priory Road	SD2973076700	01LAK0005	Trib Carter Pool
95	Priory Road	SD2973076700	17380250	Trib Carter Pool
96	Promenade	SD4524978640	17370203	R. Kent Estuary
97	Promenade CSO	SD4067077560	17370196	Kent Channel
98	Promenade/Latona St	SD1846069310	01BRW0094	The Walney Channel
99	Promenade/Silverdale Rd CSO	SD4524978640	EPRYP3621XD	Morecambe Bay
100	Rampside Village	SD2390065800	01BRW0071	Trib Piel Channel

Map Ref	Name	NGR	Permit_Number	Receiving Water
101	Rating Ln/M'Owlands Avenue	SD2194069330	01BRW0037	Roose Bridge/Millbeck
102	Ravenstown PS	SD3616074930	17380497	Windermoor Main Drain
103	Roa Island PS	SD2326064810	17480366	Piel Channel
104	Romney Rd SSO	SD1966070550	17480303	Ormsgill Reservoir
105	Roosecote SPS	SD2270068760	17480264	Walney Channel
106	Rydal Hall	NY3665006300	17390303	Rydal Beck
107	Rydal Rd PS	SD4795067930	01LAN0002	Stream
108	Sandside Sewage PS	SD4778080770	17370202	The Kent Estuary
109	Scales Village CSO	SD2604072060	01LAK0053	Gleaston Beck
110	Schneider Road	SD1958070870	17840361	Unspecified
111	Schneider Street	SD1958070871	17480361	Unspecified
112	Schola Green Lane PS	SD4355063580	17370197	Morecambe Bay
113	Schoolwaters	SD2259072870	01BRW0008	Billingecote Tarn
114	Sedgwick PS	SD5083087230	17370060	River Kent
115	Sedgwick Sewage PS	SD5085087580	17370026	River Kent
116	Shap Road	SD5174094610	17380252	River Kent
117	South East Of Newton SSO	SD2342071280	17370140	Sarah Beck
118	Spark Bridge PS	SD3070084700	EPRBP3624XL	River Crake
119	St Nicholas Lane	SD4782068760	17190855	Mill Dam
120	Staveley STW	SD4830098020	17370061	River Kent
121	Thorncliff Rd/Cliff Ln	SD2194069330	01BRW0033	Mill Beck via Roose Bridge
122	Three Bridges(Swarthmoor)PS	SD2757377572	17380500	Levy Beck
123	Town Beck CSO	SD2918078110	17380295	Town Beck
124	Ulverston STW	SD3071077240	17370179	R Leven Estuary & Carter Pool
125	Whasset	SD5101080990	01LAK0031	Trib River Bela
126	Whernside Grove PS	SD5079070830	01LAN0065	Nether Beck

Spill records for monitored intermittent discharges were available for varying periods since April 2011. Summary statistics for these are presented in Table II.5. The percentage of time active covers differing periods for each discharge, from the beginning of the period in which the first spill was recorded to the end of March 2014. No information on spill volumes was available.

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

Map Ref	Discharge name	Permit No.	Period of 1st record	No spill events	Total duration (hrs)	% time active
6	Ainslie St/Newport St	01BRW0011	Q2 2013	15	109.9	1.0%
9	Ambleside STW Off A593	017370024	Q4 2011	44	1,262.7	5.8%
10	Ash Meadow PS	017380414	Q2 2011	39	729.7	2.8%
11	Bardsea SPS (Toilet Block)	017280254	Q3 2013	1	0.1	0.0%
15	Biggar Village PS	01BRW0001	-	0	0.0	0.0%
22	Cark Tank STW	017370205	Q2 2013	25	2,797.0	31.9%
23	Cart Lane PS	017370129	Q2 2013	3	3.0	0.0%
24	Cartmel In Cark PS	017380400	Q2 2013	16	2,399.9	27.4%
26	Cooper Lane SPS	017280253	Q3 2013	5	13.9	0.2%

Map Ref	Discharge name	Permit No.	Period of 1st record	No spill events	Total duration (hrs)	% time active
27	Crag Bank SPS	017280249	Q2 2013	1	0.3	<0.1%
28	Crake Valley WWTW	EPRFP3828GS	Q4 2013	23	345.2	7.9%
34	Dragley Beck CSO	017380296	Q2 2013	65	295.9	3.4%
36	Elterwater	01LAK0025	Q3 2011	22	1,124.1	4.7%
37	Elterwater	017380246	Q2 2013	23	520.1	4.8%
39	Ferry PS	017480342	Q2 2013	38	337.6	3.9%
42	Frederick St PS	017480412	Q2 2013	22	68.5	0.8%
43	Gardner Rd	01LAN0058	Q2 2013	5	44.7	0.5%
44	Glebe Rd PS	017370148	Q2 2012	26	102.8	0.6%
45	Goose Green SPS	017470001	-	0	0.0	0.0%
47	Grange-Over-Sands STW	017370128	Q2 2012	46	107.2	0.6%
50	Graving Dock PS	017480340	Q2 2013	43	57.7	0.7%
54	Harbour Yard PS	017480339	Q2 2012	89	160.6	0.9%
58	Hawkshead PS	017380284	Q3 2011	47	3,595.0	14.9%
60	Hest Bank PS	017290499	Q3 2012	14	324.9	2.1%
62	Heysham Village PS	017370153	Q3 2011	18	12.2	0.1%
67	Hope Tce	01LAN0061	Q3 2012	28	339.2	2.2%
78	Lowick Green PS	NPSWQD000814	Q3 2013	22	528.3	8.0%
81	Midland Tce.	01LAN0059	Q2 2012	60	514.5	2.9%
89	Newbiggin (Leven) STW	017370051	Q4 2011	34	7,055.8	32.2%
92	Palace Nook SPS	017480314	-	0	0.0	0.0%
96	Promenade	017370203	Q3 2013	7	23.1	0.4%
99	Promenade/Silverdale Rd CSO	EPRYP3621XD	Q4 2012	11	55.5	0.4%
100	Rampside Village	01BRW0071	Q2 2012	35	134.4	0.8%
102	Ravenstown PS	017380497	Q2 2013	4	66.1	0.6%
108	Sandside Sewage PS	017370202	-	0	0.0	0.0%
112	Schola Green Lane PS	17370197	Q1 2011*	335	218.7	0.8%
122	Three Bridges(Swarthmoor) PS	017380500	-	0	0.0	0.0%
124	Ulverston STW	017370179	Q4 2011	51	4,345.9	19.8%

*Data only available to the end of 2013

The main cluster of intermittent discharges is in the Barrow area, but they are widespread all around the bay and further inland, and are generally associated with the more extensive urban areas. For those without spill records it is difficult to assess their impacts aside from noting their location and potential to spill untreated sewage. Of the monitored outfalls most (22 of 38) spilled for less than 1% of the time so their impacts would not generally be captured through a year of monthly monitoring. The biggest spillers (in terms of % time active) were Newbiggin STW (32.2%), Cark Tank STW (31.9%) Cartmel in Cark PS (27.4%), Ulverston STW (19.8%) and Hawkshead PS (14.9%). Newbiggin STW storm tanks were subject to upgrades in October 2013, but early indications are that this has not improved performance as they spilled for about 45% of the time in Q4 of 2013 and Q1 of 2014. Cark PS and Cartmel in Cark PS both suffer from infiltration which is likely to increase spill frequency, and United Utilities are working to improve the situation. Ulverston STW storm tanks and Dragley

Beck CSO are also to be upgraded by 2020 which are expected to reduce spill durations significantly from 2019. The Schola Green Lane PS spilled for just under 1% of the time (January 2011-December 2013) but is reported to discharge very large volumes (~18,000 m^3/day) when active, United Utilities also have plans to improve this pumping station discharge by 2020.

Although the majority of properties within the survey area are served by water company sewerage infrastructure, there are also 315 private discharges within the survey area. Where specified, these are generally treated by small package treatment works such as package plants, and the majority of these are small, serving one or a small number of properties. 146 of these discharge to soakaway, so should be of no impact on shellfisheries in Morecambe Bay assuming they are functioning correctly. The remaining 169 discharge to water. The vast majority of these are located inland and discharge to watercourses, although there are some which discharge directly to coastal waters. Table II.6 presents details of those consented to discharge more than 10 m^3/day. Discharges without sewage content (such as cooling water from the Heysham Nuclear Power Station) are of no relevance so are not included.

Table II.6: Details of private sewage discharges consented to discharge over 10 m^3/day

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	Capernwray Hall	SD5429072474	Package Plant	41	River Keer
B	Caravan Park At Bouthwaite Farm	SD5427098170	Package Plant	32.6	River Mint trib.
C	Castle View Caravan Park	SD5413471947	Package Plant	20	Lancaster Canal trib.
D	Crabtree Farm Caravan Site	SD5553081710	Package Plant	34	Lupton Beck trib.
E	Fell End Caravan Park	SD4978877794	Reedbed	12.5	Leighton Beck trib.
F	Gatebeck Park	SD5470385569	Package Plant	104	Peasey Beck
G	Glaxo Smith Kline	SD3143177311	Process effluent	8,000	Morecambe Bay
H	Graythwaite Hall	SD3704091060	Septic Tank	20	Graythwaite Hall Beck
I	Great Langdale Campsite	NY2917806053	Chemical - Phosphate Stripping	45	Great Langdale Beck
J	Guest House	SD3160098300	Biological Filtration	10	School Beck
K	Heysham Harbour 5th Quay	SD3982059940	Biological Filtration	27.3	Heysham Harbour
L	Heysham Nuclear Power Station	SD3713161272	Biological Filtration	38	Heysham Lake
M	Holbeck Ghyll Country House Hotel	NY3905802098	Package Plant	22	Hol Beck trib.
N	Holehird Mansion	NY4090000900	Biodisc	11.4	Bell Beck
O	Killington Lake Service Station	SD5846089930	Biological Filtration	100	Peasey Beck
P	Lakeside Steamer Terminal	SD3794087160	Package Plant	18	Lake Windermere
Q	Lancashire Outdoor Education Centre	SD5253072960	Septic Tank And Filter	31	Unnamed watercourse
R	Limefitt Caravan Park	NY4172903395	Package Plant	146	Troutbeck trib.
S	Mill Dam	SD3657079060	Package Plant	11	Burns Brook
T	New England Caravan Park	SD5304671944	Package Plant	90	River Keer
U	Old Dungeon Ghyll Hotel STP	NY2870006140	Unspecified	19	Great Langdale Beck trib.

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
V	Old Hall Caravan Park	SD5309070599	Package Plant	20	River Keer trib.
W	Port Of Heysham	SD4012060280	Dechlorination	15	Heysham Harbour
X	Pound Farm	SD4703095050	Septic Tank And Filter	12	Unnamed watercourse
Y	Rydal Hall	NY3665006300	Biological Filtration	58	Rydal Beck
Z	Sizergh Castle	SD5000787863	Package Plant	20	River Kent trib.
AA	Skelwith Fold Caravan Park Ltd	NY3580002800	Tertiary Biological	27	Blake Beck
BB	South End Caravan Park	SD2112062820	Biological Filtration	105	Walney Channel
CC	Stainton Cross	SD5223085460	Biological Filtration	35	Stainton Beck
DD	Strawberry Gardens Caravan Site	SD3882797387	Package Plant	10.5	Lake Windermere
EE	Swan Hotel (Newby Bridge)	SD3719086420	Biological Filtration	32	Lake Windermere
FF	The Damson Dene Hotel	SD4263091288	Package Plant	30.37	Arndale Beck trib.
GG	The Gilpin Bridge Hotel And Inn	SD4707085470	Biological Filtration	28	Levens Main Drain
HH	The Hare And Hounds	SD4177289710	Package Plant	10	River Winster
II	Watermill Inn	SD4453098650	Unspecified	14.5	River Gowan
JJ	Wings School	SD5126680394	Package Plant	20	River Bela
KK	WWTP Serving Livestock Auction	SD5375682170	Membrane Filtration	20	Farleton Beck trib.
LL	YMCA Centre Lakeside	SD3760089700	Unspecified	67.5	Lake Windermere

The largest by a considerable margin originates from the Glaxo Smith Kline industrial unit at Ulverston. It discharges to the Leven channel off Ulverston, and is tidally phased, only being active for 45 minutes starting 30 minutes after high water. The maximum permitted volume is 8,000m^3/day, although a maximum volume of 12,000m^3/day can be discharged up to 35 times a year. No details of the nature of the effluent or treatment type for this discharge was available, other than being described as process effluent, but some bacterial concentration data was available (METOC, 2007). Faecal coliform concentrations are reported to range from $5x10^2$ cfu/100ml in the summer to $1x10^8$ cfu/100ml in the winter. More recent data (January to March 2014) suggests lower concentrations with faecal coliform concentrations ranging from 1 to 20,000 cfu/100ml and a geometric mean of 182 cfu/100ml.

Other private discharges of potential relevance to the sampling plan are to Heysham Harbour (W and K), the Heysham Nuclear Power Stations sewage works, which discharges off Heysham (L) and the discharge from the South End Caravan Park from the southern end of Walney Island (BB). Those discharging to watercourses will make some contribution to the bacterial loadings they deliver to coastal waters. The majority discharge to watercourses which drain to either the Kent or Leven estuary to the north of any shellfisheries, although most significant watercourses receive some effluent from private discharges.

Appendix III. Agriculture

Land cover within the Morecambe Bay catchment is principally grassland, which is used for the grazing of sheep and cattle. There are also numerous small pockets of arable land, mainly within the lower reaches of the catchment, the highest concentrations of which are immediately north of Barrow, and around the lower reaches of the River Kent. The upper reaches of the catchment also contain significant natural areas (forest, moorland). Parts of the bay are fringed with grazed saltmarsh, particularly in the inner reaches and around the Kent and Leven estuaries.

Table III.1 presents livestock numbers and densities for the catchment. These data were provided by Defra and derive from the June 2013 census. 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, Table III.1 should give a reasonable indication of the numbers and types of livestock within the catchment.

Table III.1: Summary statistics from 2013 livestock census for the Morecambe Bay subcatchments

Subcatchment	Cattle		Sheep		Pigs		Poultry	
	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)
Barrow	2,104	35	8,228	138	283	4.7	2,046	34
Crake	15,069	81	58,616	314	309	1.7	33,805	181
Leven	5,991	36	28,158	170	140	0.8	578	3
Brathay	3,236	16	58,635	283	73	0.4	4,204	20
Kent	19,636	65	125,178	417	1,200	4.0	80,021	266
Winster	3,727	56	18,913	282	*	*	1,641	24
Bela	14,984	81	57,307	309	476	2.6	35,176	190
Keer	6,221	70	20,109	227	*	*	88,358	997
Total	**70,968**	**56**	**375,144**	**296**	**2,481**	**2.0**	**245,829**	**194**

Data from Defra

*Undisclosed for confidentiality reasons as data relates to a small number of holdings

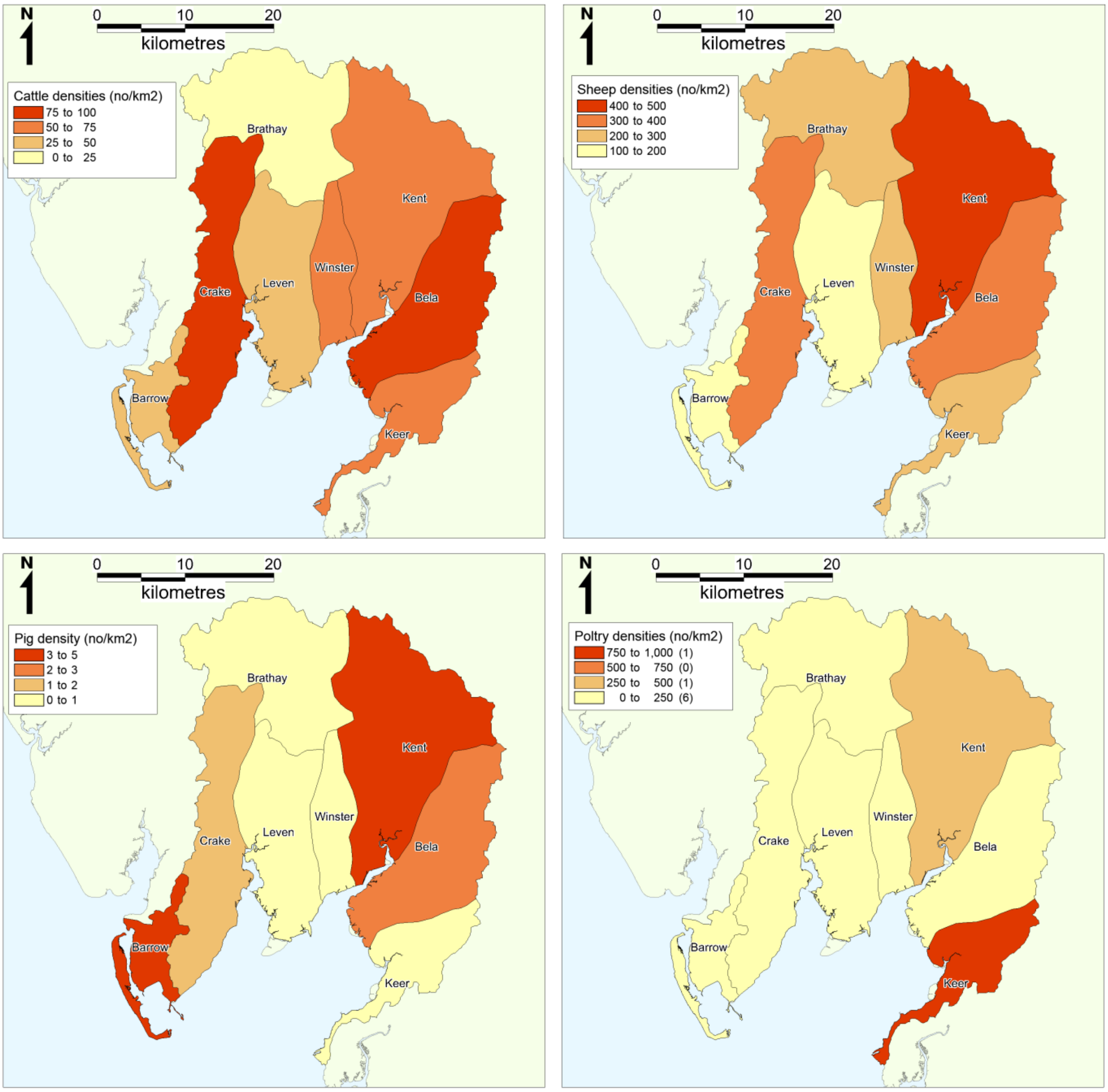

Figure III.1: Densities of livestock within the Morecambe Bay subcatchments
Data from Defra

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.

Animal	Faecal coliforms (No./g wet weight)	Excretion rate (g/day wet weight)	Faecal coliform load (No./day)
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).

Table III.1 indicates that there are very high numbers of sheep within the catchment, as well as significant numbers of cattle, some poultry units, but very few pigs. Sheep are a ubiquitous presence throughout the catchment, with highest densities in western areas. Cattle are also present throughout the catchment, but with lower densities in more upland areas. Poultry farming is concentrated in the Keer and to a lesser extent the Kent catchment.

Livestock manures will either be deposited directly on pastures by grazing animals, or collected from operations such as cattle sheds and poultry houses and spread on both arable land and pasture. This in turn may be washed into watercourses which will carry it to coastal waters. Watercourses which animals can access will be more vulnerable than those that are fenced off. Given the ubiquity of farmland throughout the survey area, all watercourses may potentially be affected at times.

The geographical pattern of agricultural impacts are likely to closely mirror those of land runoff, with the majority delivered to the Leven and Kent estuaries, and secondary hotspots where any smaller watercourses join the bay. As the primary mechanism for mobilisation of faecal matter deposited on pastures into watercourses is via land runoff, fluxes of agricultural contamination into coastal waters 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’).

As well as land runoff, there may be considerable fluxes of faecal matter into the estuary from the grazed areas of saltmarsh. This may be washed into drainage creeks by tidal inundation, which is likely to be a particularly direct and effective pathway. Highest fluxes of contamination are anticipated as the tide size increases towards spring tides, when more of the marsh is inundated, and the area inundated is increasing. 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). It is reported that most salt marshes in the survey area are grazed, mainly by sheep but also some cattle. The marshes are grazed on a year round basis, although they are taken off during the largest tides (McTaggart et al, 2007). Aerial photography (Google, date uncertain) showed that many areas of saltmarsh were heavily stocked with sheep at the time the images were taken. During the shoreline survey livestock were observed on saltmarsh by the Keer estuary, and in the Grange to Flookburgh area.

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 the warmer months, livestock are likely to access watercourses more frequently to drink and cool off. 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. Other manures and sewage sludge may be spread at any time of the year. Therefore peak levels of contamination from grazing livestock may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised basis if wet weather follows a slurry application which may occur at any time of the year.

Appendix IV. Boats

The discharge of sewage from boats is a potential source of bacterial contamination of shellfisheries within Morecambe Bay. Boat traffic here includes commercial vessels associated with the docks at Barrow and Heysham, as well as fishing vessels and recreational craft such as yachts. Navigation of larger vessels within the bay, particularly the uncharted inner reaches, is problematic due to its shallow nature and the constantly changing bathymetry. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources. There are no sewage pump out facilities within the area (The Green Blue, 2010).

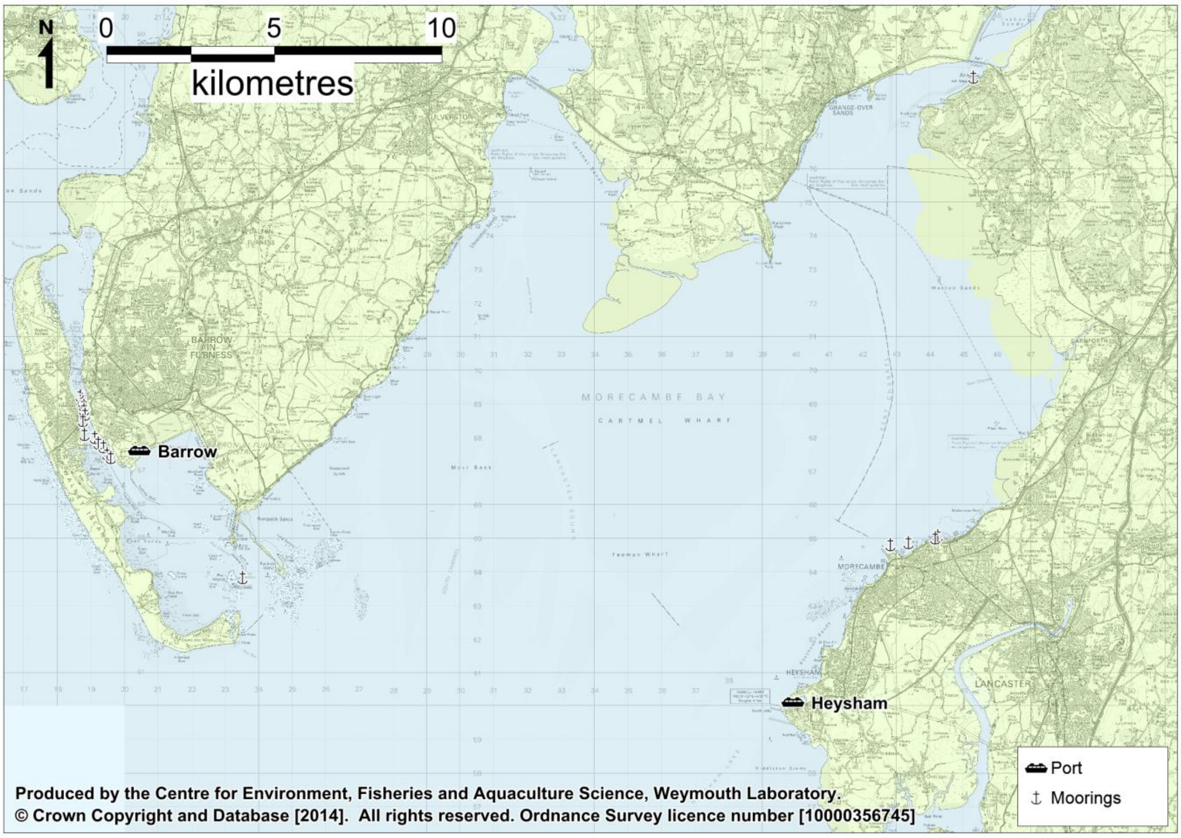

Figure IV.1: Boating activity in the Morecambe Bay area

The Port of Heysham only handles commercial shipping. The majority of traffic is vehicle ferries, which handled 115,000 vehicles and 264,000 road goods trailers in 2013 (Department for Transport, 2014). It also handles significant volumes of bulk cargoes. It is accessed via the Lune Deep and Heysham Lake, so vessels travelling to and from it do not come in close proximity to the shellfish beds. Barrow is a smaller port in terms of the volumes of shipping it receives. It accommodates a variety of commercial, naval and recreational marine traffic, including specialist vessels such as nuclear fuel carriers. Ships and submarines are built here. It is accessed via the Walney Channel, which is maintained by regular dredging. Traffic to and from the port therefore passes near to mussel beds near Roa and Foulney Islands, and any cockles on Snab Sands. Merchant shipping vessels are not permitted to make overboard discharges within three nautical miles of land[6].

There are small fishing fleets operating from both Barrow and Morecambe. There are six fishing vessels which have their home port as Barrow, of which 5 are less than 10 m in length. Morecambe hosts eleven resident fishing vessels, all of which are under 10 m in length (MMO, 2014). These may potentially make overboard discharges, although most are probably too small to have on board toilets.

The main centre for larger recreational vessels (such as yachts and cabin cruisers) is the Walney Channel, where there are over 200 moored boats visible on satellite aerial photography (Google, date uncertain). There are several moorings at Morecambe, where 30 smaller open boats and two larger yachts were observed during the shoreline survey. There is a sailing club at Arnside which may host the occasional visiting yacht, but is difficult to navigate to and is mainly concerned with open dinghy sailing.

Commercial shipping should be of no influence on shellfish hygiene within Morecambe Bay, nor should any of the small vessels used for watersports such as kayaks or sailing dinghies. Larger fishing vessels and pleasure craft such as yachts and cabin cruisers are likely to make overboard discharges in the area. This may occur whilst they are in occupation on moorings, or whilst they are on passage. The area most vulnerable to such discharges is around the moorings in the Walney Channel, and the navigation route from there out to sea. It is possible that overboard discharges are also made off Morecambe, and possibly even by boats navigating up to Arnside. However, outside of the Walney Channel it is likely that the impacts of overboard discharges are negligible. Recreational boating activity peaks in the summer, so any associated impacts would likely follow this seasonal pattern. Without any firm information on the numbers, timing and locations of such discharges it is difficult to draw any firmer conclusions.

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

Appendix V. Wildlife

Morecambe Bay includes the largest continuous area of intertidal sand and mudflats in the UK. It also contains large areas of saltmarsh, areas of boulders and cobbles which support mussel beds, as well as some eelgrass beds in the Walney Channel (English Nature, 2000). These features support significant wildlife populations. As a result, the bay or parts of the bay, are designated as a Special Protection Area (SPA), Special Area of Conservation (SAC), a Site of Special Scientific Interest (SSSI) and a Ramsar site.

The most significant wildlife aggregation in terms of shellfish hygiene is likely to be overwintering waterbirds (waders and wildfowl). Morecambe Bay currently supports the third largest population of overwintering waterbirds in the UK, after The Wash and the Ribble estuary. An average total count of 214,931 waterbirds was reported over five winters up to 2012/13 for Morecambe Bay, which includes the Lune and Wyre estuaries (Austin *et al*, 2014). A wide variety of species were recorded, the majority of which were wading species. These will forage on intertidal invertebrate communities where they will deposit faeces directly in a diffuse manner. At high water, they aggregate in numerous specific locations, and their impacts are likely to be more acute in the immediate vicinity of such areas. At least 89 specific areas have been identified as high tide roosts around the coast of Morecambe Bay. The habitat types used are primarily saltmarsh, although shingle banks, seawalls and groynes are also used (Marsh *et al*, 2012). Some waterbird species (e.g. geese) are herbivorous, and will forage on eelgrass, saltmarsh and coastal grasslands. As such their faeces may be deposited directly on the intertidal on the Walney eelgrass beds, on saltmarsh areas which are only inundated on the larger tides, or on pastures which are never inundated. Their impacts will therefore either be diffuse and to the intertidal, or possibly more concentrated in runoff from pasture and tidal drainage from saltmarsh. It is therefore concluded that whilst waterbirds are likely to contribute to levels of *E. coli* found in shellfish in Morecambe Bay, particularly during the winter, their impacts are largely diffuse and so will have little bearing on the locations of RMPs. However, drainage channels from saltmarsh areas and streams draining coastal pastures may carry elevated concentrations of faecal indicator organisms originating from waterbirds and there may also be higher impacts around shingle banks and groynes used as roosts.

Whilst most waterbirds migrate elsewhere outside of the overwintering period, some will breed here and remain in the area throughout the year so they will continue to impact in a similar but much reduced manner at other times of the year. There are also significant breeding populations of seabirds (gulls, terns etc) in the area. The JNCC Seabird 2000 census recorded a total of 31,866 pairs of breeding seabirds around the perimeter of the survey area (Mitchell *et al*, 2004). The vast majority of these (29,616 pairs of gulls) were nesting on the South Walney nature reserve, at the southern tip of Walney Island. A much smaller breeding colony (1,836 pairs of gulls) was recorded on the Carnforth Marshes and Leighton Moss, an area of wetland just to the north of the Keer estuary. Aside from these, only a few scattered pairs were recorded. Seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. Their faeces will be carried into coastal waters via runoff from their nesting sites or via direct deposition to the adjacent intertidal. Neither of the seabird colonies lies in close proximity to any identified shellfish resources, so seabirds will have no material bearing on the sampling plan.

There is a grey seal colony at the South Walney nature reserve. It is reported that there are usually between 20 and 50 individuals present, although occasionally numbers may exceed 100 (Cumbria Wildlife, 2014). They forage widely throughout Morecambe Bay, and have been reported as far inshore as Arnside. Their impacts will be highest at their haul out site, where they lie on the sand in a relatively dense aggregation. The haul out area is not in the immediate vicinity of any shellfish resources. Away from their haul out site they range widely and so their impacts may be considered diffuse and spatially and temporally unpredictable. As such, they will have no influence on the sampling plan. No other wildlife species of relevance to shellfish hygiene in Morecambe Bay have been identified.

Appendix VI. Rainfall

There are numerous rainfall gauges within the Morecambe Bay catchment. Figure VI.2 shows the location of five of these, which were selected as they have the most complete records and show the range of rainfall conditions across the area.

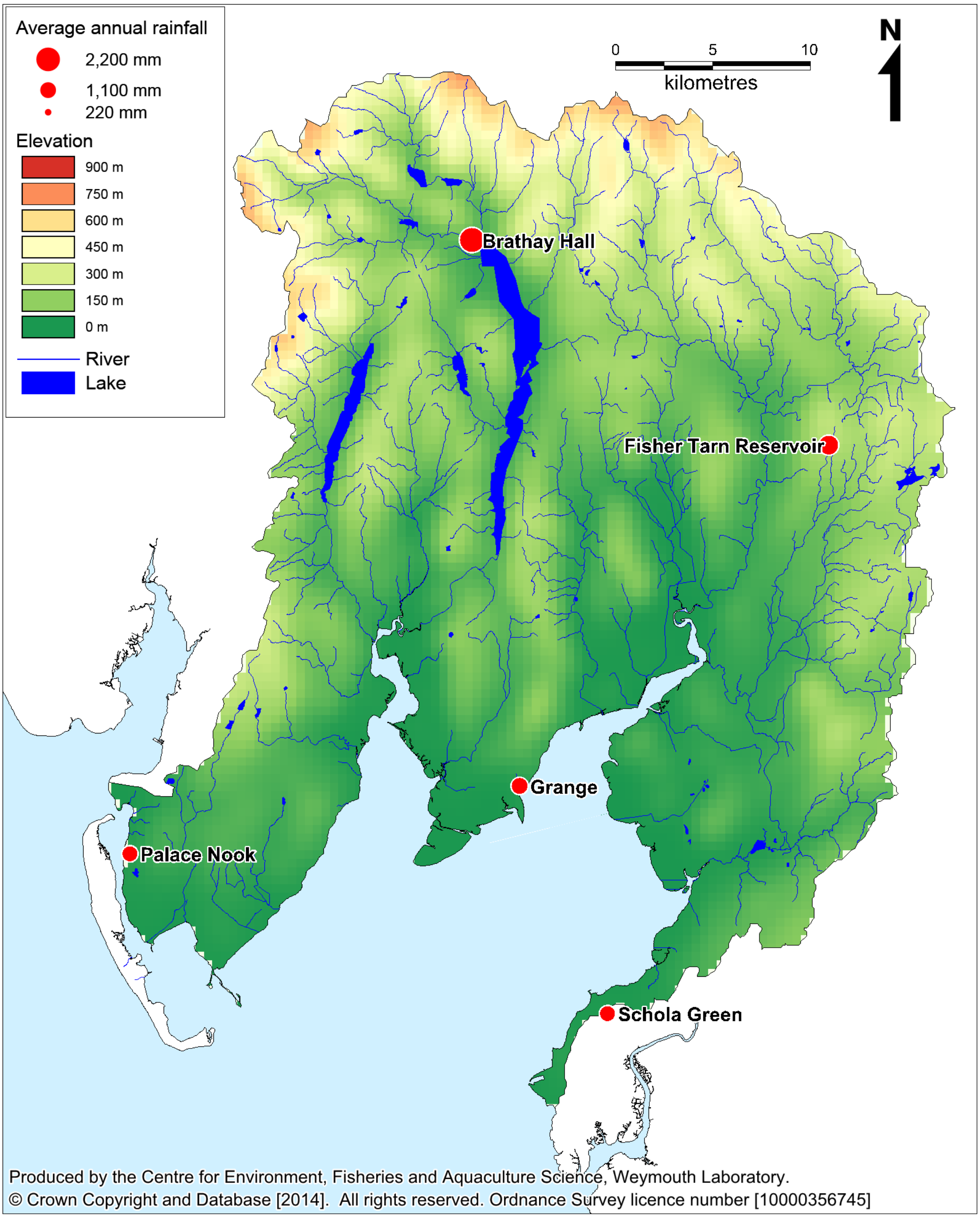

Figure VI.1: Location of rainfall gauges

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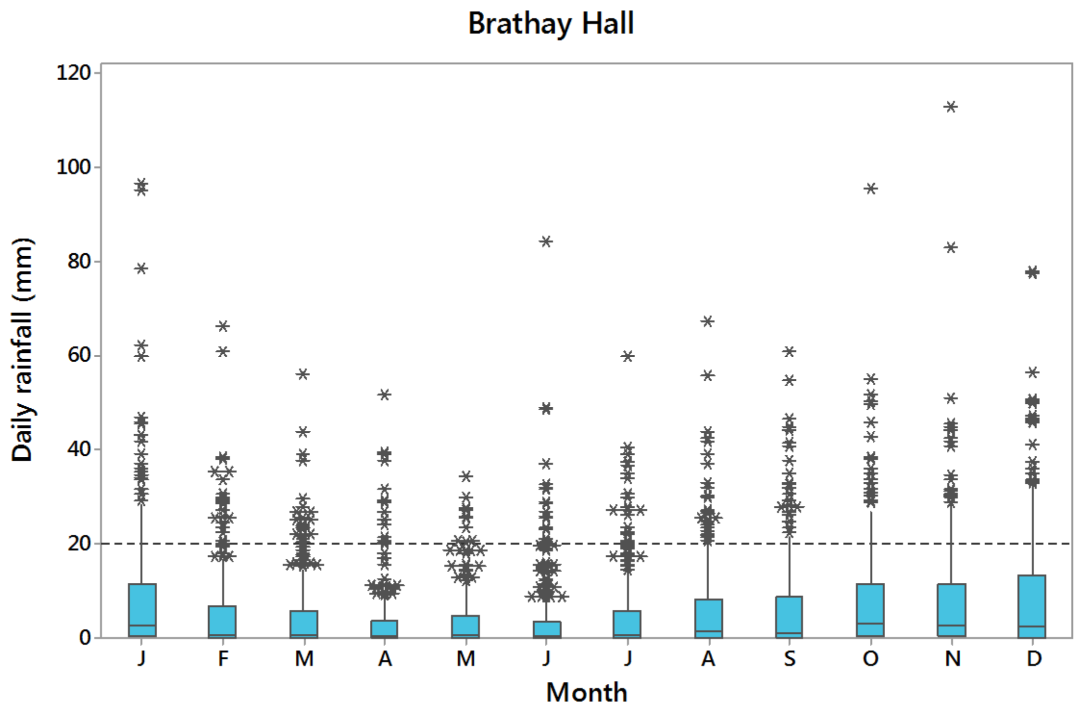
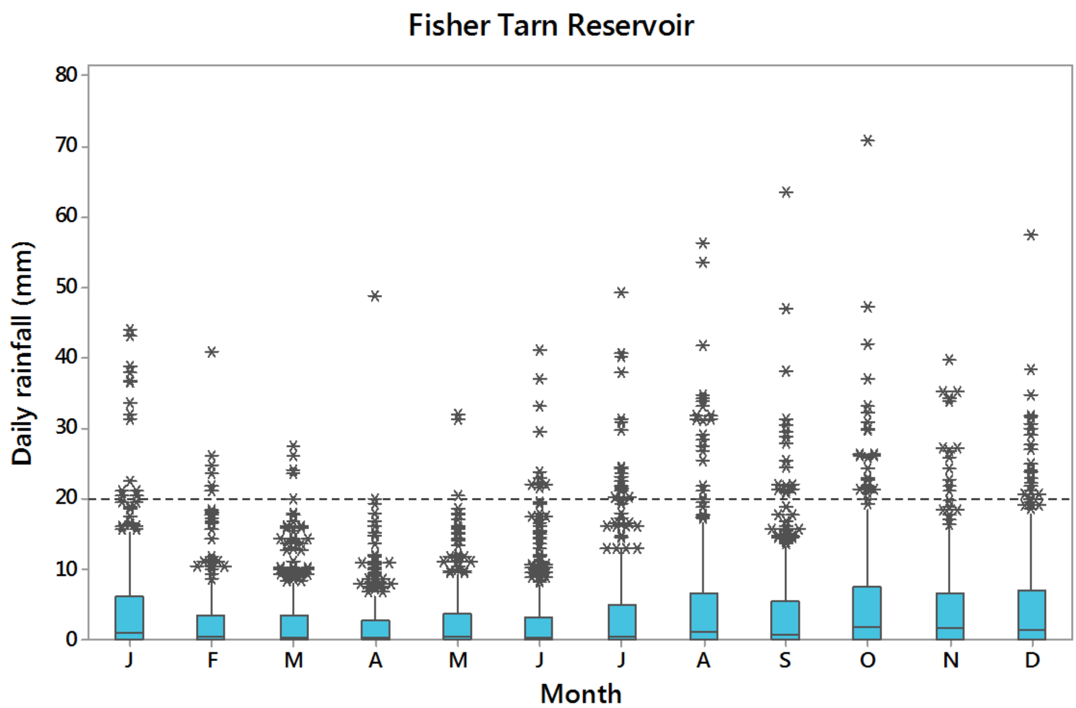
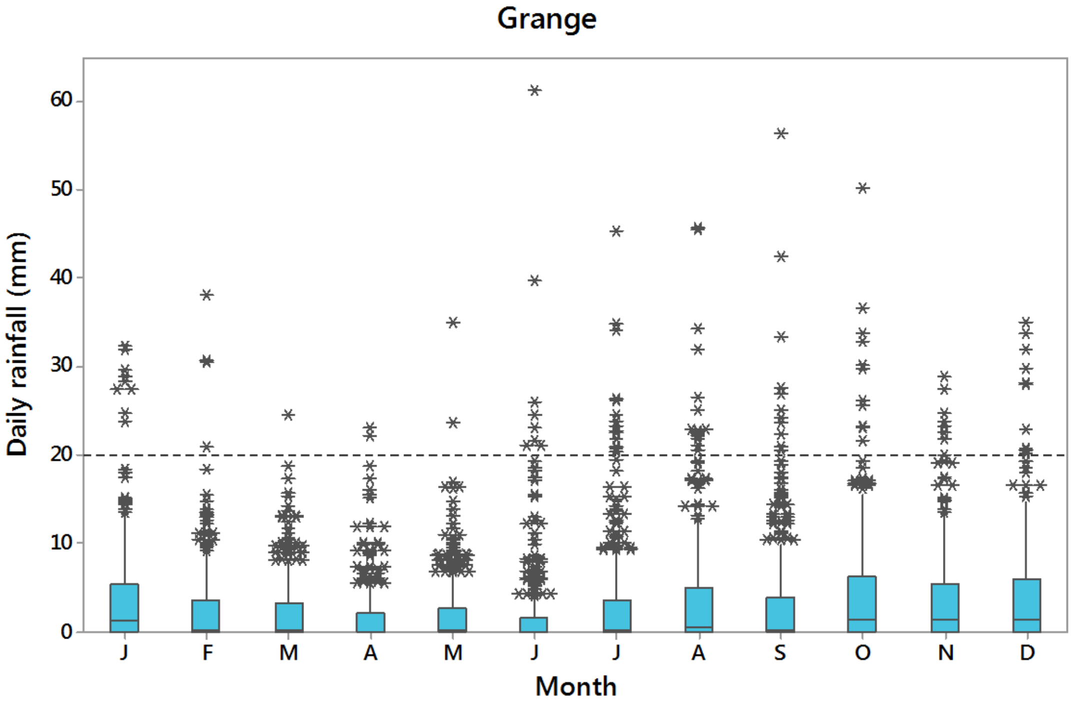
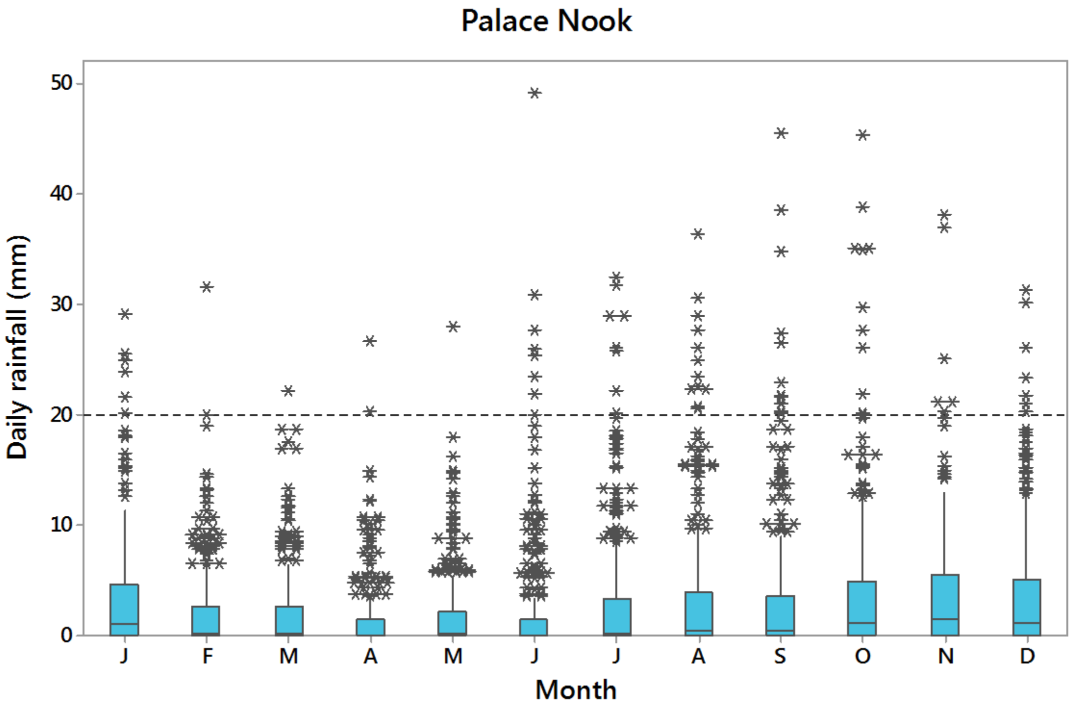
Figure VI.2 presents boxplots of daily rainfall records by month from these rainfall gauges.


Brathay Hall
Daily rainfall (mm)
120
100
80
60
40
20
0
J
F
M
A
M
J
J
A
S
O
N
D
Month


Fisher Tarn Reservoir
Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
Month



Grange
Daily rainfall (mm)
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
Month



Palace Nook
Daily rainfall (mm)
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
Month

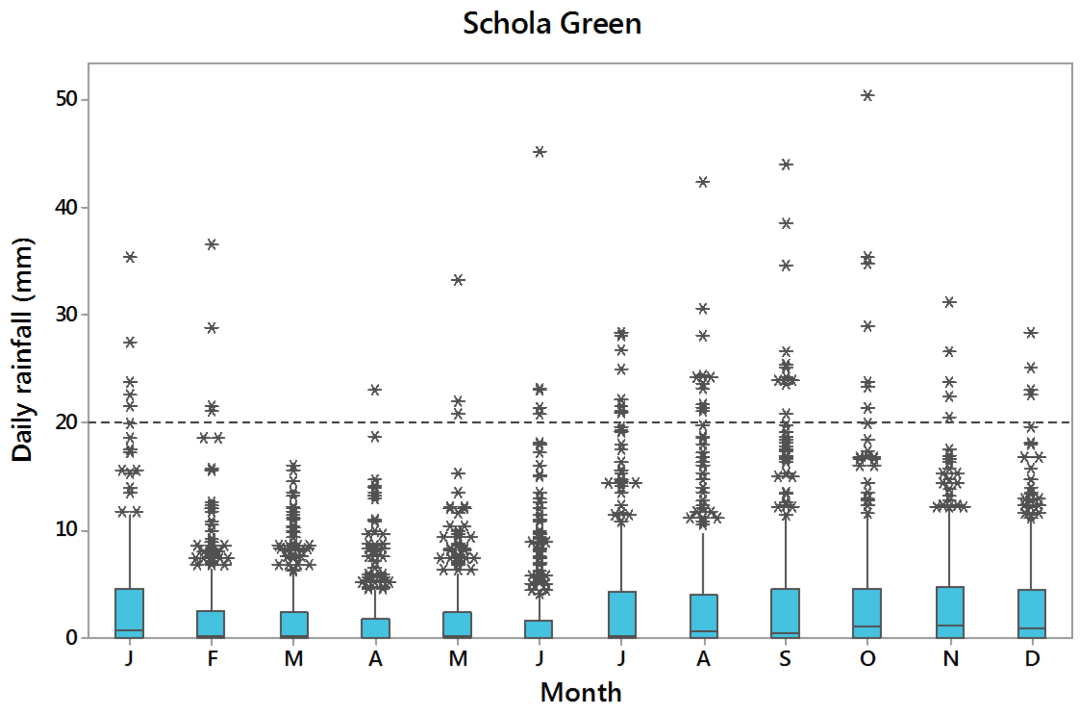


Figure VI.2: Boxplots of daily rainfall totals at the various rain gauges, January 2004 to June 2014.
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Rainfall increases significantly in the more inland, higher lying areas of the catchment. The average annual rainfall (2004-2014) across the five weather stations ranged from 1,001 mm at Palace Nook to 2,119 mm at Brathay Hall. Some seasonality in rainfall was observed, although this differed slightly between the rain gauges. It was most pronounced at Brathay Hall, where rainfall was highest on average during the late autumn and early winter, and lowest during the spring. At the other stations, which are closer to the coast, rainfall was again lowest on average in the spring, but was markedly higher from the late summer through to early winter. The frequency and magnitude of high rainfall events also tended to follow these patterns. The percentage of records where daily rainfall exceeded 20 mm ranged from 1.8% at Schola Green to 8.2% at Brathay Hall, and the percentage of dry days ranged from 32% at Brathay Hall to 43% at Schola Green.

Rainfall may lead to the discharge of raw or partially treated sewage from combined sewer overflows (CSOs) 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. 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, 2012).

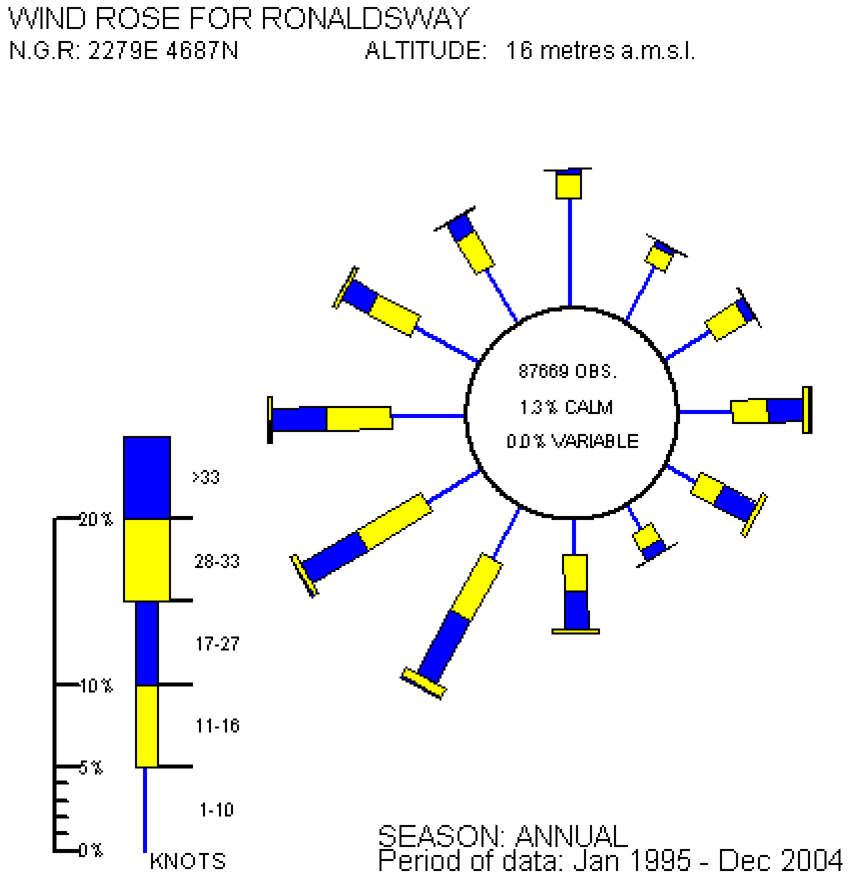

Figure VII.1 Windrose for Ronaldsway, Isle of Man

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. Morecambe Bay is an open, south west facing embayment and so is largely exposed to the prevailing winds. The Barrow Docks and Walney Channel lie in the lee of Walney Island so are much more sheltered than the rest of the bay.

Appendix VIII. Freshwater Inputs

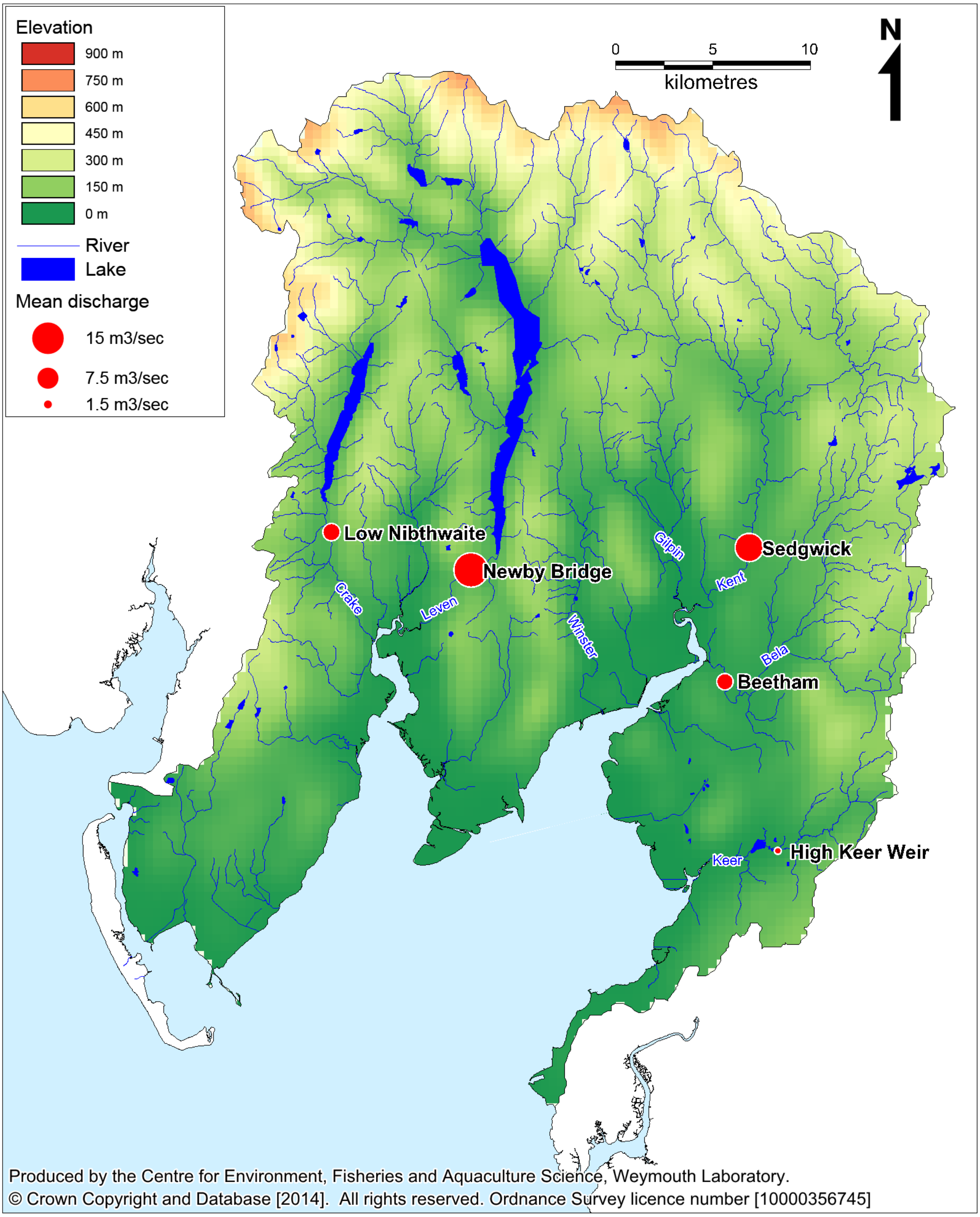

Figure VIII.1: Principle freshwater inputs to Morecambe Bay

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Morecambe Bay has a hydrological catchment of 1,268 km², as estimated from topographical maps. A large proportion of the catchment drains to the Leven and Kent estuary channels, inshore of the fishery area. A general principle of locating RMPs towards the northern end of shellfish beds as close to the two main river channels as possible would therefore be most effective at capturing runoff borne contamination from the wider catchment. There are also several streams and minor rivers which drain to the shore of the bay in the vicinity of the shellfish beds. These are likely to create more localised hotspots of contamination, which will be most acute in the immediate vicinity of drainage channels they follow across the intertidal around low water.

The dominant land cover is pasture, with some natural areas (woodland and heathland). There are several built up areas, most of which are close to the coast. The catchment is quite hilly, reaching a maximum elevation of just under 900 m. The hydrogeology varies from very low permeability throughout most of the more inland areas to moderate permeability throughout most coastal areas, and areas of high permeability at Barrow and Roosebeck (NERC, 2012). Rainfall increases significantly away from the coast. A rapid response to rainfall and high runoff rates are anticipated for watercourses in the upper catchment, but a slower response is anticipated from the smaller, lower lying coastal streams draining directly to the bay. The Rivers Crake and Leven both have large natural lakes which will have buffering effects on their discharge rates, and will also retain water from the upper catchment for significant periods. It is therefore likely that a high proportion of bacterial contamination delivered to these lakes from upstream sources dies off before it drains from their outlets. However, their base flow indices suggest that their response to rainfall is not heavily damped by the presence of these lakes.

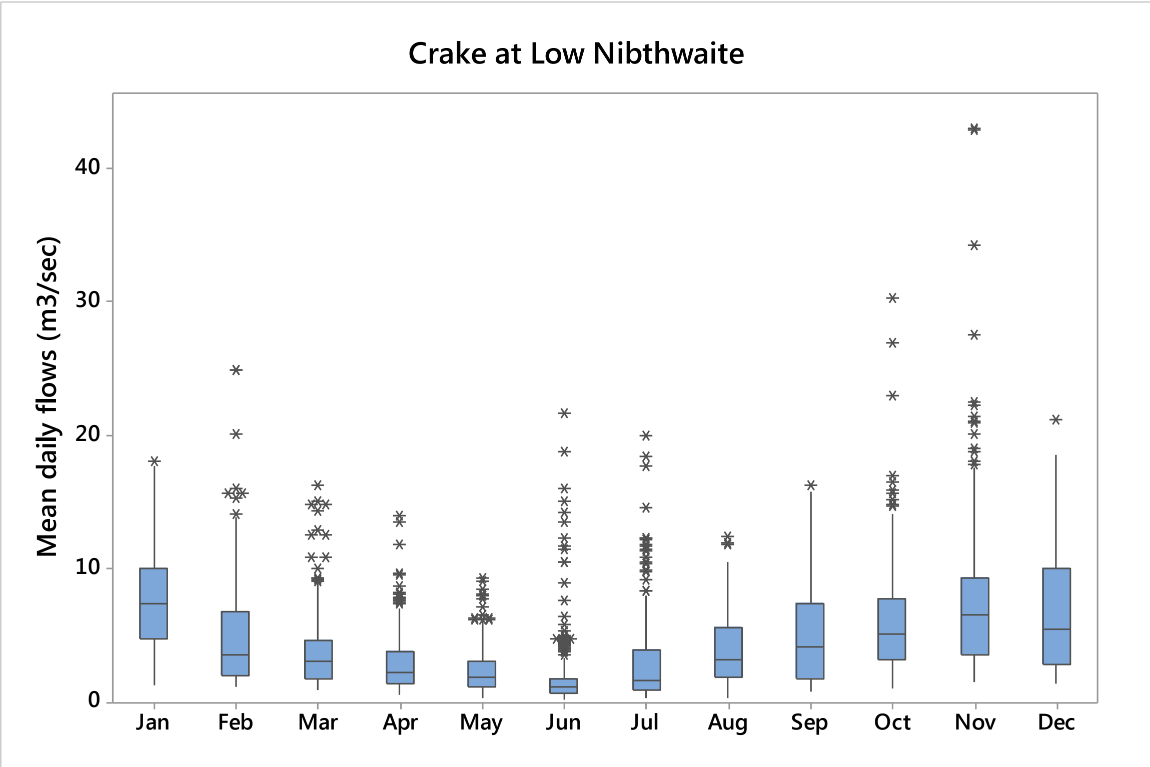
There are flow gauging stations on the Rivers Crake, Leven, Kent, Bela and Keer. Table VIII.1 presents summary statistics, and Figure VIII.2 presents boxplots of mean daily flows by month for the gauging stations located closest to the coast on these watercourses.

Table VIII.1: Summary flow statistics for flow gauging stations on watercourses draining to Morecambe Bay, 2004-2014

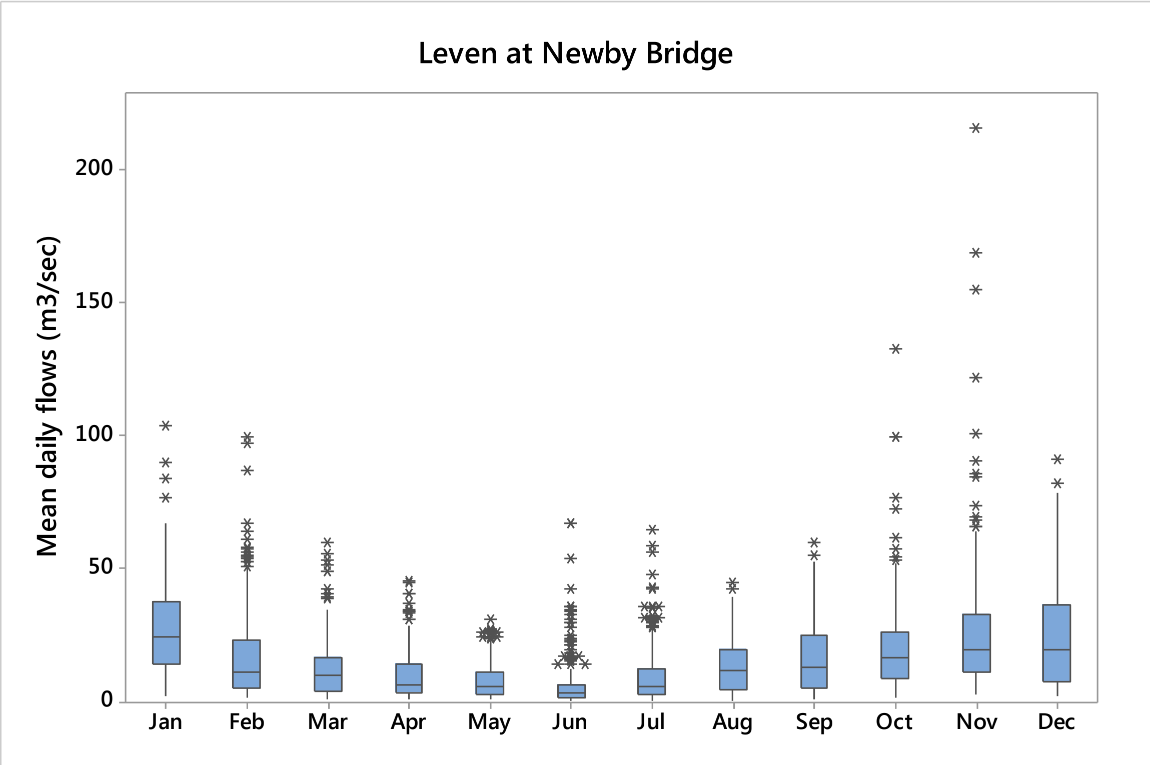
Watercourse	Station Name	Catchment Area (km^2)	Mean Annual Rainfall 1961-1990 (mm)	Mean Flow (m^3s-1)	Q95[1] (m^3s-1)	Q10[2] (m^3s-1)	Base flow index
Crake	Low Nibthwaite	73	2147	4.61	0.70	10.17	0.57
Leven	Newby Bridge	247	2167	15.70	1.61	35.87	0.49
Kent	Sedgwick	209	1732	10.44	1.38	24.50	0.41
Bela	Beetham	131	1291	3.93	0.59	8.99	0.49
Keer	High Keer Weir	48	1160	0.64	0.06	1.51	0.36

Data from NERC (2012) and contains Environment Agency information © Environment Agency and database right

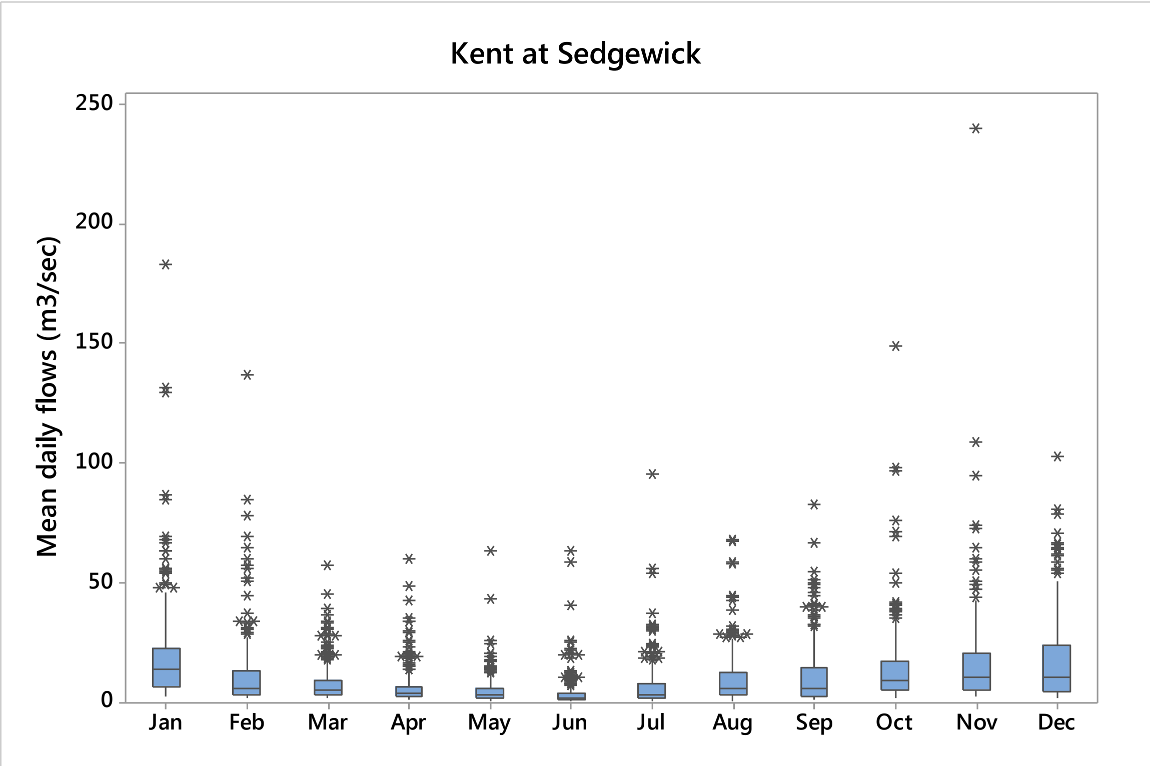
[1]Q95 is the flow that is exceeded 95% of the time (i.e. low flow). [2]Q10 is the flow that is exceeded 10% of the time (i.e. high flow). [3]The base flow index may be considered as a measure of the proportion of the river runoff that derives from stored sources (groundwaters and lakes/reservoirs).

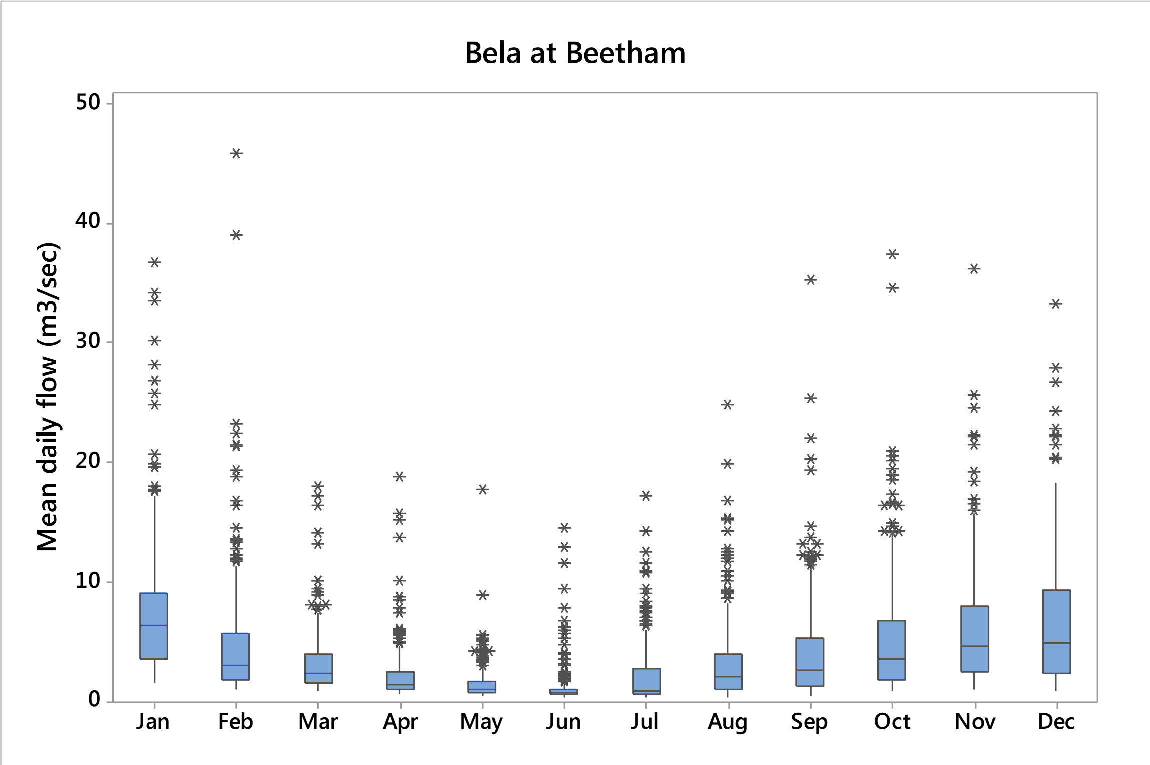


Crake at Low Nibthwaite
Mean daily flows (m3/sec)
0
10
20
30
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



Leven at Newby Bridge
Mean daily flows (m3/sec)
0
50
100
150
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Kent at Sedgewick
Mean daily flows (m3/sec)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Bela at Beetham
Mean daily flow (m3/sec)
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

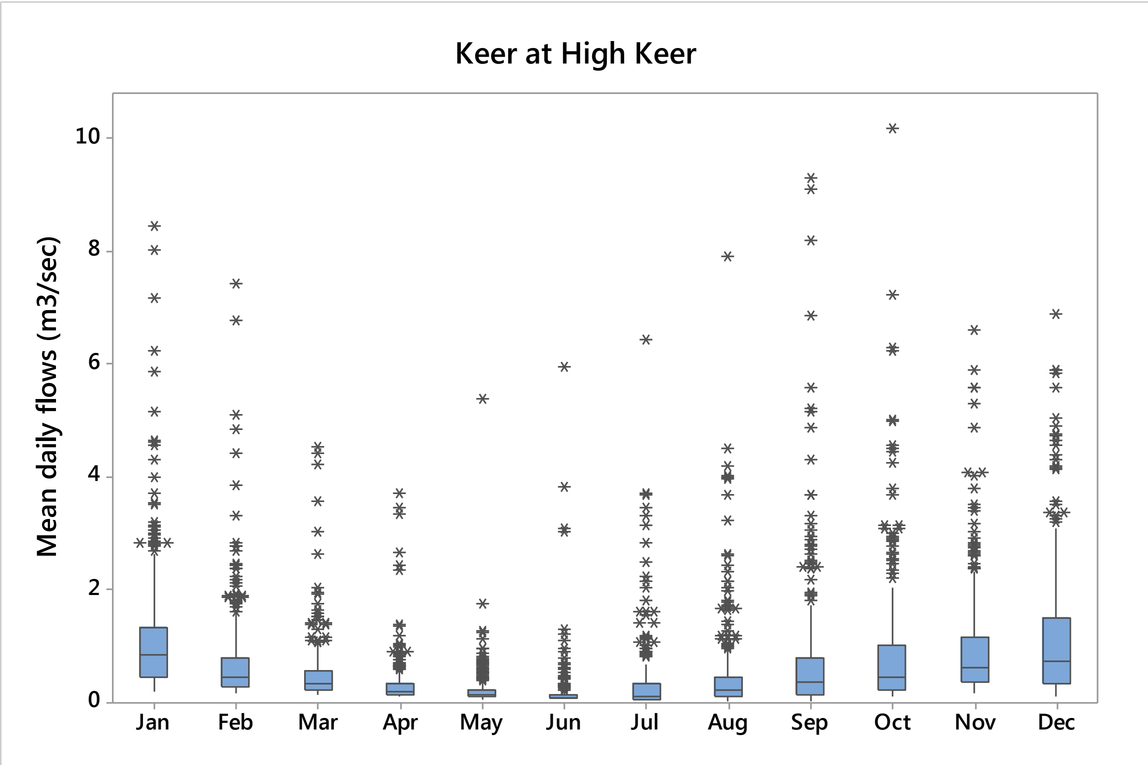


Figure VIII.2: Boxplots of mean daily flow records from gauging stations on watercourses draining to Morecambe Bay, 2004-2014

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Flows were higher on average during the colder months. 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. 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.

As well as these larger rivers, there are also numerous smaller watercourses discharging at intervals along the shore of the bay. These are of importance to the sampling plan as there may be significant but localised hotspots of contamination associated with any drainage channels they follow through intertidal shellfish beds. During the shoreline survey samples were taken and spot flow measurements made if it was possible to safely access them. The survey was undertaken in dry conditions in early autumn. These measurements should be treated with some caution as they only relate to conditions on the day, and many were not subject to spot flow estimates.

Table VIII.2: Shoreline survey bacteriological samples and spot flow measurements of freshwater inputs

Map ID	Description	Flow (m^3/s)	*E. coli* (cfu/100ml)	*E. coli*/day
1	150 mm cast iron pipe	1.82×10^{-5}	31	4.87×10^{5}
2	Unnamed watercourse (flap valve outfall)	0.00308	>20,000	$>5.31 \times 10^{10}$
3	Spring on beach	0.0439	500	1.90×10^{10}
4	Spring on beach	0.0105	5,600	5.07×10^{10}
5	Leighton Moss outfall	0.0214	87	1.61×10^{9}
6	River Keer	1.01	270	2.36×10^{11}
7	Black Dike (flap valve outfall).	0.0258	87	1.94×10^{9}
8	River Eea	Not measured	2,900	
9	Unnamed sluice outfall	Not measured	220	
10	Drainage channel	Not measured	220	
11	Unnamed sluice outfall	0.00613	1,000	5.30×10^{9}
12	Unnamed watercourse	Not measured	1,400	
13	Unnamed watercourse	0.00331	150	4.29×10^{8}
14	Unnamed watercourse	0.0037	2,500	8.00×10^{9}
15	Surface water pipe	Not measured	31	
16	Unnamed watercourse	Not measured	210	
17	Unnamed watercourse	0.00821	1,200	8.51×10^{9}
18	Surface water pipe	0.0979	5,900	4.99×10^{11}
19	Surface water pipe	0.0111	53	5.10×10^{8}
20	River Winster	Not measured	450	
21	Pipe with flap valve	0.00232	ND	
22	Culverted stream	0.00474	3,200	1.31×10^{10}
23	Roose Beck	0.015	1,600	2.07×10^{10}
24	750 mm pipe with flap valve	8.75×10^{-5}	53	4.01×10^{6}
25	Pipe with flap valve	0.00162	>20,000	$>2.81 \times 10^{10}$
26	Large pipe	0.00252	1,300	2.83×10^{9}
27	Small pipe	0.00137	42	4.96×10^{7}
28	Unnamed watercourse	0.000952	120	9.87×10^{7}
29	Unnamed watercourse	Not measured	2,000	
30	Unnamed watercourse	0.000271	270	6.31×10^{7}
31	Unnamed watercourse	Not measured	1,300	
32	Red Gutter Stream	Not measured	2,900	
33	Deep Meadow Beck	0.168	>20,000	$>2.90 \times 10^{12}$
34	Sarah Beck	0.00851	5,000	3.68×10^{10}
35	Surface water pipe	0.0156	420	5.66×10^{9}
36	Surface water pipe	0.00711	200	1.23×10^{9}
37	Unnamed watercourse	0.0168	450	6.52×10^{9}
38	Unnamed watercourse	0.00851	200	1.47×10^{9}
39	Unnamed watercourse	0.00304	4,300	1.13×10^{10}
40	Canal overflow	Not measured	10	

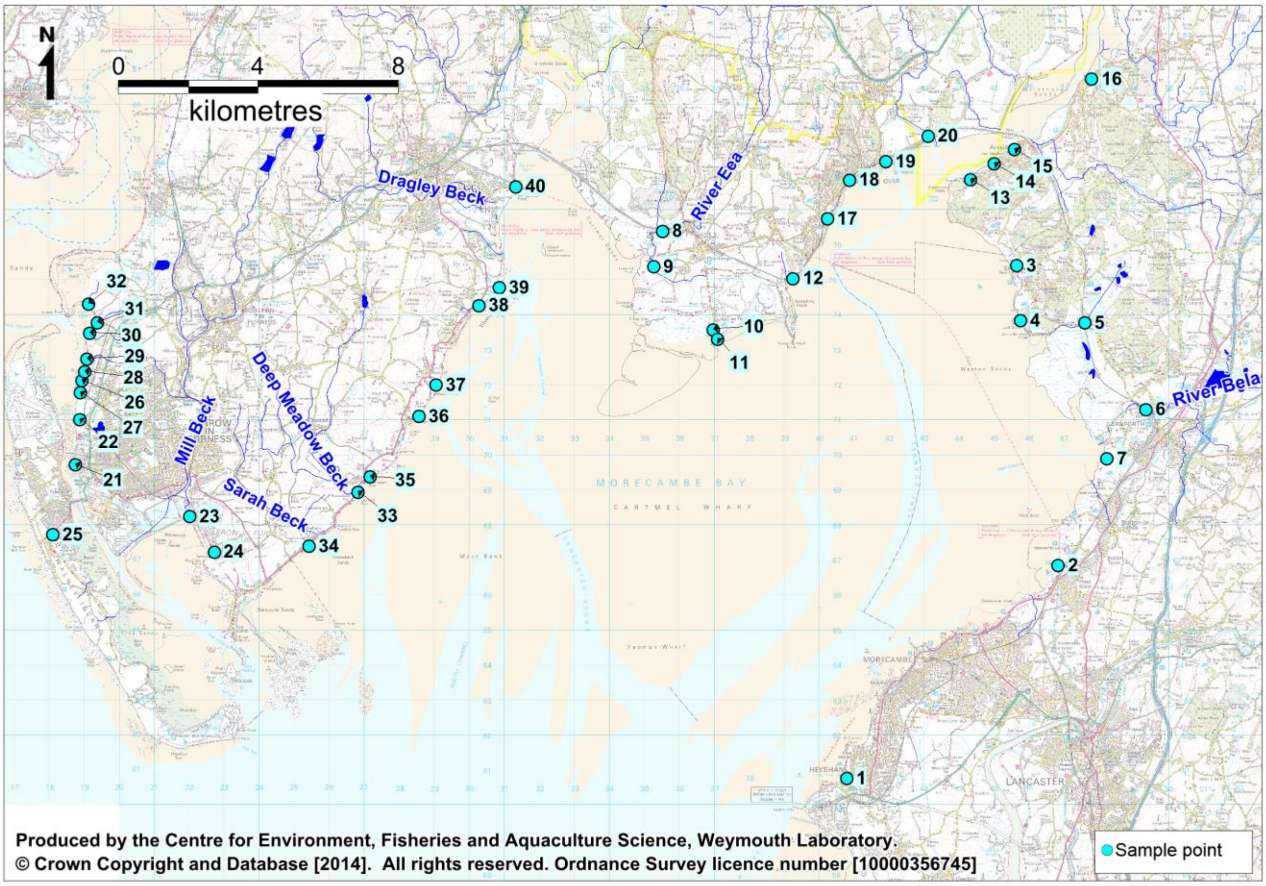

Figure VIII.3: Locations of shoreline survey bacteriological samples and spot flow measurements

The main freshwater input to the Walney Channel is Mill Beck, which is also referred to as Poaka Beck. This drains to the Walney Channel via the Cavendish Reservoir and then the docks at Barrow. A large proportion of indicator bacteria are likely to die off whilst retained within the reservoir and docks. This watercourse was not sampled or measured during the shoreline survey. There are several small freshwater outfalls draining to the northern end of the Walney Channel from the mainland (21, 22, 26-32) but none was of much significance either in terms of volumes discharged or concentrations of bacterial indicators. There are two further minor freshwater inputs to the Roosecote Sands area (23 & 24). Only one freshwater input to the channel from Walney Island was observed (25) and whilst the discharge volume was very low, high levels of contamination (and sewage related debris) were observed within it during the shoreline survey.

There are several minor but nevertheless potentially significant freshwater inputs to the shore between Rampside and Ulverston. The largest of these are Deep Meadow Beck and Dragley Beck. Deep Meadow Beck (33) receives effluent from Newbiggin STW and associated overflows just upstream from its outfall. It was carrying a very high concentration of *E. coli* at the time of shoreline survey, so the bacterial loading it was delivering was about two orders of magnitude higher (and possibly more) than the adjacent, smaller Sarah Beck (34). Dragley Beck was neither sampled nor measured during the shoreline survey.

The main watercourse draining to the central isthmus is the River Eea (8). This was not measured, but was carrying a bacterial concentration of 2,900 *E. coli* cfu/100ml. A smaller marsh drain also feeds into the drainage channel it follows across the intertidal (9). The largest watercourse draining to the eastern shore of the bay is the River Bela (6). Whilst this was the largest measured watercourse in terms of volume, the bacterial concentration it was carrying at the time of survey was low. Nevertheless, it was carrying the largest measured bacterial loading to this shore, and is likely to be of local significance. Also of potential significance along this shore was a small freshwater outfall carrying a very high concentration of *E. coli* (2).

Appendix IX. Hydrography

IX.1. Bathymetry

The area under consideration may be split into two hydrographically distinct water bodies. The first, and by far the largest, is Morecambe Bay, although the area being surveyed does not include the southern part of the bay to which the Lune and Wyre estuaries drain. The second is the channel which runs between the mainland and Walney Island (Walney Channel).

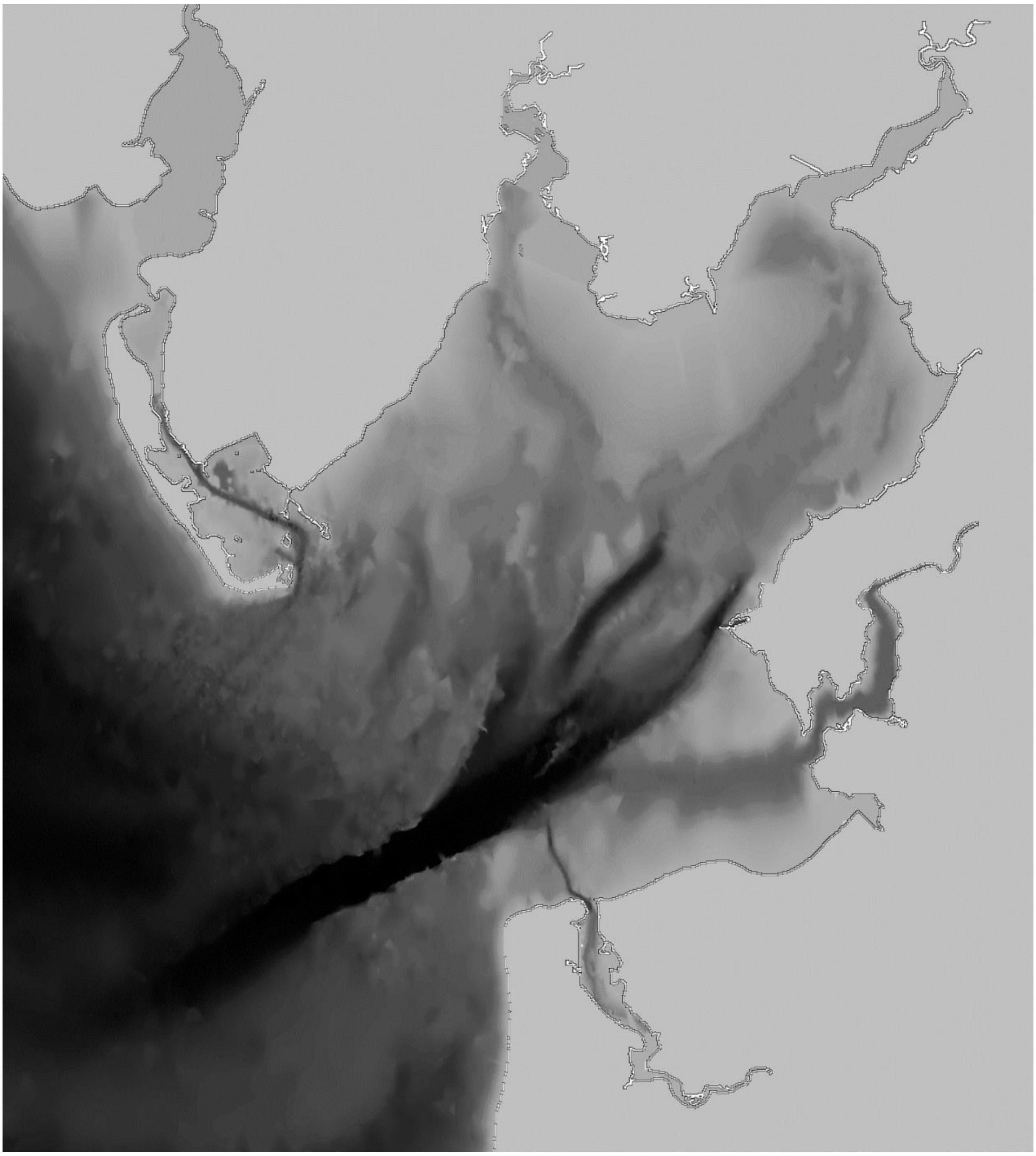

Figure IX.1: Bathymetry of Morecambe Bay

From Mason et al*, 1999. Reproduced with permission of the author.*

Figure IX.1 shows the bathymetry of the survey area, created from a number of sources (see Mason *et al*, 1999 for details). Whilst there have been significant changes to channel orientations in the inner reaches of the bay since this image was generated (e.g. Mason *et al*, 2010) the main features are shown clearly. Morecambe Bay consists of a vast area of constantly shifting intertidal sandflats within which there is a network of intertidal and subtidal channels. There are two significant estuaries (Leven and Kent) which drain to the inner reaches of the bay on the west and east sides, between which there is a central peninsula. These both become progressively narrower in their upper reaches, and consist only of a river channel at their tidal limits. There are significant areas of saltmarsh fringing the inner reaches of the bay and the two estuaries. The drainage channels from the two estuaries meander southwards through the bay and are braided in places. They are highly mobile. Between 1991 and 2004 for example, the Leven channel off Ulverston migrated north-east by about 5 km, then a straighter channel formed to the west, leaving the previous channel decoupled from the river (Mason *et al*, 2010). There are also numerous other intertidal drainage channels, some of which carry land runoff delivered by smaller watercourses.

The outer reaches of the bay consist of several parallel sandbanks between which lie subtidal channels. The channels on the eastern side are deeper, including the Grange Channel where depths exceed 10 m relative to chart datum. The subtidal channels merge into the Lune Deeps to the south of the survey area. On the western side of the bay, to the south of the survey area, there are several offshore intertidal sandbanks which will provide some protection against incoming wave action. The mainly intertidal nature of the bay will mean that a large proportion of water is exchanged each tide, but the dilution potential will be limited. Elevated concentrations of faecal indicator bacteria delivered by land runoff are likely to arise in the drainage channels around low water.

Figure IX.2: Nautical charts of the Walney Channel

The Walney Channel forms a connection between Morecambe Bay and the adjacent Duddon estuary to the north. At its southern end, a dredged, trained, subtidal channel connects the docks at Barrow to the Irish Sea. Either side of this dredged channel there are extensive areas of intertidal mudflats, fringed with saltmarsh adjacent to Walney Island. A dendritic network of intertidal drainage channels feed into the main subtidal channels from these areas. There is a scoured channel just south of Piel Island (Bass Pool) through which a proportion of the water flooding to and draining from Snab Sands will pass. The Barrow STW outfall discharges to the edge of the dredged channel, about 500 m south of the dock entrance.

To the north of the dock entrance the main channel narrows and shallows, becoming intertidal in the vicinity of the Jubilee Bridge. The elevation of the channel bed peaks to the north of the Jubilee Bridge around an area called the Walney Meetings, where the incoming tides from the north and south meet. Admiralty Chart 1320 indicates that the seabed here is 7 m above chart datum, but the coverage is poor and this may not necessarily represent the lowest part of the cross section. The connection to the Duddon estuary will therefore be limited to higher states of the tide, and may not be made at all on the smallest neap tides. Again, the generally shallow and intertidal nature of the Walney Channel will mean that a large proportion of water is exchanged each tide, but the dilution potential will be limited.

IX.2. Water circulation

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The tidal amplitude in the area is large, and this drives extensive water movements within the area.

Table IX.1: Tidal levels and ranges within the survey area

Port	Height above chart datum (m)				Range (m)	
	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Roa Island	9.04	7.08	2.93	0.96	8.08	4.15
Barrow (Ramsden Dock)	9.08	7.08	2.93	0.93	8.15	4.15
Morecambe	9.50	7.40	2.90	1.10	8.40	4.50
Heysham	9.37	7.32	3.04	0.99	8.38	4.28

Data from Admiralty TotalTide©

In simplistic terms, the tide floods up into Morecambe Bay from the south, moving first through the main subtidal channels, then progressing up more minor channels and spreading across the intertidal. The reverse occurs on the ebb. In most areas the main channels are orientated broadly along the north-south axis so the main tidal streams will be along this plane. Tidal currents will therefore carry contamination from shoreline sources in these general directions. In some areas the minor channels are orientated more along the east-west axis, so currents across the higher parts of the intertidal may be more perpendicular rather than parallel to the shore. Such areas include Warton Sands and some areas off the central isthmus. It is difficult to be precise about the exact orientation of tidal streams on a small scale as the channels and sandbanks are highly mobile.

In the Walney Channel, tides arrive from both the north and south at the same time. They meet at an area called the Walney Meetings, about 2-3 km north of the Jubilee Bridge. Therefore, areas to the north and south of the Walney Meetings will be subject to different sources of contamination. In the southern part of the channel, the main tidal streams will generally align with the subtidal dredged channel, moving up the intertidal drainage channels and spreading across the intertidal flats. The reverse will occur on the ebb.

There are four tidal diamonds within the survey area, two of which are located in the Barrow Dock approach channel, and two of which are located in the Heysham Dock approach channel (Figure IX.1). These confirm that tidal streams are bidirectional (Table IX.2) and that they align with the orientation of the two channels that they lie within. Current velocities on spring tides peak at just over 1 m/s and are about twice that experienced during neap tides. Very approximate estimates of tidal excursions within these channels based on the tidal diamonds range from 11 to 15 km on spring tides and 7-9 km on neap tides. It must however be noted that these diamonds apply to a fixed point. Nevertheless, they give an indication of the distance particles may travel in the main channels during the course of a flood or an ebb tide. Assuming that similar excursions apply within the estuaries, contamination released at the tidal limit at high water may not reach any cockle beds before the flood tide begins. Tidal streams will be retarded over shallower and intertidal areas due to the effects of friction.

Tides within the area are asymmetrical, with some areas showing flood dominance and others showing ebb dominance (Aldridge, 1997). For example the Heysham Channel and the Walney Channel show flood dominance, whereas the Grange Channel shows ebb dominance. Although this is of great importance to longer term processes such as residual sediment transport, it is of much less relevance to the dispersal patterns of relatively short lived faecal indicator organisms.

Table IX.2: Tidal stream information

Hours before / after high water	Diamond A			Diamond B			Diamond C			Diamond D		
	Direction (°)	Spring rate (m/s)	Neap rate (m/s)	Direction (°)	Spring rate (m/s)	Neap rate (m/s)	Direction (°)	Spring rate (m/s)	Neap rate (m/s)	Direction (°)	Spring rate (m/s)	Neap rate (m/s)
HW-6	217	0.1	0.1	-	0.0	0.0	209	0.1	0.0	228	0.1	0.1
HW-5	283	0.2	0.1	48	0.4	0.2	56	0.1	0.1	-	0.0	0.0
HW-4	303	0.4	0.3	53	0.8	0.5	29	0.3	0.2	40	0.3	0.2
HW-3	317	0.9	0.5	53	1.0	0.6	29	0.7	0.4	32	0.8	0.4
HW-2	321	0.9	0.5	55	0.9	0.5	29	1.2	0.7	30	1.0	0.5
HW-1	321	0.8	0.5	55	0.7	0.4	29	1.1	0.7	33	0.9	0.4
HW	316	0.5	0.3	265	0.5	0.3	29	0.4	0.3	47	0.3	0.2
HW+1	91	0.2	0.1	236	1.0	0.6	182	0.5	0.4	189	0.3	0.2
HW+2	127	0.9	0.6	237	1.0	0.6	209	1.0	0.6	211	0.9	0.5
HW+3	137	1.1	0.6	233	0.7	0.4	209	1.1	0.7	213	0.8	0.4
HW+4	141	0.9	0.5	231	0.5	0.3	209	0.7	0.5	212	0.6	0.3
HW+5	147	0.5	0.3	230	0.3	0.2	209	0.3	0.2	215	0.3	0.2
HW+6	173	0.2	0.1	223	0.1	0.1	209	0.1	0.1	224	0.2	0.1
Flood direction/ excursion	WNW	13.3km	7.6km	NE	13.7km	7.6km	SSW	13.9km	8.3km	NE	11.3km	5.7km
Flood direction/ excursion	SE	13.5km	7.8km	SW	14.6km	8.1km	NNE	13.3km	8.5km	SSW	11.7km	5.7km

Data from the UK Hydrographic office (Admiralty Chart 2010)

Superimposed on tidally driven currents are the effects of freshwater inputs and wind. The flow ratio (freshwater input:tidal exchange) is low for Morecambe Bay as a whole (mean of 0.001 and maximum 0.019) indicating little possibility of density driven circulation (Futurecoast, 2002). Such effects may arise within the upper reaches of the Kent and Leven estuaries, particularly at times of high river discharge, but are unlikely to occur in the vicinity of any shellfish resources.

Areas of decreased average salinity are likely to represent areas of increased microbiological contamination deriving from land runoff. Repeated salinity measurements were made at six locations (Figure X.1) under the bathing waters and shellfish waters monitoring programmes. Results from the two programmes are not directly comparable as bathing waters are only monitored from May to September whereas shellfish waters are monitored throughout the year but at a much lower frequency.

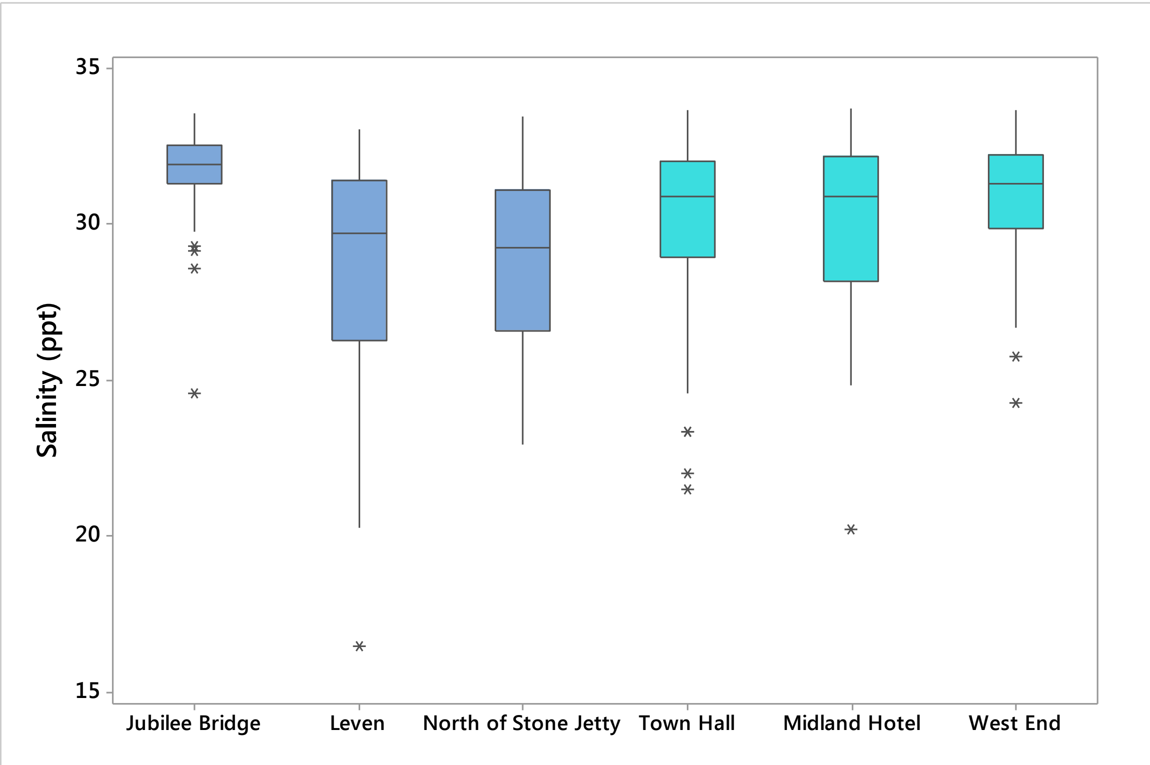

Figure IX.3: Boxplot of salinity measurements at shellfish waters (darker blue) and bathing waters (lighter blue)

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Within the Walney Channel (Jubilee Bridge) there is little freshwater influence, although occasional salinities of less than 30 ppt were recorded. At Leven, which is located off Ulverston, the average salinity was 28.3 ppt, and the minimum was 16.5 ppt. This indicates that there is a significant freshwater influence here at times. At North of Stone Jetty on the Morecambe seafront the average salinity was similar to Leven (28.9 ppt) but the minimum was higher (22.9 ppt). This suggests that the influence of the estuaries extends throughout the bay. It is however uncertain to what extent this applies to runoff borne faecal indicator bacteria, as they may take several tides to be carried to the outer reaches of the bay during which time significant die-off may be anticipated. Across the three bathing water sites the average and minimum recorded salinities were all very similar indicating that the salinity gradient along the Morecambe/Heysham seafront is very slight.

Strong winds will modify surface currents. Winds typically drive surface water at about 3% of the wind speed (Brown, 1991) so gale force wind (34 knots or 17.2 m/s) would drive a current of about 0.5 m/s. These surface currents drive return currents which may travel lower in the water column or along sheltered margins. Morecambe Bay is exposed to the prevailing winds from the south west, whereas the Walney Channel is sheltered from all directions by the surrounding land. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. The prevailing south westerly winds will tend to enhance surface flood flows, and retard surface ebb flows within the bay for example.

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. A published study undertaken off Morecambe demonstrated that intertidal sediments act as a reservoir of faecal indicator bacteria which can be remobilised into the overlying water by energetic wave action (Obiri-Danso and Jones, 2000). Due to the large size of the embayment, strong winds from any direction will blow across a considerable distance of water, and so nowhere in the bay is particularly sheltered from an onshore wind. Incoming swells from the Irish Sea will break over the sandbanks in the outer reaches of the western side of the bay at lower states of the tide at least, but will travel up the deeper waters on the eastern side, which may therefore be more exposed to wave action. Whilst remobilisation of sediment entrained contamination may also occur from time to time in the Walney Channel, particularly the wider southern part, it is much more sheltered than the bay.

Appendix X. Microbiological Data: Seawater

X.1. Bathing Waters

There are three bathing waters in Morecambe Bay designated under the Directive 76/160/EEC (Council of the European Communities, 1975), the locations of which are shown in Figure X.1.

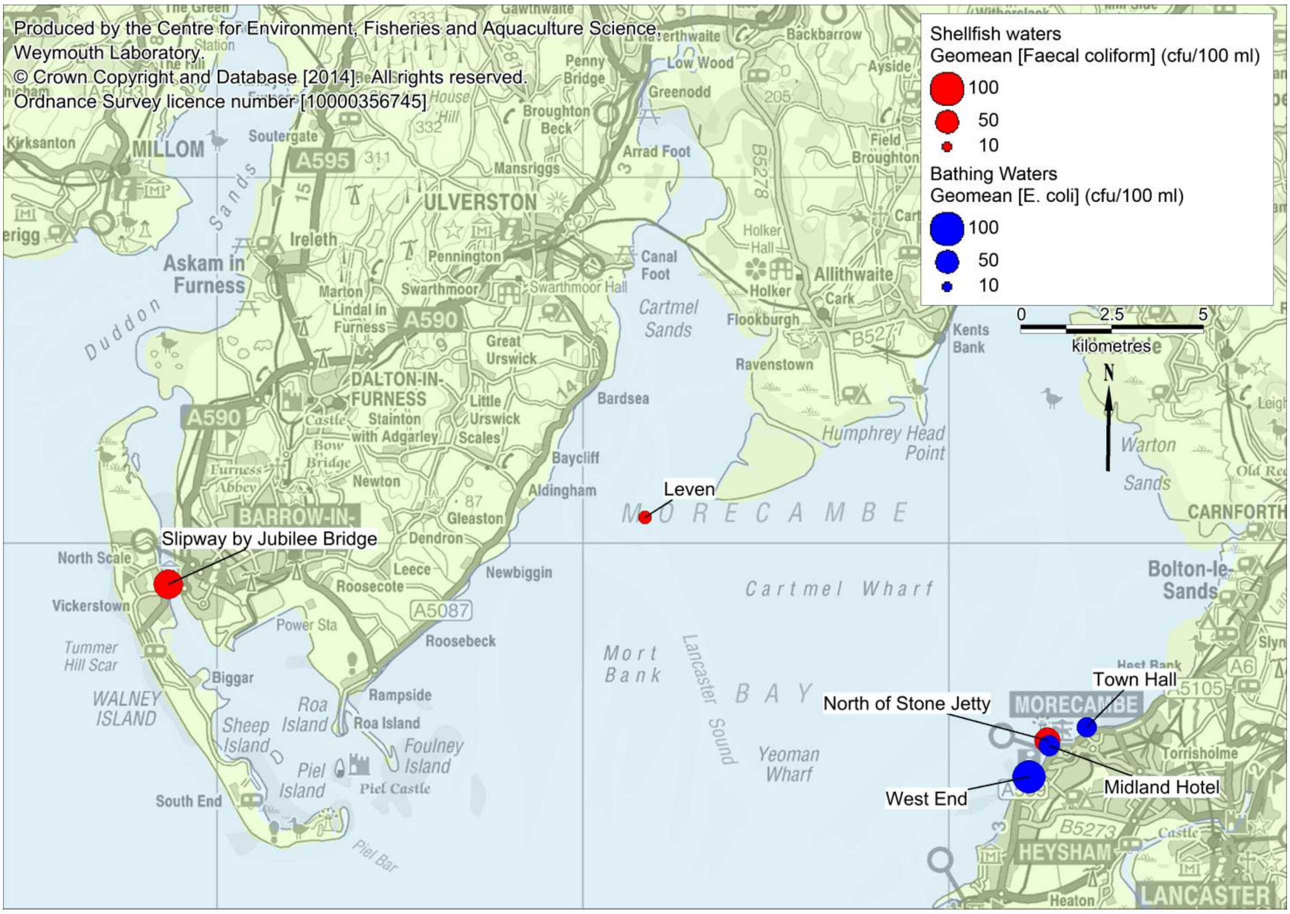

Figure X.1: Location of designated bathing and shellfish waters monitoring points in Morecambe Bay

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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. *E. coli* were enumerated in all of 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 *E. coli* results, 2009-2014 (cfu/100ml).

Sampling Site	N.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000	% over 10,000
Town Hall	68	14/05/2009	13/07/2014	38.4	<2	1,700	32.4	7.4	0.0
Midland Hotel	50	09/05/2012	14/07/2014	42.3	<10	2,300	30.0	4.0	0.0
West End	18	14/05/2009	21/09/2009	95.7	<2	7,000	44.4	11.1	0.0

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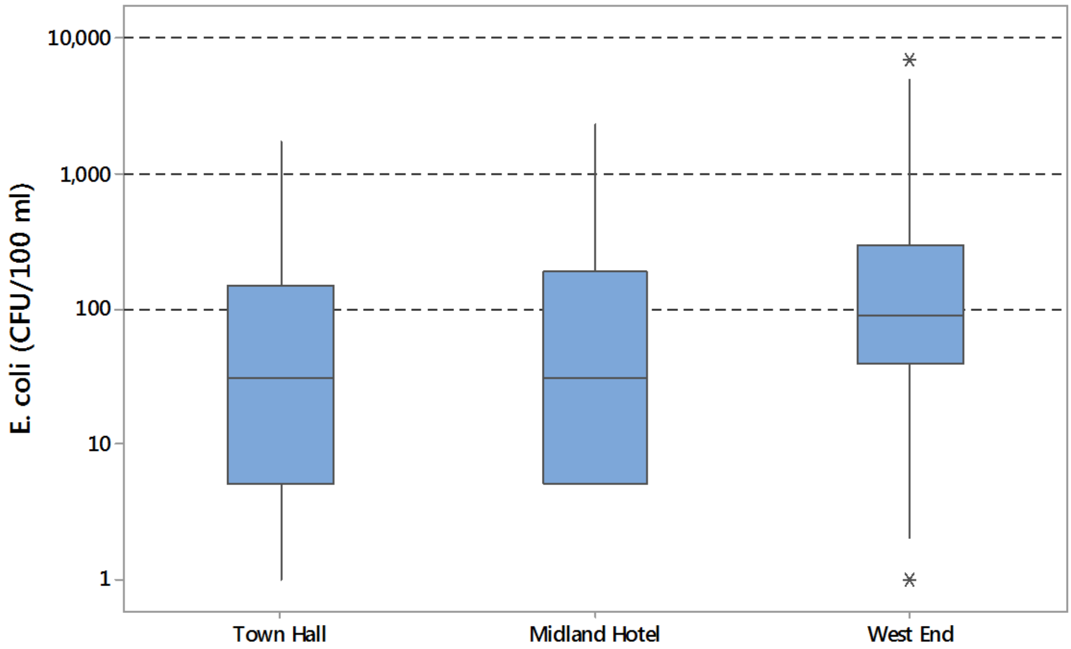

Figure X.2: Box-and-whisker plots of all *E. coli* results by site
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The West End sampling site had the highest geometric mean and maximum *E. coli* concentrations, while Town Hall, had the lowest geometric mean and maximum *E. coli* concentrations. This suggests a gradient of increasing levels of contamination towards the western end of the Morecambe seafront. Due to the differing periods sampled at the three locations it was not appropriate to compare results from them all directly. During 2009, when Town Hall and West End were both sampled on the same day on 18 occasions, results were significantly higher at West End (paired T-test, $p<0.001$). Results from paired (same day) samples were strongly correlated (Pearson's correlation, $r=0.918$, $p<0.001$). From 2012 to 2014, Town Hall and Midland Hotel were both samples on the same day on 48 occasions and there was no significant difference in average result (paired T-test, $p=0.901$). Results were again strongly correlated on a sample by sample basis (Pearson's correlation, $r=0.714$, $p<0.001$). These analyses suggest that all three locations are subject to similar sources of contamination, and that levels of contamination increase significantly towards the western end of the Morecambe seafront.

Temporal and seasonal patterns in results

The period for which *E. coli* results were available was too short to investigate any long term temporal changes. As bathing water sampling is only undertaken from May to September it was not possible to investigate seasonality either.

Influence of tides

To investigate the effects of tidal state on *E. coli* results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of the bathing waters sampling points that were sampled on 30 or more occasions. Correlation coefficients are presented in Table X.2 and significant correlations are highlighted in yellow.

Table X.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	**r**	**p**	**r**	**p**
Town Hall	0.308	0.002	0.095	0.556
Midland Hotel	0.093	0.664	0.077	0.757

Figure X.3 presents polar plots of $\log_{10}$ *E. coli* results against tidal states on the high/low cycle at Town Hall, where the only significant effect was found. High water at Morecambe is at 0° and low water is at 180°. Results of 100 *E. coli* cfu/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.

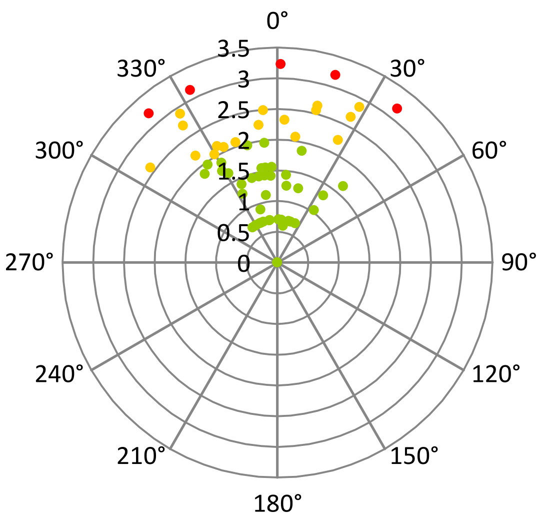

Figure X.3: Polar plots of $\log_{10}$ *E. coli* results (cfu/100 ml) against high/low tidal state.

All samples at Town Hall were taken around high water. While the analyses showed a significant correlation with tidal state, no obvious patterns can be seen in the polar plot.

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 Grange weather station (Appendix VI for details) over various periods running up to sample collection and *E. coli* results. These are presented in Table X.3 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.3: Spearman's Rank correlation coefficients for *E. coli* results against recent rainfall

	Site	Town Hall	Midland Hotel	West End
	n	68	50	18
24 hour periods prior to sampling	1 day	-0.053	-0.057	-0.288
	2 days	0.418	0.244	0.198
	3 days	0.376	0.194	0.567
	4 days	0.351	0.308	0.411
	5 days	0.433	0.458	0.133
	6 days	0.265	0.353	0.424
	7 days	0.194	0.121	0.630
Total prior to sampling over	2 days	0.157	0.089	-0.043
	3 days	0.254	0.142	0.105
	4 days	0.362	0.256	0.213
	5 days	0.441	0.391	0.187
	6 days	0.488	0.461	0.268
	7 days	0.503	0.451	0.428

Rainfall had less of an effect on *E. coli* concentrations at West End, although sample numbers here were lower. Both Town Hall and Midland Hotel were significantly affected by rainfall. The influence was more delayed at Midland Hotel. This suggests that the main rainfall dependent sources lie to the north east, although it should be noted that the sample numbers and periods represented vary between the three monitoring points.

Salinity

Salinity was recorded on most sampling occasions. Figure X.4 shows scatter-plots between *E. coli* and salinity. Pearson's correlations were run to determine the effect of salinity on *E. coli* at the bathing waters site.

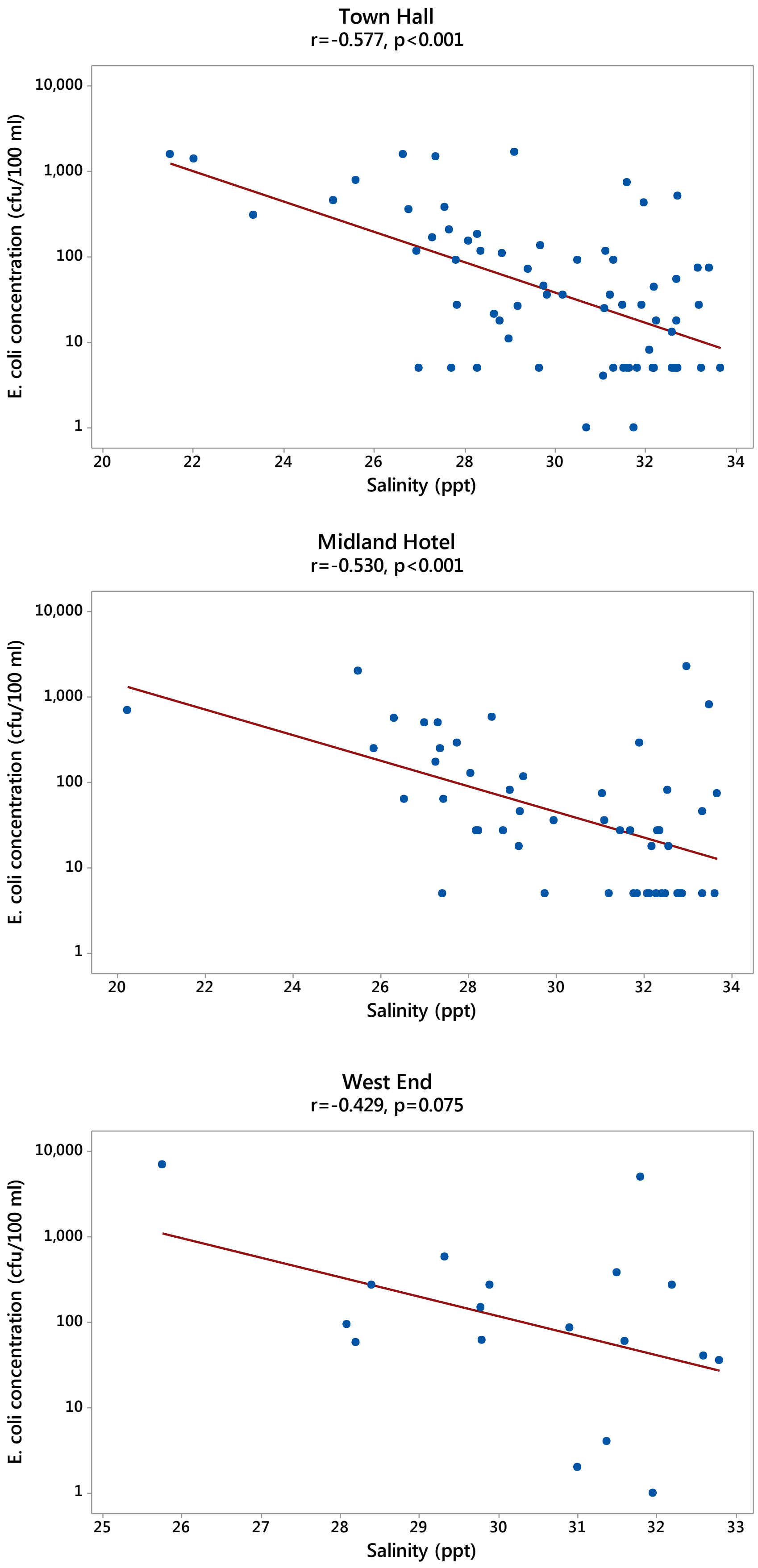

Figure X.4: Scatter-plots of salinity against *E. coli* concentration.
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E. coli levels at all sites correlated significantly with salinity. This suggests that land runoff is a significant influence on the Morecambe seafront.

X.2. Shellfish Waters

Summary statistics and geographical variation

There are three shellfish waters monitoring sites designated under Directive 2006/113/EC (European Communities, 2006) in Morecambe Bay. Figure X.1 shows the location of these sites. Table X.4 presents summary statistics for bacteriological monitoring results and Figure X.5 presents a boxplot of faecal coliform levels from the monitoring point. One of these shellfish waters (Leven) was only monitored from 2011.

Table X.4: Summary statistics for shellfish waters faecal coliform results, 2004 to 2013 (cfu/100ml).

Sampling Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000	% over 10,000
Slipway by Jubilee Bridge	40	06/01/2004	23/07/2013	76.9	<2	67,200	27.5	7.5	5.0
Leven	11	04/03/2011	09/04/2013	18.9	<10	3,400	18.2	18.2	0.0
North of Stone Jetty	38	07/01/2004	24/07/2013	60.2	<2	27,000	34.2	10.5	2.6

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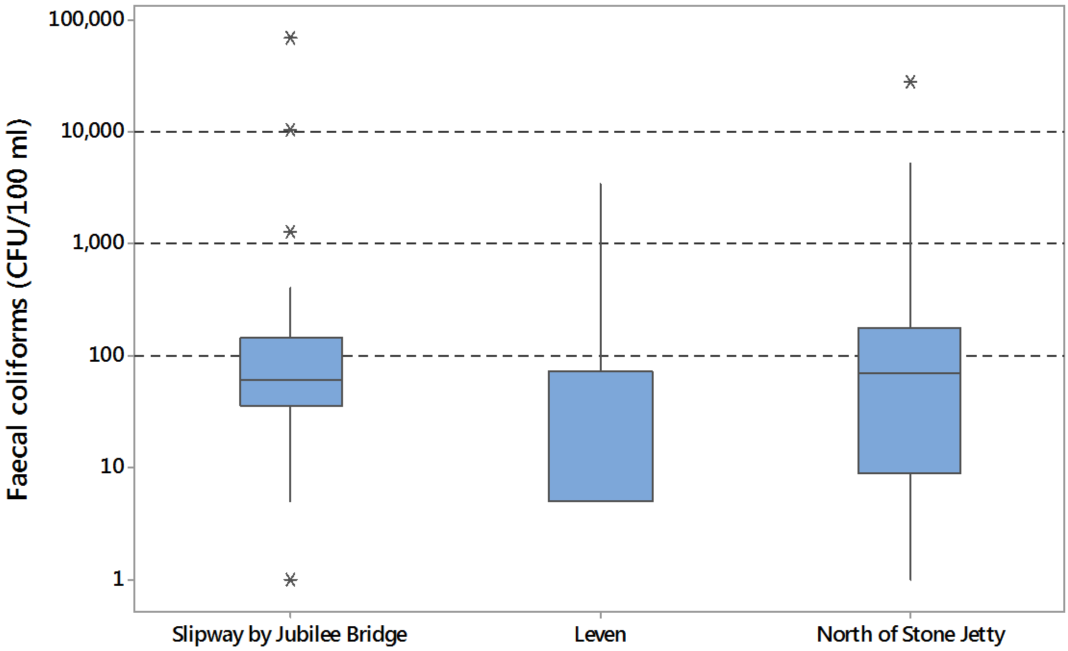

Figure X.5: Box-and-whisker plots of all faecal coliforms results
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The Slipway by Jubilee Bridge sampling site had the highest geometric mean and maximum faecal coliform concentrations, while Leven, had the lowest geometric mean and maximum faecal coliform concentrations. A one-way ANOVA test showed that there were no significant differences in faecal coliform concentrations between sites (p=0.150).

Overall temporal pattern in results

The overall variation in faecal coliform levels found at shellfish water sites over time is shown in Figure X.6.

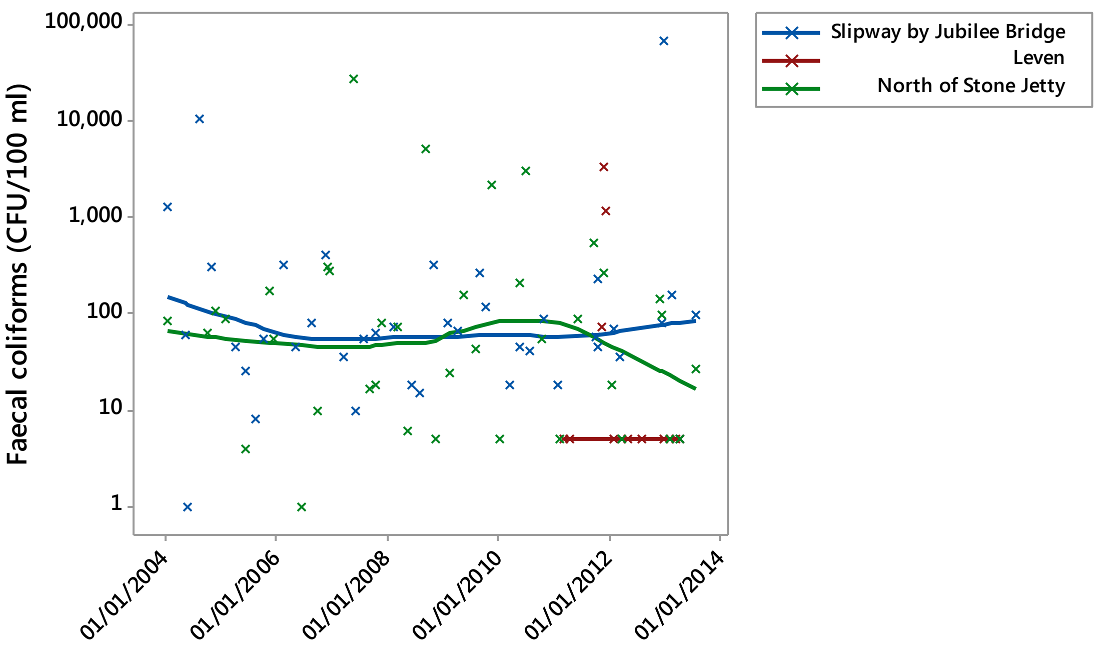

Figure X.6: Scatterplot of faecal coliform results by date, overlaid with loess lines
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Faecal coliform concentrations have remained fairly stable since 2004. The apparent decline in concentrations at North of Stone Jetty is likely to be a consequence of the increased weighting given to the last few samples by the loess calculation rather than an actual effect.

Seasonal patterns of results

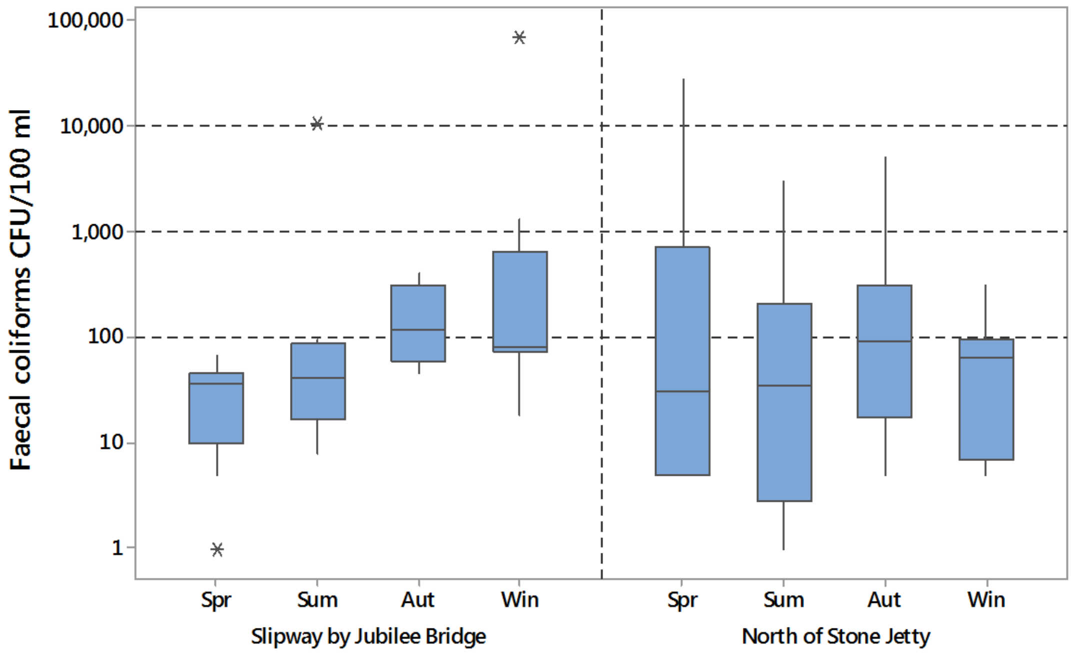

Figure X.7: Boxplot of faecal coliform results by site and season
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Leven was not sampled on enough occasions to assess any seasonal patterns. One-way ANOVA tests showed that there were significant variations in faecal coliform concentrations between seasons at Slipway by Jubilee Bridge (p=0.018), but not at North of Stone Jetty (p=0.632). Post-hoc Tukey tests showed that faecal coliform levels at Slipway by Jubilee Bridge were significantly higher in winter than in spring. The differing seasonal patterns suggest that the two sites are subject to different profiles of contaminating influences.

Influence of tide

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of these shellfish waters sampling points. Again, there were insufficient samples to undertake a meaningful analysis of results from Leven. Correlation coefficients are presented in Table X.5, with statistically significant correlations highlighted in yellow.

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

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Slipway by Jubilee Bridge	0.481	0.000	0.161	0.385
North of Stone Jetty	0.221	0.180	0.404	0.003

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Figure X.8 presents a polar plot of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle for Slipway at Jubilee Bridge, where a significant correlation was found. High water at Morecambe is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

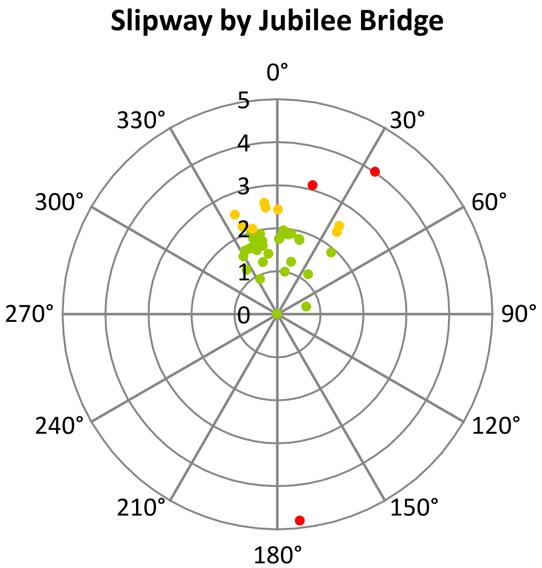

Figure X.8: Polar plots of log_{10} faecal coliforms against tidal state on the high/low tidal cycle for shellfish waters monitoring points with significant correlations
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All but one sample from Slipway by Jubilee Bridge was taken around high tide. However a tendency for higher results after high water is apparent in the polar plot, and the sample taken at low water returned the highest individual result. This may indicate there are significant contamination sources up-tide (to the north) of the sampling location.

Figure X.9 presents a polar plot of log_{10} faecal coliform results against the lunar spring/neap cycle for North of Stone Jetty, for which a 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.

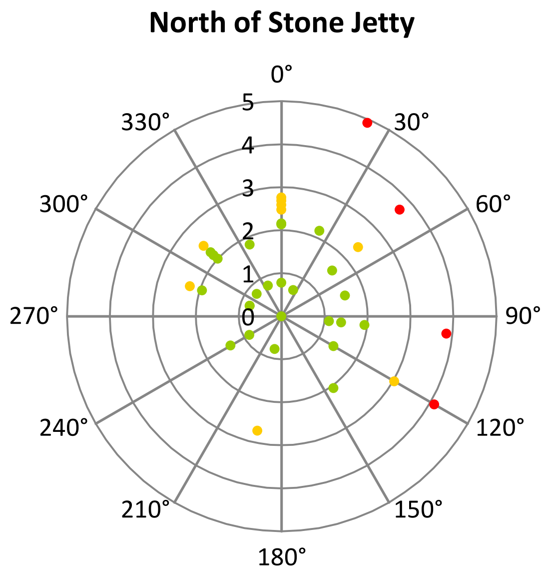

Figure X.9: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the spring/neap tidal cycle for shellfish waters monitoring points with significant correlations

At North of Stone Jetty, higher results tended to occur in samples taken on larger tides. This may suggest that a more remote source or possibly tidal inundation of grazed salt marsh may be of significance in this part of the bay.

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 Grange weather station (Appendix VI 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: Spearman's Rank correlation coefficients for faecal coliform results against recent rainfall

Site		Slipway by Jubilee Bridge	Leven	North of Stone Jetty
n		40	11	38
24 hour periods prior to sampling	1 day	0.308	0.316	0.310
	2 days	0.546	0.448	0.507
	3 days	0.444	0.420	0.427
	4 days	0.423	0.030	0.215
	5 days	0.409	0.381	0.347
	6 days	0.390	0.545	0.407
	7 days	0.294	-0.352	0.283
Total prior to sampling over	2 days	0.468	0.460	0.379
	3 days	0.619	0.650	0.473
	4 days	0.658	0.369	0.514
	5 days	0.696	0.317	0.522
	6 days	0.718	0.392	0.617
	7 days	0.715	0.341	0.669

Rainfall had a significant impact on faecal coliform levels at both Slipway by Jubilee Bridge and North of Stone Jetty, by not at Leven. However, the correlation coefficient vales at Leven are similar to those at the other sampling sites. It is possible therefore that Leven is significantly affected by rainfall, but the low sample numbers relative to the other sampling sites reduced the power of the analyses to detect this effect.

Salinity

Salinity was recorded on most sampling occasions. Figure X.10 shows scatter-plots between faecal coliforms and salinity. Pearson's correlations were run to determine the effect of salinity on faecal coliforms at the three sites.

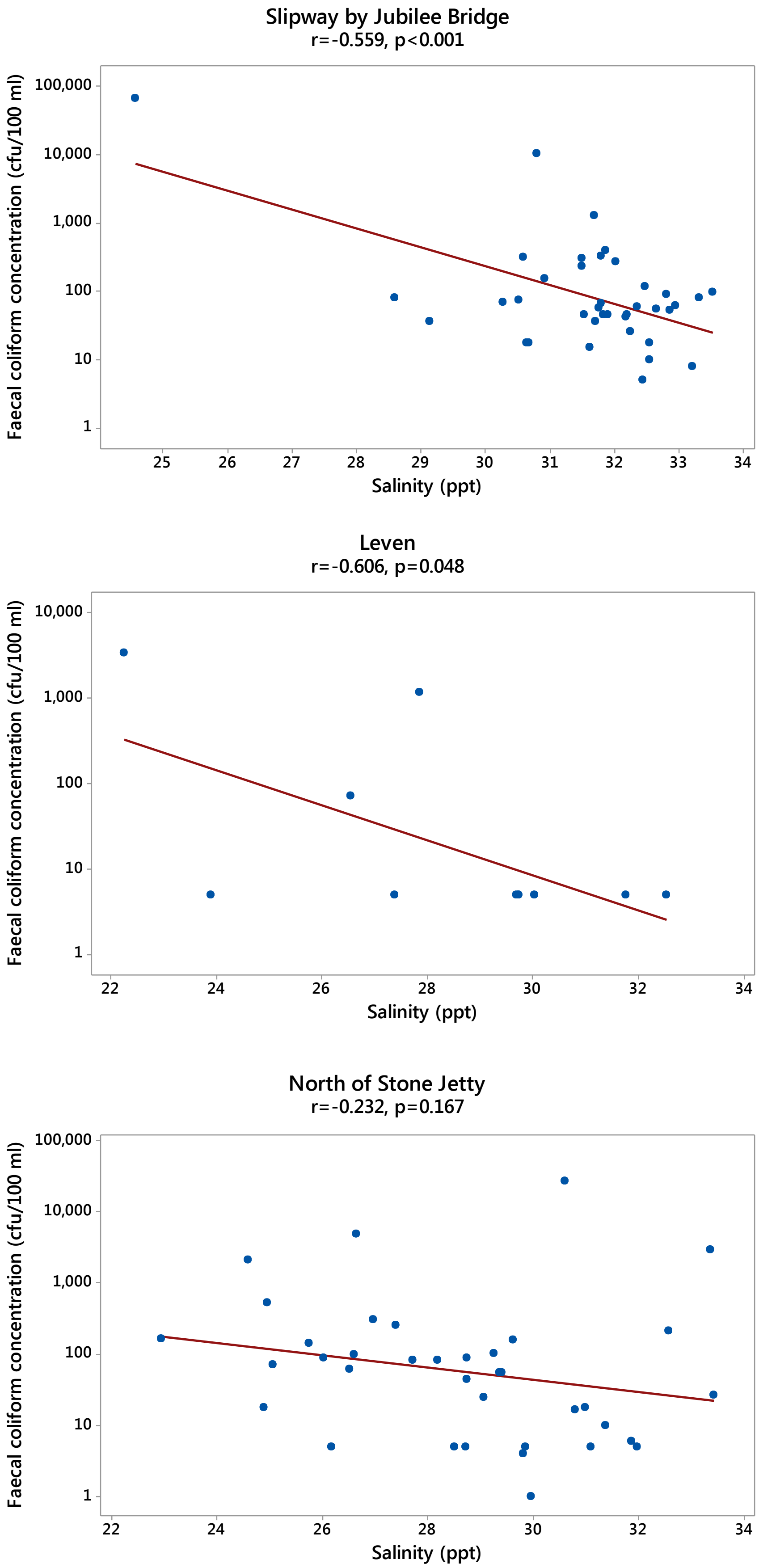

Figure X.10: Scatter-plots of salinity against faecal coliform concentration.

At Slipway by Jubilee Bridge and Leven, faecal coliform levels correlated significantly with salinity. This indicates that land runoff is a significant contaminating influence at these locations. At North of Stone Jetty, there was no significant correlation between faecal coliform concentrations and salinity. As a similar range of salinities were recorded at all three sites, it is probable that the source of freshwater at North of Stone Jetty is different in nature to the freshwater sources at the other sampling locations.

Appendix XI. Microbiological Data: Shellfish Flesh

XI.1. Summary statistics and geographical variation

There are a total of 34 RMPs in Morecambe Bay that have been sampled between 2005 and 2014, 26 of which are for cockles, seven are for mussels and one is for Pacific oysters. The geometric mean results of shellfish flesh monitoring from all RMPs sampled from 2005 onwards are presented in Figure XI.1. Summary statistics are presented in Table XI.1 and boxplots for sites are show in Figure XI.2 to Figure XI.4. Most (20) of these RMPs were sampled on fewer than 10 occasions and so will not be considered in the more detailed analyses.

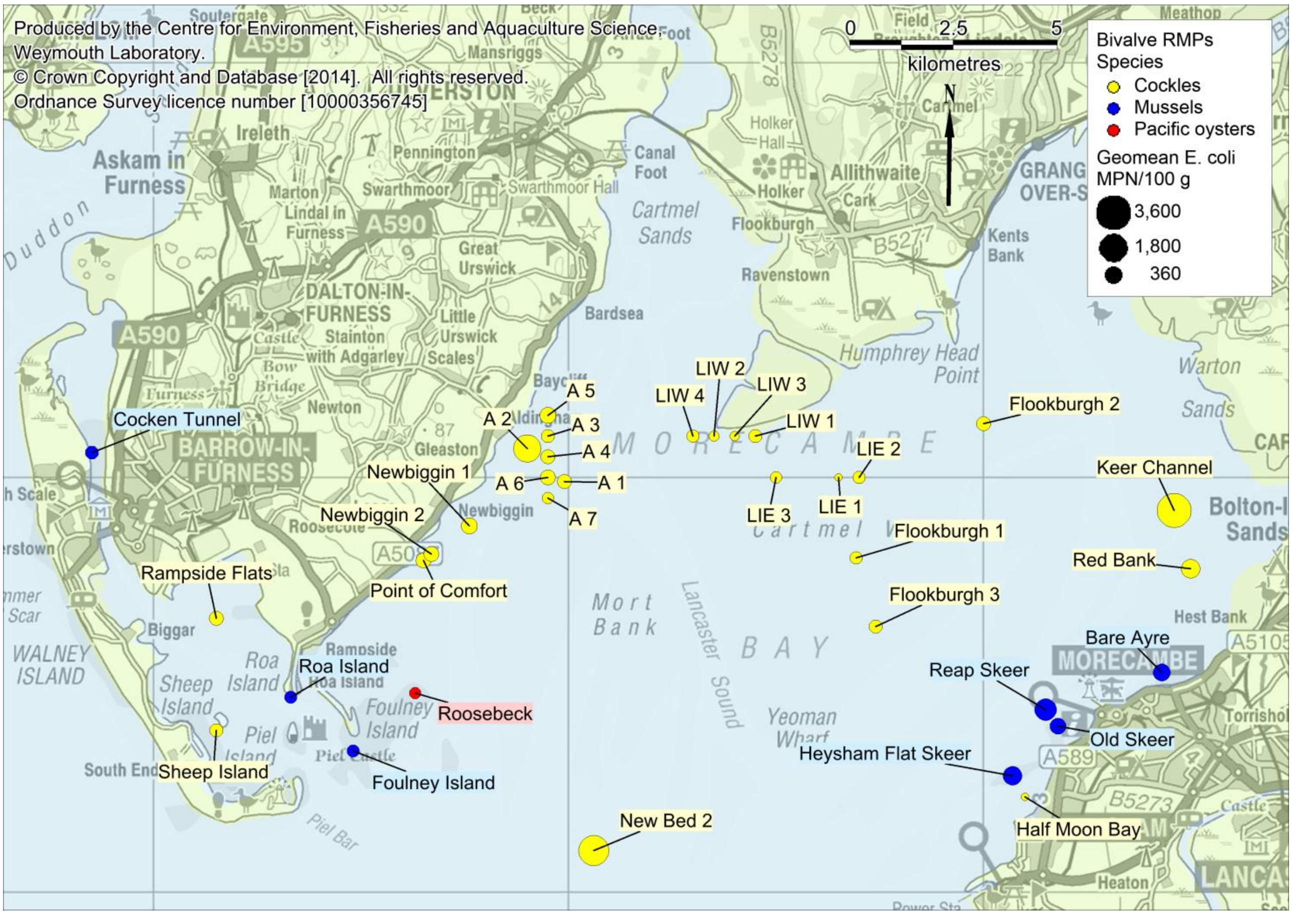

Figure XI.1: Bivalve RMPs active since 2004. A is Aldingham, LIW is Leven Island West and LIE is Leven Island East.

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) from RMPs sampled from 2005 onwards.

Sampling Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600	% over 46,000
Rampside Flats	Cockle	50	18/01/2005	19/03/2013	175.8	<20	5,000	46.0	2.0	0.0
Sheep Island	Cockle	48	18/01/2005	19/03/2013	147.6	<20	5,400	39.6	2.1	0.0
Point of Comfort	Cockle	2	16/03/2005	07/06/2007	259.8	90	750	50.0	0.0	0.0
Newbiggin 1	Cockle	56	05/10/2005	28/07/2014	317.7	<20	>180,000	51.8	3.6	1.8
Newbiggin 2	Cockle	1	02/02/2009	02/02/2009	230.0	230	230	0.0	0.0	0.0
Aldingham 1	Cockle	7	18/06/2012	16/04/2013	218.7	20	2,400	42.9	0.0	0.0
Aldingham 2	Cockle	3	23/11/2005	07/03/2006	1,797.5	220	24,000	66.7	33.3	0.0
Aldingham 3	Cockle	2	14/02/2008	11/06/2008	162.5	80	330	50.0	0.0	0.0
Aldingham 4	Cockle	34	30/01/2008	28/07/2014	199.0	<20	3,500	41.2	0.0	0.0
Aldingham 5	Cockle	4	04/03/2008	05/10/2010	293.7	130	1,300	25.0	0.0	0.0
Aldingham 6	Cockle	1	31/03/2008	31/03/2008	230.0	230	230	0.0	0.0	0.0
Aldingham 7	Cockle	7	21/10/2008	05/03/2012	106.3	20	460	14.3	0.0	0.0
Leven Island West 1	Cockle	21	05/03/2008	10/09/2013	159.7	<20	3,500	33.3	0.0	0.0
Leven Island West 2	Cockle	1	31/03/2008	31/03/2008	80.0	80	80	0.0	0.0	0.0
Leven Island West 3	Cockle	5	29/04/2008	06/04/2011	55.4	<20	1,300	20.0	0.0	0.0
Leven Island West 4	Cockle	2	13/05/2008	10/09/2008	107.2	50	230	0.0	0.0	0.0
Leven Island East 1	Cockle	3	31/03/2008	13/05/2008	25.2	<20	80	0.0	0.0	0.0
Leven Island East 2	Cockle	27	17/03/2008	29/07/2014	128.9	<20	3,500	25.9	0.0	0.0
Leven Island East 3	Cockle	5	04/03/2008	03/07/2012	94.3	<20	1,300	20.0	0.0	0.0
Flookburgh 1	Cockle	7	17/03/2005	15/08/2006	132.1	40	750	14.3	0.0	0.0
Flookburgh 2	Cockle	17	05/07/2007	26/08/2010	215.6	20	>180,000	29.4	5.9	5.9
Flookburgh 3	Cockle	65	12/05/2005	29/07/2014	140.9	<20	3,500	30.8	0.0	0.0
New Bed 2	Cockle	1	28/07/2005	28/07/2005	2,400.0	2,400	2,400	100.0	0.0	0.0
Keer Channel	Cockle	2	14/02/2005	05/10/2005	3,600.0	2,400	5,400	100.0	50.0	0.0
Red Bank	Cockle	67	05/10/2005	05/03/2013	503.2	<20	>180,000	64.2	10.4	1.5
Half Moon Bay	Cockle	1	18/05/2010	18/05/2010	20.0	20	20	0.0	0.0	0.0
Roa Island	Mussel	96	18/01/2005	04/08/2014	114.6	<20	9,100	22.9	3.1	0.0
Foulney Island	Mussel	81	15/03/2005	16/07/2014	110.7	<20	3,100	29.6	0.0	0.0
Cocken Tunnel	Mussel	97	18/01/2005	04/08/2014	146.7	<20	5,400	28.9	3.1	0.0
Bare Ayre	Mussel	103	13/01/2005	18/08/2014	387.2	<20	9,200	64.1	2.9	0.0
Reap Skeer	Mussel	4	14/02/2005	01/11/2005	831.0	220	1,700	75.0	0.0	0.0
Old Skeer	Mussel	4	14/02/2005	15/12/2011	316.9	110	1,700	50.0	0.0	0.0
Heysham Flat Skeer	Mussel	6	13/01/2005	15/12/2011	548.3	40	3,500	66.7	0.0	0.0
Roosebeck	Pacific oyster	57	16/03/2005	04/08/2014	91.1	<20	16,000	22.8	1.8	0.0

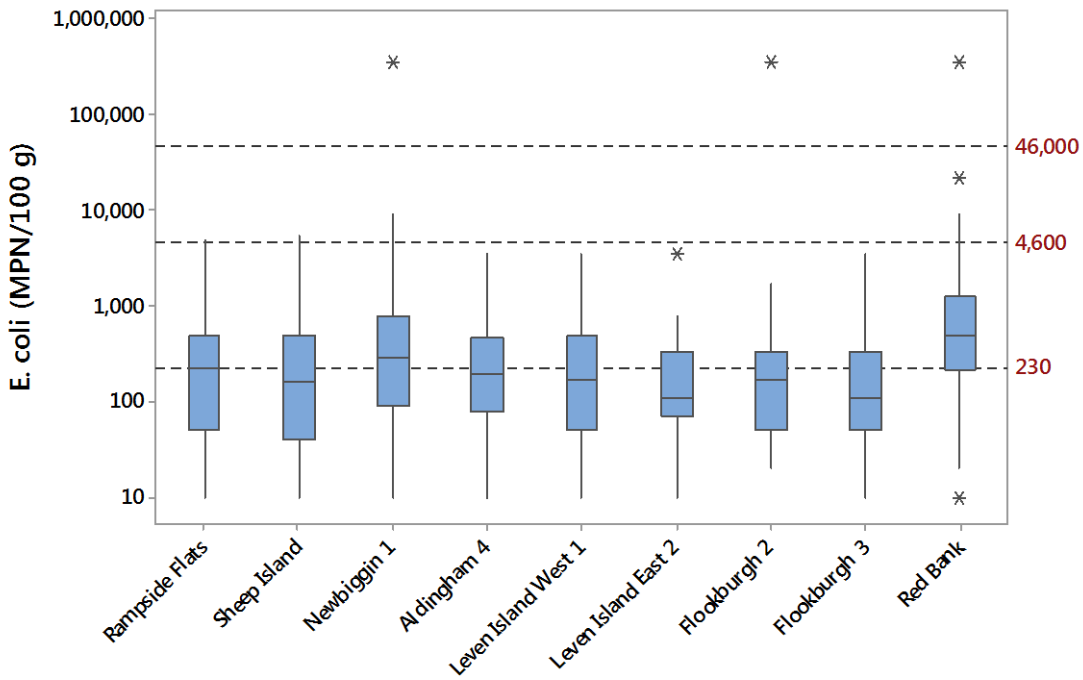

Figure XI.2: Boxplots of *E. coli* results from cockle RMPs from 2005 onwards.

Cockle sampling locations have varied with time across the various beds/zones, largely due to fluctuations in the geographic distribution of stocks. This complicates the interpretation of the spatial variation in levels of contamination, as the sets of results from each individual monitoring point are not directly comparable with other monitoring points as different temporal periods are represented. Results were broadly similar across the survey area as a whole, and generally aligned with a solid B classification. In the Red Bank area however, average *E. coli* levels were highest and the results were more aligned with a C classification. A less marked area of elevated contamination is also apparent in the Newbiggin/Point of Comfort area, and the Leven Island area appears to be slightly less contaminated than other areas. There is no suggestion of a consistent increase in *E. coli* levels towards the innermost reaches of the bay, although the cockle beds do not extend up into the two main river estuaries where the influence of runoff from the wider catchment would become more acute. Results were very similar at the two monitoring points in the outer Walney Channel (Rampside Flats and Sheep Island). One prohibited level result was recorded at each of Newbiggin 1, Flookburgh 2 and Red Bank.

A one-way ANOVA test showed that there were significant differences in *E. coli* levels between these RMPs ($p<0.001$). Post ANOVA Tukey tests showed that Red Bank had significantly higher *E. coli* levels than Rampside Flats, Sheep Island, Leven Island East 2 and Flookburgh 3.

Comparisons of RMPs were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared at least 20 sampling dates, and therefore environmental conditions. Only three comparisons could be made (Rampside Flats/Sheep Island [$r=0.549$, $p<0.001$], Newbiggin 1/Aldingham 4 [$r=0.518$, $p=0.002$], Leven Island East

2/Flookburgh 3 [r=0.699, p<0.001]). *E. coli* levels at these RMPs correlated significantly indicating that they are probably influenced by similar contamination sources.

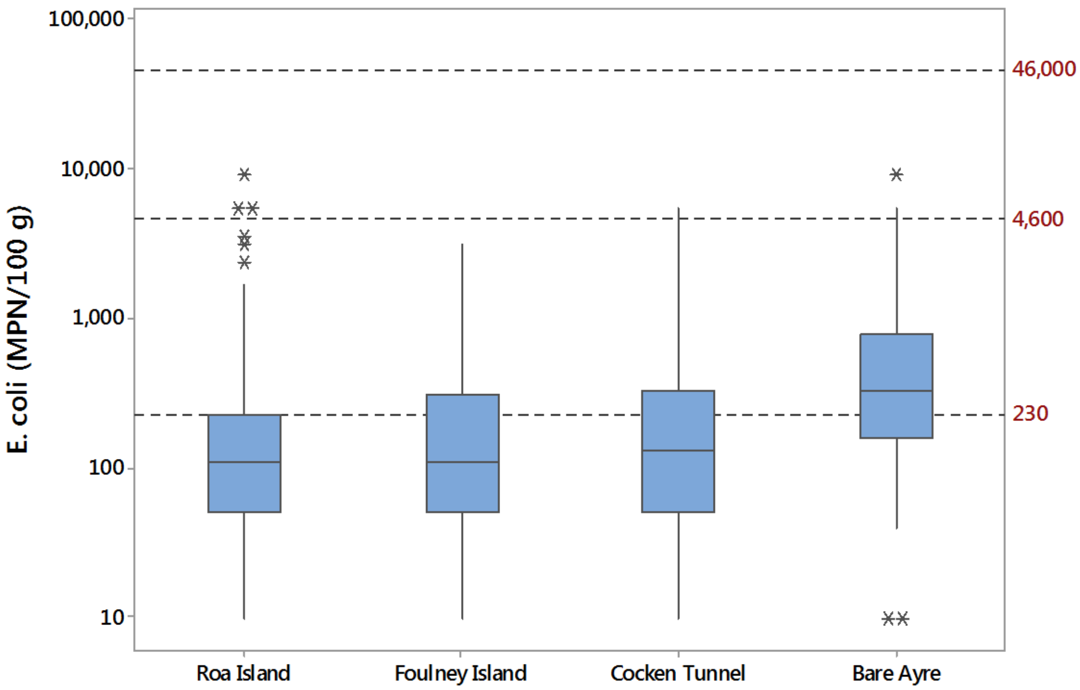

Figure XI.3: Boxplots of *E. coli* results from mussel RMPs from 2005 onwards.

Average results were considerably higher on the mussel beds off Morecambe compared to those on the other side of the Bay and within the Walney Channel. At mussel RMPs sampled on 10 or more occasions, *E. coli* levels exceeded 230 MPN/100 g at least 22% of samples at all sites and none exceeded 4,600 MPN/100 g in more than 10% of samples. No sites had any samples exceeding 46,000 *E. coli* MPN/100 g. A one-way ANOVA test showed that there were significant differences in *E. coli* levels between sites (p<0.001). Post ANOVA Tukey tests showed that Bare Ayre had significantly higher *E. coli* levels than all other sites.

Comparisons of RMPs were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared at least 20 sampling dates, and therefore environmental conditions. It was not possible to compare Bare Ayre with any of the other sites in this way. Only one comparison (Cocken Tunnel/Roa Island) correlated significantly (r=0.440, p<0.001) indicating that they probably share similar contamination sources.

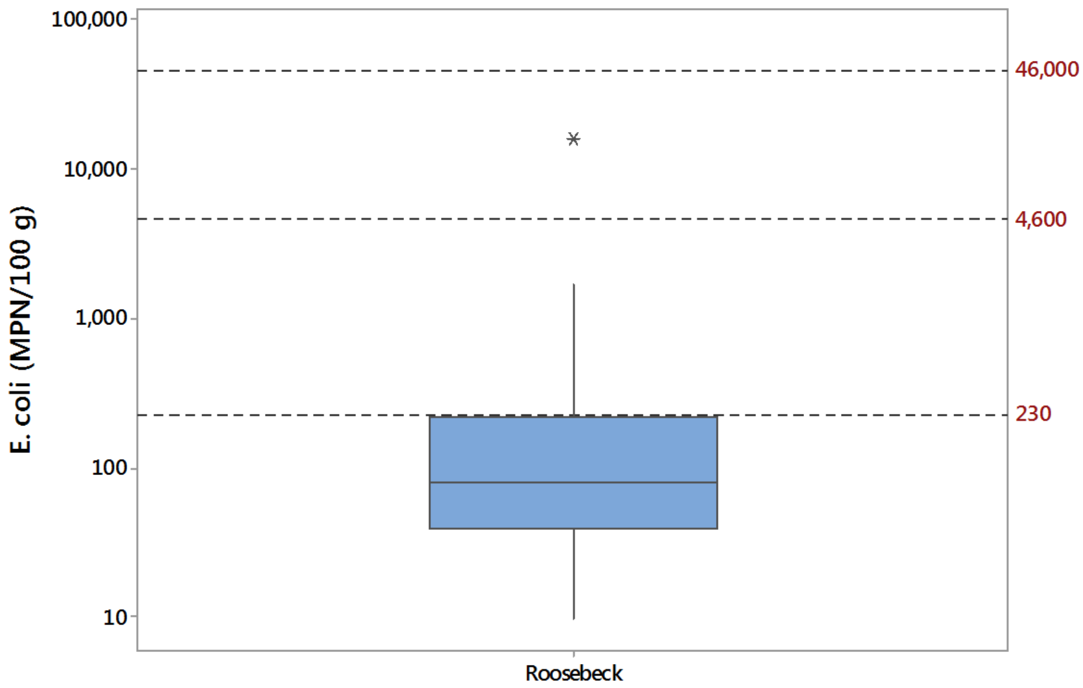

Figure XI.4: Boxplots of *E. coli* results from Pacific oyster RMPs from 2005 onwards.

At the Roosebeck Pacific oyster RMP, *E. coli* results exceeded 230 MPN/100 g in 22.8% of samples and 4,600 MPN/100 g in 1.8% of samples. No samples exceeded 46,000 MPN/100 g.

XI.2. Overall temporal pattern in results

The overall variation in *E. coli* levels found in bivalves is shown in Figure XI.5 to Figure XI.8. Cockle results are presented in two separate graphs for the west and the east of Morecambe Bay for clarity.

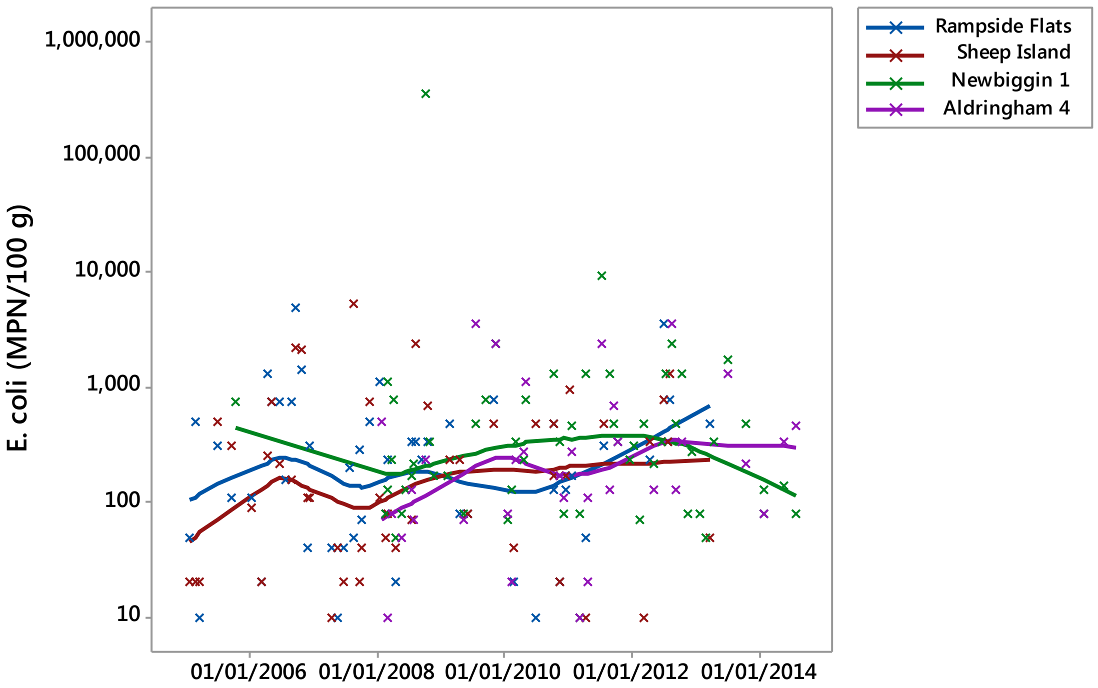

Figure XI.5: Scatterplot of *E. coli* results for cockles from RMPs in the west of Morecambe Bay overlaid with loess line.

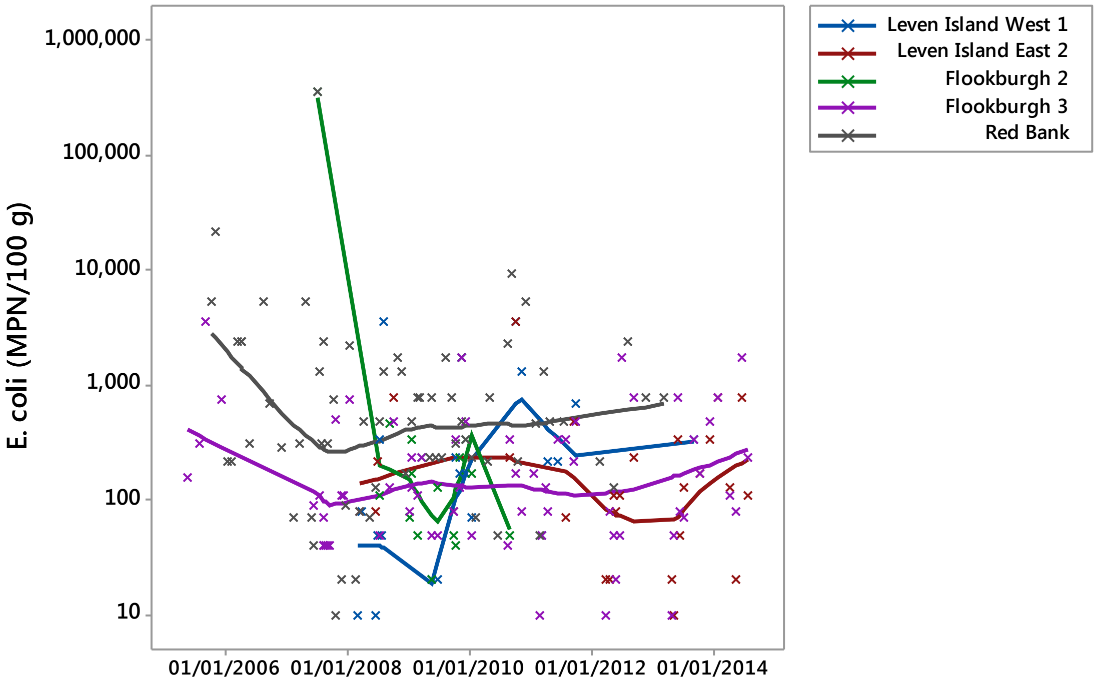

Figure XI.6: Scatterplot of *E. coli* results for cockles from RMPs in the east of Morecambe Bay overlaid with loess line.

In the west of Morecambe Bay, *E. coli* results have remained stable at all sites since 2005. This is also true of the east of Morecambe Bay. However, an unusually high result at Flookburgh 2 skewed the loess plot at the beginning of the data set.

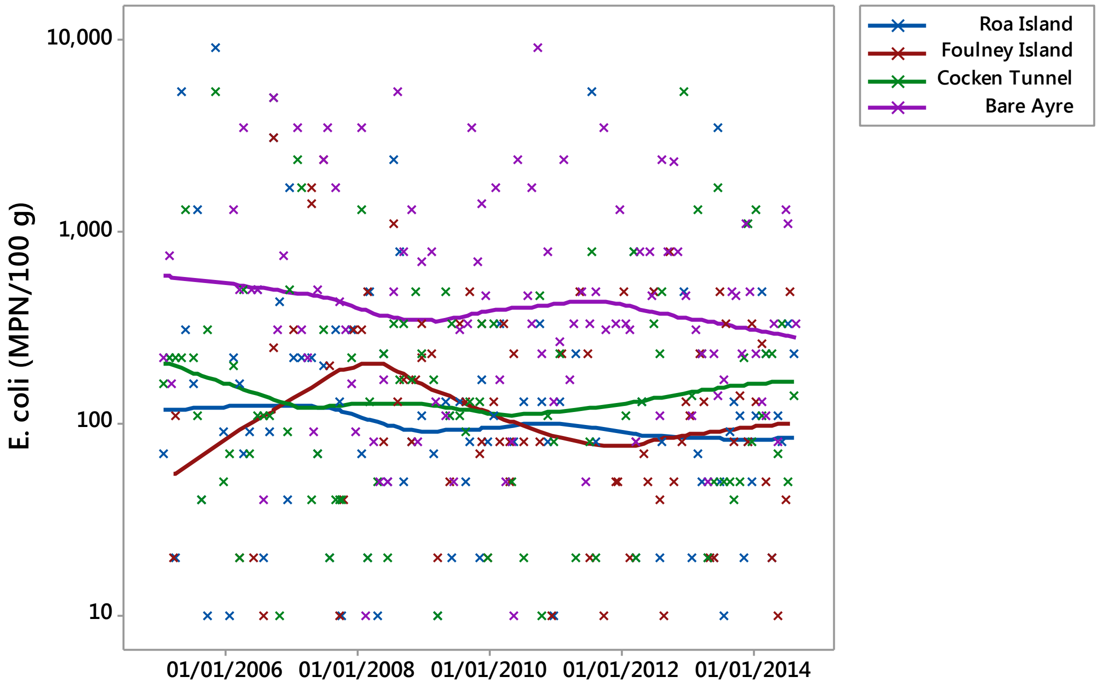

Figure XI.7: Scatterplot of *E. coli* results for mussels overlaid with loess line.

E. coli results have remained relatively stable since 2005, with Bare Ayre consistently having higher results than the other sites.

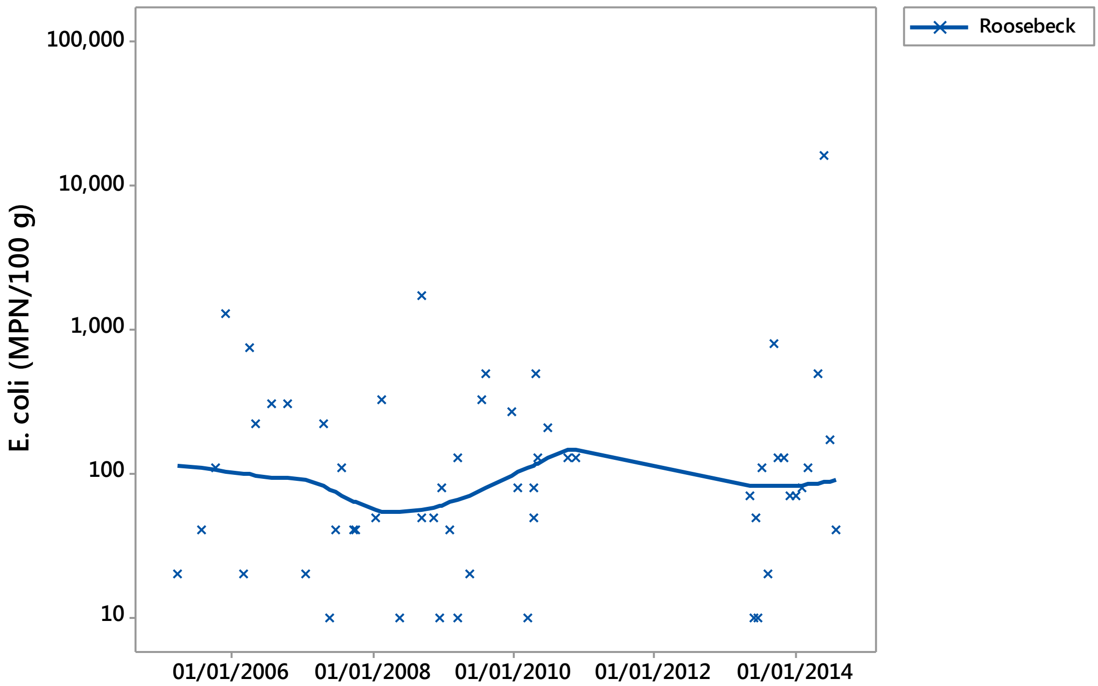

Figure XI.8: Scatterplot of *E. coli* results for Pacific oysters overlaid with loess line.

E. coli results at the Roosebeck Pacific oyster RMP have also remained stable since 2005.

XI.3. Seasonal patterns of results

The seasonal patterns of results from 2005 to 2014 were investigated by RMP. Figure XI.9 shows box plots of *E. coli* levels at each cockle site by season.

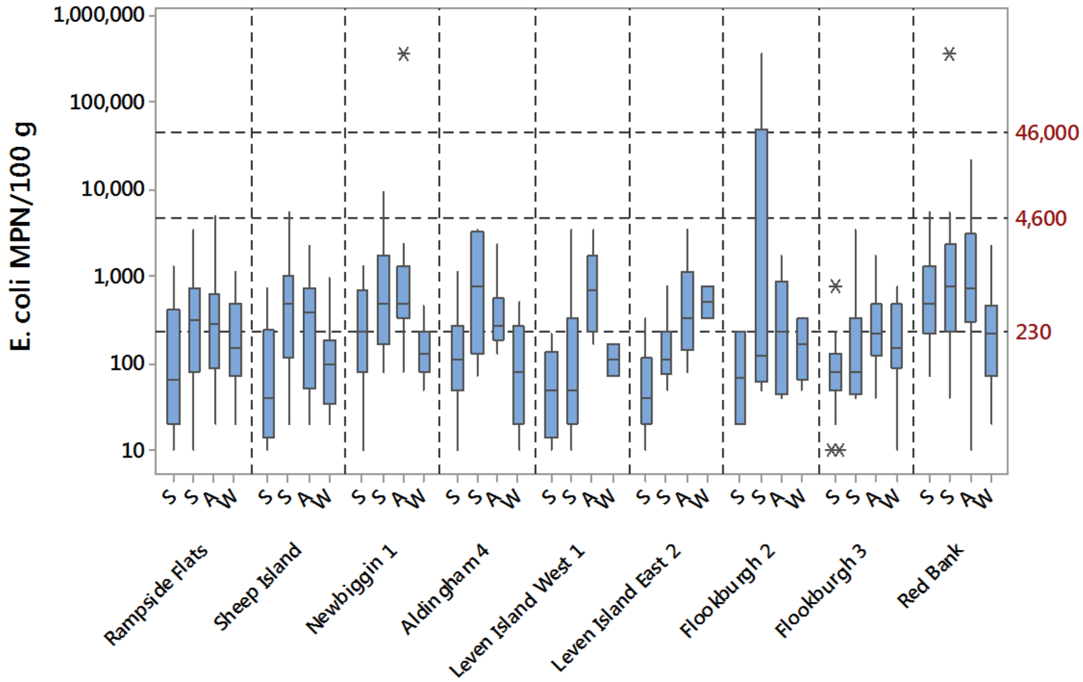

Figure XI.9: Boxplot of *E. coli* results for cockles by RMP and season

Across all the cockle RMPs a similar pattern of higher average results in the summer and autumn was apparent. One-way ANOVAs showed that there were significant differences in *E. coli* levels in cockles between seasons at Sheep Island (p=0.007), Newbiggin 1 (p=0.002), Aldingham 4 (p=0.011), Leven Island West 1 (p=0.031), Leven Island East 2 (p=0.002) and Flookburgh 3 (p=0.034). Post ANOVA Tukey tests showed that at Sheep Island *E. coli* results were higher in the summer than the spring. At Newbiggin 1, *E. coli* results were significantly higher in summer and autumn than in winter. At Aldingham 4, *E. coli* results were significantly higher in summer than spring and winter. At Leven Island West 1, *E coli* results were higher in autumn than spring. At Leven Island East 2, *E .coli* results were significantly higher in autumn and winter than in spring. At Flookburgh 3, *E. coli* results were significantly higher in autumn than in spring. At Red Bank, *E .coli* results were significantly higher in summer and autumn than in spring.

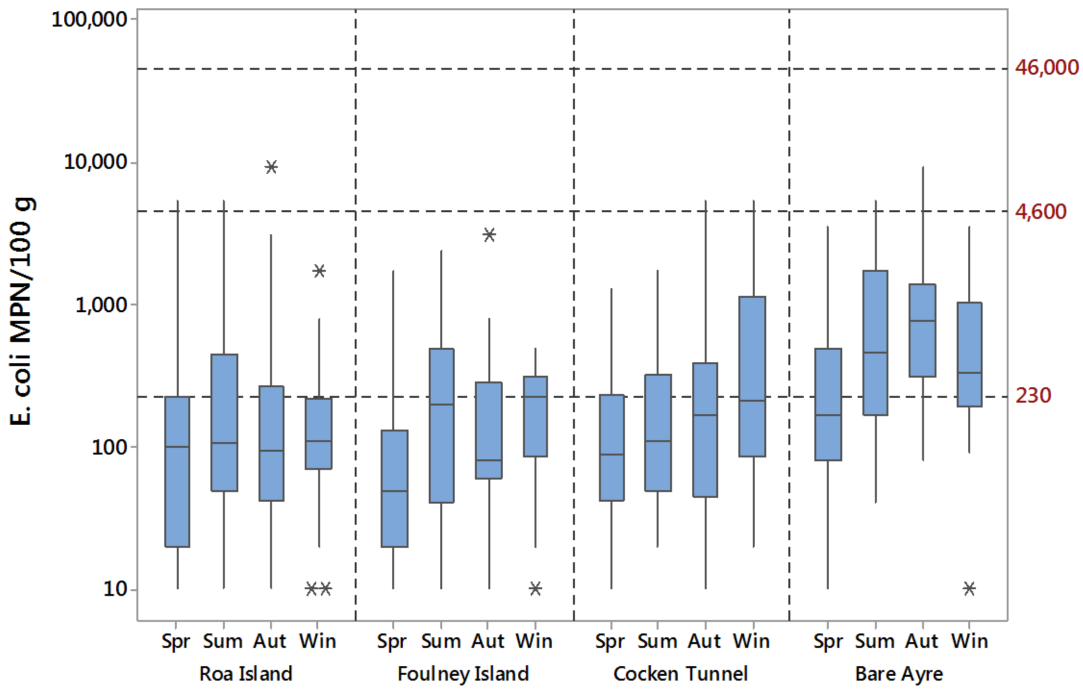

Figure XI.10: Boxplot of *E. coli* results for mussels by RMP and season

Different seasonal patterns show in the plots for the mussel RMPs on the western side of the survey area compared to the eastern side. At the western RMPs, results were lowest on average in the spring and highest on average in the winter, whereas on the eastern side there was a summer/autumn peak. This suggests the two sides are subject to contamination from different profiles of sources.

One-way ANOVAs showed that of the four mussel RMPs tested, there were significant differences in *E. coli* results between seasons at Bare Ayre only (p=0.001). Post ANOVA Tukey tests showed that *E. coli* results were significantly higher in summer and autumn than in spring.

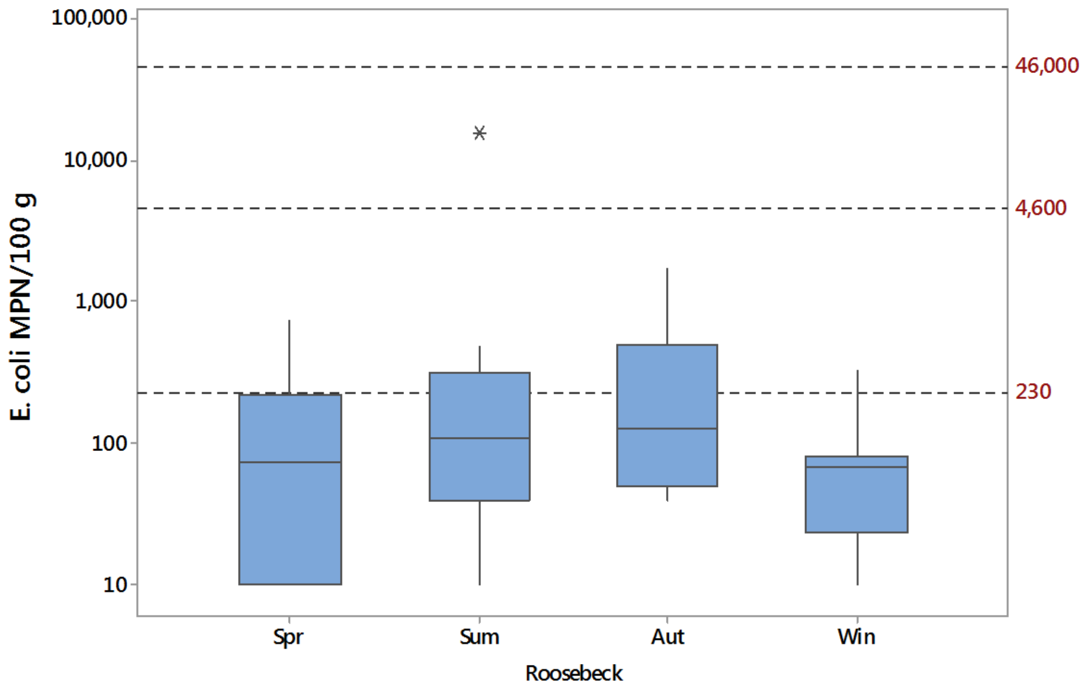

Figure XI.11: Boxplot of *E. coli* results for Pacific oysters by RMP and season

One-way ANOVAs showed that there were no significant differences in *E. coli* levels between seasons at the Roosebeck Pacific oyster RMP (p=0.173). The plot shows a pattern of higher average results in the summer/autumn.

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 tides at either Barrow (Ramsden Dock) or Morecambe 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

Site Name	Species	Tidal station	High/low tides		Spring/neap tides	
			r	p	r	p
Rampside Flats	Cockle	Barrow (Ramsden Dock)	0.122	0.499	0.030	0.960
Sheep Island	Cockle	Barrow (Ramsden Dock)	0.285	0.026	0.321	0.009
Newbiggin 1	Cockle	Barrow (Ramsden Dock)	0.117	0.482	0.199	0.122
Aldingham 4	Cockle	Barrow (Ramsden Dock)	0.23	0.195	0.161	0.449
Flookburgh 3	Cockle	Morecambe	0.051	0.854	0.158	0.211
Red Bank	Cockle	Morecambe	0.171	0.153	0.098	0.538
Roa Island	Mussel	Barrow (Ramsden Dock)	0.032	0.909	0.136	0.181
Foulney Island	Mussel	Barrow (Ramsden Dock)	0.026	0.948	0.290	0.001
Cocken Tunnel	Mussel	Barrow (Ramsden Dock)	0.122	0.249	0.080	0.552
Bare Ayre	Mussel	Morecambe	0.193	0.024	0.158	0.084
Roosebeck	Pacific oyster	Morecambe	0.268	0.020	0.207	0.099

Figure XI.12 to Figure XI.14 present polar plots of $\log_{10}$ *E. coli* results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Barrow (Ramsden Dock) or Morecambe 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.

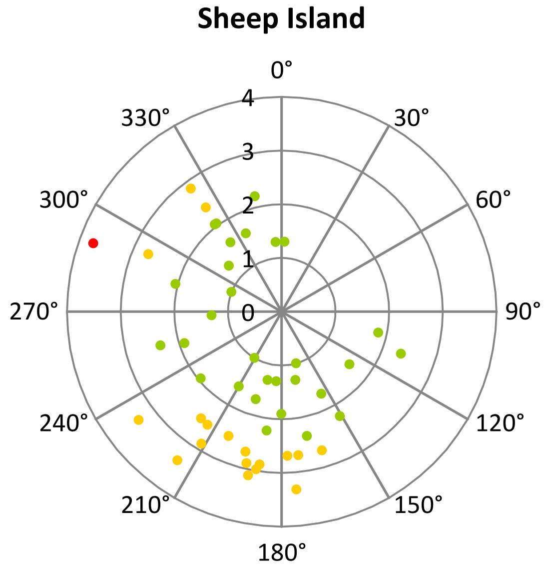

Figure XI.12: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) at Sheep Island (cockles) against high/low tidal state at Barrow (Ramsden Dock)

At Sheep Island, most of the samples were taken around low water and on the flood tide. There appears to be a slight tendency for higher results in samples taken nearer to low tide.

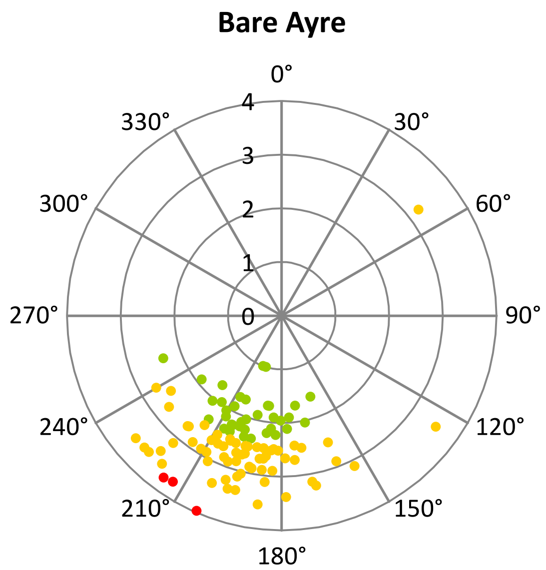

Figure XI.13: Polar plot of log$_{10}$ *E. coli* results (MPN/100g) at Bare Ayre (mussels) against high/low tidal state at Morecambe

Samples of mussels from Bare Ayre were nearly all taken at low tide, and no strong patterns are apparent in the polar plot.

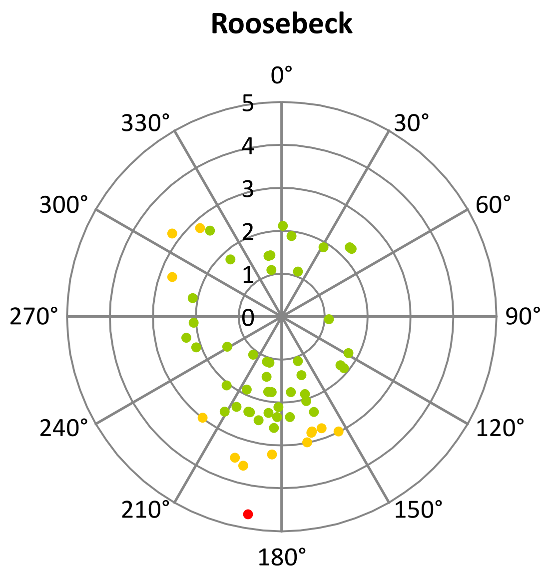

Figure XI.14: Polar plot of log$_{10}$ *E. coli* results (MPN/100g) at Roosebeck (Pacific oysters) against high/low tidal state at Morecambe

At Roosebeck, most of the higher results occurred in those samples taken around low water.

Figure XI.15 and Figure XI.16 present polar plots of log$_{10}$ *E. coli* results against the spring neap tidal cycle for the two RMPs for which a significant correlation was detected. 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.

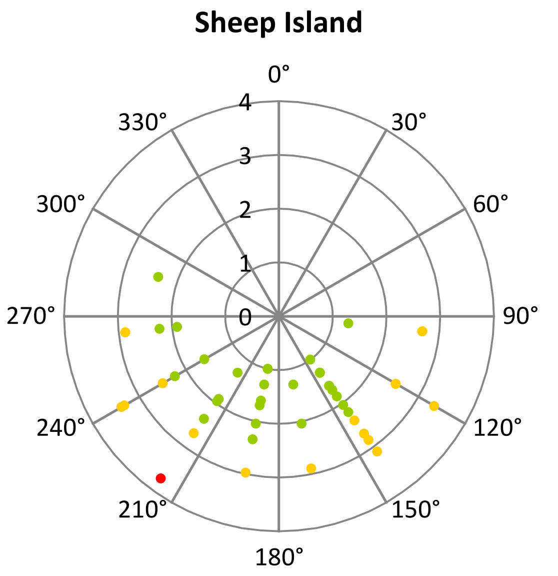

Figure XI.15: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) at Sheep Island (cockles) against spring/neap tidal state

Most samples of cockles from Sheep Island were taken during the decreasing tidal range, and no obvious patterns are apparent in the polar plot.

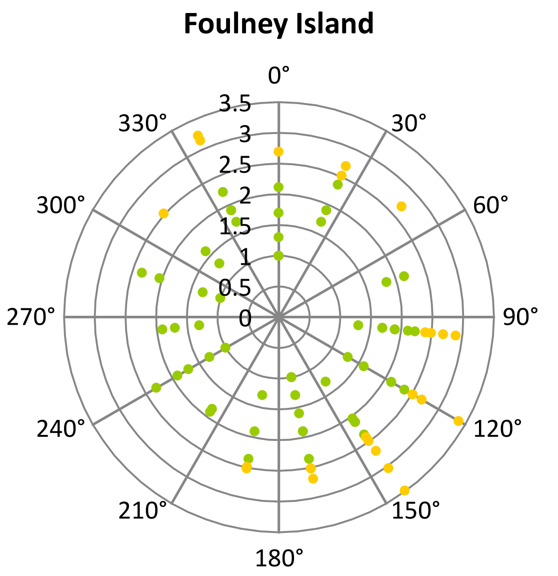

Figure XI.16: Polar plot of log10 *E. coli* results (MPN/100g) at Foulney Island (mussels) against spring/neap tidal state

Samples of mussels taken at Foulney Island tended to have lower *E. coli* levels during neap tides, possibly suggesting that the main contamination sources are located some distance from the RMP and only reach the site during periods of larger tidal excursions.

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 Grange 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.

Rainfall had a significant impact on *E. coli* levels in cockles at Newbiggin 1, Flookburgh 2 and Red Bank. These are the only three cockle monitoring points where prohibited level results have been recorded. *E. coli* levels in samples from all mussel RMPs except Foulney Island are affected by rainfall. It had no influence on levels of *E. coli* in Pacific oysters at Roosebeck.

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

	Site	Rampside Flats	Sheep Island	Newbiggin 1	Aldingham 4	Leven Island West 1	Leven Island East 2	Flookburgh 2	Flookburgh 3	Red Bank	Roa Island	Foulney Island	Cocken Tunnel	Bare Ayre	Roosebeck
	Species	Cockle									Mussel				Pacific oyster
	n	50	48	54	33	21	26	17	64	67	95	80	96	102	56
24 hour periods prior to sampling	1 day	0.021	0.069	0.325	0.295	-0.043	0.096	0.221	-0.057	0.237	0.040	0.159	0.072	0.015	-0.042
	2 days	0.171	0.029	0.152	0.115	0.202	0.091	0.473	0.127	0.336	0.203	0.054	0.199	0.115	0.004
	3 days	0.081	0.093	0.109	0.015	0.149	0.097	0.490	-0.059	0.241	0.184	0.126	0.228	0.051	-0.130
	4 days	0.247	0.161	0.039	0.037	0.216	0.341	0.331	0.296	0.326	0.105	0.132	0.156	0.290	0.089
	5 days	0.161	0.120	0.108	-0.114	0.139	0.344	0.467	0.108	0.261	0.111	0.176	0.173	0.148	-0.034
	6 days	0.344	0.279	-0.026	-0.217	0.058	0.168	0.625	-0.016	0.361	0.037	0.084	0.218	0.178	-0.143
	7 days	0.102	-0.064	0.167	-0.193	0.016	0.419	0.201	0.277	0.435	-0.038	-0.071	0.105	0.287	0.008
Total prior to sampling over	2 days	0.161	0.055	0.341	0.327	0.210	0.032	0.346	0.033	0.331	0.222	0.111	0.196	0.121	-0.043
	3 days	0.120	0.110	0.328	0.263	0.312	0.129	0.461	0.040	0.374	0.260	0.160	0.199	0.127	-0.030
	4 days	0.206	0.184	0.324	0.305	0.286	0.182	0.417	0.094	0.400	0.280	0.183	0.219	0.248	-0.021
	5 days	0.246	0.238	0.306	0.243	0.269	0.225	0.569	0.080	0.400	0.278	0.209	0.251	0.249	0.019
	6 days	0.264	0.252	0.297	0.202	0.204	0.202	0.561	0.065	0.423	0.224	0.207	0.272	0.276	-0.007
	7 days	0.210	0.211	0.331	0.169	0.190	0.220	0.550	0.081	0.461	0.193	0.210	0.294	0.323	0.040

Appendix XII. Shoreline Survey Report

Date (time):
21st May 2014 (08:30 – 15:30)
2nd September 2014 (08:00 – 14:30)
3rd September 2014 (08:00 – 15:00)
4th September 2014 (08:00 – 15:30)
16th October 2014 (08:30 – 15:30)

Cefas Officers:
Rachel Parks (22nd May, 2nd – 4th September South Lakeland, Barrow-in-Furness and Walney Island; 16th October, Roosebeck)
Alastair Cook (2nd – 4th September Lancaster, Barrow-in-Furness and Walney Island)
David Walker (3rd September South Lakeland, 16th October, Roosebeck)

Local Enforcement Authority Officers:
Sue Carey, Barrow Council (22nd May)
Joanne Alexander, Lancaster Council (2nd and 3rd September)
Allan Watson, North West and North East FSA Regional Office (2nd September)
Kevin Maher, North West and North East FSA Regional Office (3rd September pm)

Area surveyed:
See Figure XII.1.

Weather:
2nd September - Sunny, 21.1°C, wind bearing 157° at 3 km/h
3rd September – Overcast with sunny spells, 20.2°C, wind bearing 100° at 3 km/h
4th September - Overcast with sunny spells, 20.7°C, wind bearing 88° at 3 km/h
16th October – Overcast with sunny spells,

Tides:
Admiralty Totaltide predictions for Barrow (Ramsden Dock) (54°06'N 3°13'W). All times in this report are BST.

22/05/2014	02/09/2014	03/09/2014	04/09/2014	16/10/2014
High 04:50 7.7 m	High 04:43 8.0 m	High 05:44 7.6 m	High 07:02 7.4 m	High 05:37 7.2 m
High 17:28 7.2 m	High 17:14 7.7 m	High 18:21 7.5 m	High 19:42 7.5 m	High 18:08 7.2 m
Low 11:36 1.5 m	Low 11:25 2.6 m	Low 12:38 2.9 m	Low 01:14 2.9 m	Low 11:48 3.4 m
	Low 23:59 2.8 m		Low 13:55 2.9 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 shown in Figure XII.1.

XII.2. Description of Fishery

During the visit to Morecambe Bay it was possible to meet with representatives from all three local authorities and Mandy Knott from the NWIFCA. Information obtained from this meeting is presented in the shellfisheries description (Section 4).

XII.3. Sources of contamination

Sewage discharges

No continuous discharges were seen on the survey, however a couple of streams, to which Grange-over-Sands and Newbiggin (Leven) continuous and intermittent outfalls are thought to discharge to were sampled (observation 43, SL05 and observation 114, MB01). They both gave elevated *E. coli* concentrations of 14,000 and >2.0×10^4 cfu/100ml respectively which may suggest some sewage input. The sample from the Newbiggin stream was taken after a period of heavy rain and it is possible that the intermittent discharge it receives was in operation at the time.

The locations of seven intermittent discharges were confirmed (observations 4, 15, 45, 48, 71, 76 & 102) and two pipes thought to be intermittent outfalls were observed (observations 46 and 51). The majority of outlets were not flowing at the time of survey. Morecambe CSO (48, SL12) and Barrow WWTW overflow (76, B03) were flowing and contained *E. coli* concentrations of 5,900 and 1,600 cfu/100ml respectively. Heysham Village CSO (4) was submerged so it was not possible to see if it was discharging at the time of survey. Sandside sewage PS is thought to discharge to a small stream sampled on the survey (observation 56, SL09), it gave a low *E. coli* concentration of 210 cfu/100ml suggesting it was not operating at the time. The locations of Roa Island Treatment Works Mill Lane PS and Carr Lane PS were confirmed (observations 74, 80 & 84). A large pipe with a grid not shown on the permit database gave an elevated *E. coli* concentration of >2.0×10^4 cfu/100ml and a loading of 5.6×10^{10} cfu/day which is suggestive of sewage contamination. Sanitary debris was also observed in the channel the pipe was discharging to (observation 83).

The location of the South End Caravan Park private discharge was (observation 98) was confirmed. A possible (unpermitted) private discharge was observed discharging to the North Walney Channel adjacent to the mussel beds. It had a strong detergent smell and contained >2.0×10^4 *E. coli*/100ml (Observation 79, B05) suggesting some foul water input. A possible septic tank was observed in a field on South Walney but was not confirmed as such, and no outlet was visible (observation 92).

Sanitary debris was seen along the high water mark in several places in Morecambe Bay (observation 16, 78, 109, 122 & 128).

Freshwater inputs

Two rivers, the River Keer (observation 23, L06) and the River Winster (observation 54, SL11) were observed and sampled on the shoreline survey and gave low *E. coli* concentrations of 270 and 450 cfu/100ml. In addition to this numerous streams, culverted streams, drainage channel and springs discharge to Morecambe Bay (observations 19, 24, 29, 30, 32, 34, 39,40, 43, 44, 56, 63, 65, 67, 96, 104, 106, 108, 112, 114, 119, 126, 129, 135 & 136). Most of the freshwater inputs contained *E.* coli concentrations between 10 – 3,200 cfu/100ml. Much of the contamination in these streams is likely to be from runoff from grazing land. A culverted stream at Newbiggin thought to hold the outlets for Newbiggin intermittent and continuous discharges, gave an elevated *E. coli* concentration suggestive of faecal contamination (>2.0×10^4 cfu/100ml).

Livestock

A large proportion of land surrounding Morecambe Bay is used for grazing by sheep, cattle and horses (observations 5, 17, 18, 20 - 22, 24 – 28, 36, 38, 41, 42, 85-91, 93-95, 99, 101, 107, 111, 117, 118, 120, 130, 132 & 133). Livestock numbers observed ranged from between 3 and around 100. In some areas they were free to roam on the marshland and sand flats (observations 20, 25, 27, 36 & 101) and were able to enter streams and watercourses (observations 90 & 118). A manure heap next to a drainage ditch was seen at a farm in Newbiggin, (observation 117).

Wildlife

Large numbers of birds were observed throughout Morecambe Bay, generally on the intertidal flats (observations 6, 33, 35, 66, 105, 114 &124). The largest aggregation was observed at Newbiggin (observation 114) where thousands were observed on the sand flats. Dog walking was evident at several locations throughout the estuary particularly on public footpaths which ran adjacent to the shore (observation 64).

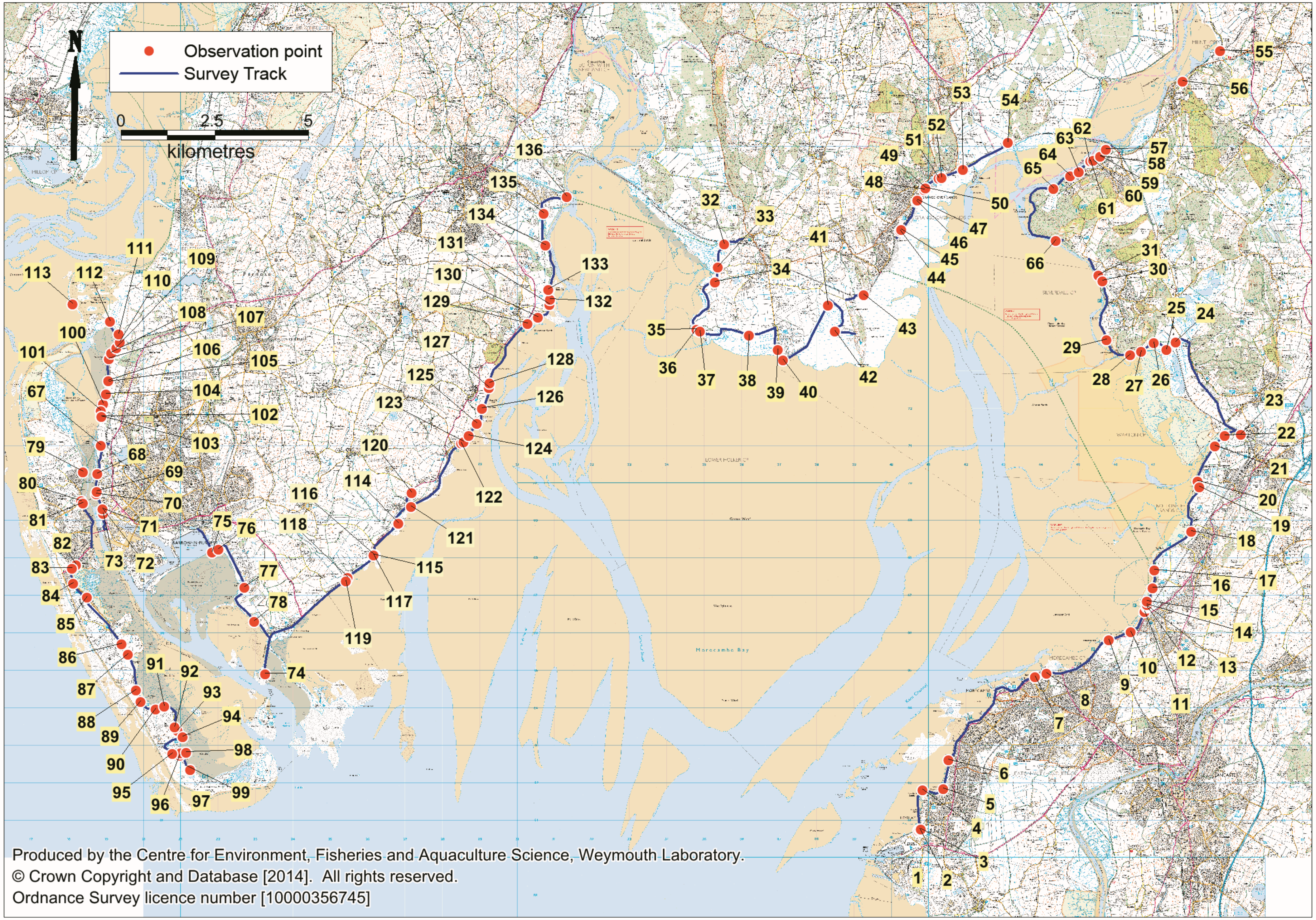

Figure XII.1: Locations of Shoreline Observations (Table XII.1 for details)

Table XII.1: Details of Shoreline Observations

Observation no	NGR	Date	Time	Description	Photo
1	SD4072160746	02/09/2014	08:57	Flap valve outfall (~750 mm) in sea wall behind grate. Not sampled (hardly any flow)	Figure XII.3
2	SD4075460772	02/09/2014	08:59	150 mm cast iron pipe not flowing	
3	SD4078160780	02/09/2014	09:01	150 mm cast iron pipe (11 secs to fill 200 ml pot). Sample L01	Figure XII.4
4	SD4082661826	02/09/2014	09:19	Sewer pipe, ~500 mm diameter, end underwater (Heysham Village CSO pipe)	
5	SD4137961853	02/09/2014	09:30	13 horses in field	
6	SD4152862628	02/09/2014	09:43	Several hundred gulls out on rocky/shingly area	
7	SD4383664855	02/09/2014	10:38	Location used by Lancashire Council for fishery observation	
8	SD4414864945	02/09/2014	10:45	About 30 small boats and 2 slightly larger yachts.	
9	SD4581565841	02/09/2014	11:33	Concrete encased pipe (~200 mm diameter) may be drainage from golf course on other side of road. Not flowing	
10	SD4639666058	02/09/2014	11:44	Concrete encased pipe from leisure centre, ~120 mm diameter, not flowing	
11	SD4676566591	02/09/2014	11:59	~600 mm diameter iron sewer pipe not flowing	Figure XII.5
12	SD4682666710	02/09/2014	12:02	~120 mm surface water drainage pipe not flowing	
13	SD4682566749	02/09/2014	12:03	~120 mm surface water drainage pipe not flowing	
14	SD4682666771	02/09/2014	12:04	~120 mm surface water drainage pipe not flowing	
15	SD4683166864	02/09/2014	12:06	Stream to beach via flap valve outfall and Hest Bank PS not flowing (0.3 m x 0.05 m x 0.205 m/s). Sample L02	Figure XII.6
16	SD4698267218	02/09/2014	12:17	Sanitary debris (rag)	
17	SD4701967700	02/09/2014	12:25	45 sheep in field	
18	SD4552775581	03/09/2014	13:03	7 horses in field.	
19	SD4564275429	03/09/2014	12:34	Stream discharging via flap valve. Also 60 sheep in fenced field (0.65 m x 0.14 m x 0.284 m/s). Sample L07	Figure XII.7
20	SD4574973860	03/09/2014	12:30	Sheep droppings on saltmarsh tide line	
21	SD4638273461	03/09/2014	12:10	Sewage works. 20 cattle in field in front	
22	SD4667673545	03/09/2014	12:02	3 cattle	
23	SD4701873778	03/09/2014	11:52	River Keer (5.8 m x 0.45 m x 0.388 m/s). Sample L06	Figure XII.8
24	SD4735273592	03/09/2014	10:55	Stream. Also 4 horses in field. Measured in 2 sections. (1 m x 0.05 m x 0.404 m/s + 0.7 m x 0.02 m x 0.085 m/s). Sample L05	Figure XII.9
25	SD4759073795	03/09/2014	10:48	30 sheep on saltmarsh. Dung in tide line.	

26	SD4933771323	03/09/2014	10:42	35 cattle	
27	SD4891371300	03/09/2014	10:34	Sheep droppings on saltmarsh	
28	SD4865171016	03/09/2014	10:28	6 cattle in field	
29	SD4818970077	03/09/2014	09:54	Spring on beach (0.65 m x 0.09 m x0.179 m/s). Sample L04	Figure XII.10
30	SD4822969917	03/09/2014	09:21	Spring on beach (0.85 m x 0.16 m x 0.323 m/s). Sample L03	Figure XII.11
31	SD4800768733	03/09/2014	09:12	50 mm blue plastic pipe down cliff from building. Dry.	
32	SD3552276414	02/09/2014	09:01	River Eea. Not accessible. Sample SL01	Figure XII.12
33	SD3535975804	02/09/2014	09:18	~300 birds on sandflats	
34	SD3527075400	02/09/2014	09:27	Stream flowing through sluice gate. Not accessible. Sample SL02	Figure XII.13
35	SD3478674135	02/09/2014	10:08	~400 birds on sandflats	
36	SD3478674135	02/09/2014	10:08	~60 sheep on marsh and sandflats	Figure XII.14
37	SD3487674087	02/09/2014	10:13	Pile of dead cockle shells	Figure XII.15
38	SD3619273982	02/09/2014	10:43	~ 40 sheep	
39	SD3696373592	02/09/2014	11:30	Drainage channel, very low flow. Sample SL03	Figure XII.16
40	SD3708973321	02/09/2014	11:45	Sluice gate flowing. Field drainage behind caravan site (7.5 secs for a small twig to travel 1 m). Sample SL04	Figure XII.17
41	SD3829674782	02/09/2014	12:41	~ 90 cows	
42	SD3847974083	02/09/2014	13:02	~ 20 sheep	
43	SD3925375059	02/09/2014	13:47	Stream with Grange-Over-Sands continuous sewage outfall. Sample SL05	Figure XII.18
44	SD4438676505	03/09/2014	12:51	Drainage channel flowing (5.36 secs for a small twig to travel 1 m). Sample SL11	Figure XII.19
45	SD4432777893	03/09/2014	12:59	Cart Lane Intermittent - not flowing	
46	SD4478278227	03/09/2014	13:14	Pipe with flap - not flowing (possibly Promenade CSO)	
47	SD4500578342	03/09/2014	13:16	Pipe with flap - not flowing	
48	SD4530378625	03/09/2014	13:21	1 m pipe flowing (Morecambe CSO), 300 mm valved pipe above not flowing (1.66 secs for a small twig to travel 1 m). Sample SL12	Figure XII.20
49	SD4531878635	03/09/2014	13:27	2 x 400 mm valved pipes not flowing	
50	SD4538678644	03/09/2014	13:28	2 x 100 mm pipes not flowing	
51	SD4558178757	03/09/2014	13:35	300 mm pipe not flowing (possibly Grange SPS)	
52	SD4558178758	03/09/2014	13:38	Pipe flowing through marsh	
53	SD4572478951	03/09/2014	13:48	Pipe flowing (3.5 secs for a small twig to travel 1 m). SL13	
54	SD4778680757	03/09/2014	14:18	River Winster. Flowing. Too large to measure. Sample SL14	Figure XII.21

55	SD4878881577	03/09/2014	11:39	Milnthorpe Continuous flowing into River Bela. Sample SL10	Figure XII.22
56	SD4023076764	03/09/2014	11:21	Stream - very low flow. Sample SL09 (possible Sandside Sewage PS discharge)	
57	SD4026376805	03/09/2014	10:44	Arnside United Utilities Pumping Station	Figure XII.23
58	SD4066677552	03/09/2014	10:35	Manhole cover - no visible pipes	
59	SD4069377594	03/09/2014	10:34	Pipe flowing. Sample SL08	Figure XII.24
60	SD4086977871	03/09/2014	10:30	series of drainage pipes	
61	SD4090077907	03/09/2014	10:27	Manhole cover on beach - no visible pipes	
62	SD4090777913	03/09/2014	10:25	300 mm Pipe with flap not flowing	
63	SD4125478166	03/09/2014	10:14	Stream flowing (0.1 m x 0.07 m x 0.529 m/s). Sample SL07	Figure XII.25
64	SD4134178195	03/09/2014	10:09	Dog walkers	
65	SD4190578402	03/09/2014	09:53	Stream flowing through marsh (0.17 m x 0.05 m x 0.389 m/s). Sample SL06	Figure XII.26
66	SD4311079131	03/09/2014	09:07	~ 30 birds on the flats	
67	SD1892069215	04/09/2014	09:24	Culverted stream flowing (0.5 m x 0.04 m x 0.237 m/s). Sample B02	Figure XII.27
68	SD1891069302	04/09/2014	09:06	600 mm pipe with flap not flowing	
69	SD1889769332	04/09/2014	08:56	Possible pipe covered by the tide	Figure XII.28
70	SD1873169743	04/09/2014	08:51	Large pipe with flap flowing (0.4 m x 0.01 m x 0.581 m/s). Sample B01	Figure XII.29
71	SD1874169797	04/09/2014	08:43	1500 mm pipe with flap not flowing (Graving Dock Barrow Island Intermittent)	
72	SD1876570272	04/09/2014	08:42	3 x pipes not flowing - 2x 100 mm, 1 x 400 mm with flap	
73	SD1885571030	04/09/2014	08:39	400 mm pipe with flap not flowing	
74	SD2324964930	04/09/2014	10:18	Roa Island Treatment Works	
75	SD2182568176	04/09/2014	10:55	Manhole cover	
76	SD2200168261	04/09/2014	10:59	Large pipe with flap flowing (0.4 m/s approximate estimate - as not accessible) Barrow WWTW Intermittent. Sample B03	Figure XII.30
77	SD2269967247	04/09/2014	11:25	750 mm pipe with flap flowing (0.25 m x 0.01 m x 0.035 m/s). Sample B04	Figure XII.31
78	SD2296366336	04/09/2014	11:47	Cotton wool buds	
79	SD1838170323	04/09/2014	12:53	Possible private discharge, gently flowing, cloudy discharge with a smell of detergent. Sample B05	Figure XII.32
80	SD1833669545	04/09/2014	13:12	Mill Lane Pumping Station	
81	SD1836969498	04/09/2014	13:13	Small pipe through marsh - not flowing	
82	SD1819567837	04/09/2014	13:33	Manhole covers	

83	SD2032563980	04/09/2014	14:56	Pipe with flat valve and grid - sanitary towel visible in channel (0.8 m x 0.07m x 0.029 m/s). Sample B06	Figure XII.33
84	SD2083463508	04/09/2014	14:35	Carr Lane Pumping station	Figure XII.34
85	SD2096662757	04/09/2014	14:32	5 horses in field	
86	SD2098562811	04/09/2014	14:29	~ 30 cows in field	
87	SD2114362837	04/09/2014	14:29	~ 15 sheep and 1 horse in field	
88	SD2125162370	04/09/2014	14:27	~ 25 cows in field	
89	SD2076662796	04/09/2014	14:26	~100 sheep in field	
90	SD2104463241	04/09/2014	13:46	Tidal creek not flowing - ~ 80 sheep in the field adjacent	Figure XII.35
91	SD2091163414	04/09/2014	14:24	~100 sheep in field	
92	SD2055364065	04/09/2014	13:52	Septic tank in field - no outfall apparent	Figure XII.36
93	SD1991164188	04/09/2014	14:22	~10 sheep & 3 horses in field	
94	SD1979964499	04/09/2014	14:22	~11 sheep in field	
95	SD1957965455	04/09/2014	14:19	~40 cows and ~25 sheep in field	
96	SD1940565725	04/09/2014	14:00	Culverted stream/ tidal creek not flowing	
97	SD1848166985	04/09/2014	14:02	Caravan park sewage pumping station	
98	SD1811867354	04/09/2014	14:06	Pipe - very low flow - private discharge from caravan park & hoof marks on the marsh	
99	SD1808767746	04/09/2014	14:16	~15 cows in field	
100	SD1891872142	21/05/2014	09:56	Large pipe flowing (brown water). Sample DR8 (0.45 m x0.05 m x.112 m/s)	Figure XII.37
101	SD1885971959	21/05/2014	10:09	~ 12 sheep on beach	
102	SD1887171804	21/05/2014	10:14	Palace Nook Intermittent - Not flowing	Figure XII.38
103	SD1887171804	21/05/2014	10:14	Small pipe to the side of intermittent – flowing. Sample DR9 (0.38 m x 0.03 m x 0.12 m/s)	Figure XII.39
104	SD1899972402	21/05/2014	10:33	Stream (possibly with Sowerby Lodge Farm private discharge). Sample DR10 (0.16 m x 0.05 m x 0.119 m/s)	Figure XII.40
105	SD1906372726	21/05/2014	10:45	~30 birds on the sandflats in the middle of the channel	
106	SD1906272767	21/05/2014	10:47	Stream flowing. Sample DR11 (0.72 m x0.07 m x 2.291 m/s)	Figure XII.41
107	SD1907673353	21/05/2014	11:08	1 cow seen in field	
108	SD1913273494	21/05/2014	11:12	Stream – Flowing. Sample DR12 (0.41 m x 0.06 m x 0.011 m/s)	Figure XII.42
109	SD1926573644	21/05/2014	11:32	Sanitary debris along HW mark	

110	SD1935873794	21/05/2014	11:40	2 x concrete pipes - Flowing fast. Sample DR13	Figure XII.43
111	SD1933474002	21/05/2014	11:52	~50 sheep in field	
112	SD1910274341	21/05/2014	11.58	Red Gutter Stream – Flowing. Sample DR14 (1.18 m x 0.08 m x 2.439 m/s)	
113	SD1810274815	21/05/2014	13:00	Lots of cockle shells	
114	SD2680468950	16/10/2014	08:38	Culverted stream, flowing. Sample MB01. Measured in three sections (0.3 m x 0.05 m x 0.219 m/s + 1.2 m x 0.19 m x 0.578m/s + 0.4 m x 0.13 m 0.629m/s). Thousands of birds all along intertidal flats. Cockle and mussel shells.	Figure XII.44
115	SD2617268105	16/10/2014	08:53	2 x pipes with flaps (~800 mm wide), not flowing	Figure XII.45
116	SD2616768096	16/10/2014	08:55	1 x pipe (300 mm wide), not flowing	
117	SD2614468098	16/10/2014	08:57	Cattle farm with drainage ditch and manure heap behind	
118	SD2545767505	16/10/2014	09:00	~50 sheep in the field and ~40 cows, can access drainage ditch stream	
119	SD2541467410	16/10/2014	09:03	Culvert/drainage from fields, flowing. Sample MB02 (0.08 m x 0.95 m x0.112m/s)	Figure XII.46
120	SD2716869770	16/10/2014	09:28	Sheep & donkeys in fields	
121	SD2715869394	16/10/2014	09:38	Pipe flowing. Sample MB03 (0.75 m x 0.09 m x 0.231 m/s)	Figure XII.47
122	SD2849971089	16/10/2014	10:23	Cotton wool buds	
123	SD2855571124	16/10/2014	10:25	Broken pipe flowing. Sample MB04 (0.10 m x0.45 m x 0.158 m/s)	Figure XII.48
124	SD2869971297	16/10/2014	10:35	~ 300 birds on intertidal flats	
125	SD2890271615	16/10/2014	10:42	Potential shellfish harvesting activity	
126	SD2904972017	16/10/2014	10:52	Stream flowing. Sample MB05 (0.35 m x 0.08 m x0.599 m/s)	Figure XII.49
127	SD2923772582	16/10/2014	11:15	Drainage pipes under houses	
128	SD2925472700	16/10/2014	11:18	Cotton wool buds	
129	SD3026974287	16/10/2014	11:56	Stream. Sample MB06 (0.35 m x 0.18 m x 0.135 m/s)	
130	SD3054274451	16/10/2014	12:05	100 sheep in field	
131	SD3085374802	16/10/2014	12:19	Pipe and stream, flowing. Sample MB07 (0.25 m x 0.05 m x 0.243 m/s)	Figure XII.50
132	SD3085974936	16/10/2014	12:28	4 horses in field	
133	SD3082275191	16/10/2014	12:32	24 cows in field	
134	SD3074176377	16/10/2014	13:04	Large pipe with flap (1 m) submerged, not flowing	
135	SD3069277227	16/10/2014	13:20	Sluice gate, not flowing	
136	SD3131777686	16/10/2014	13:39	Canal, no lock, but a couple of overflow pipes. Sample MB08	

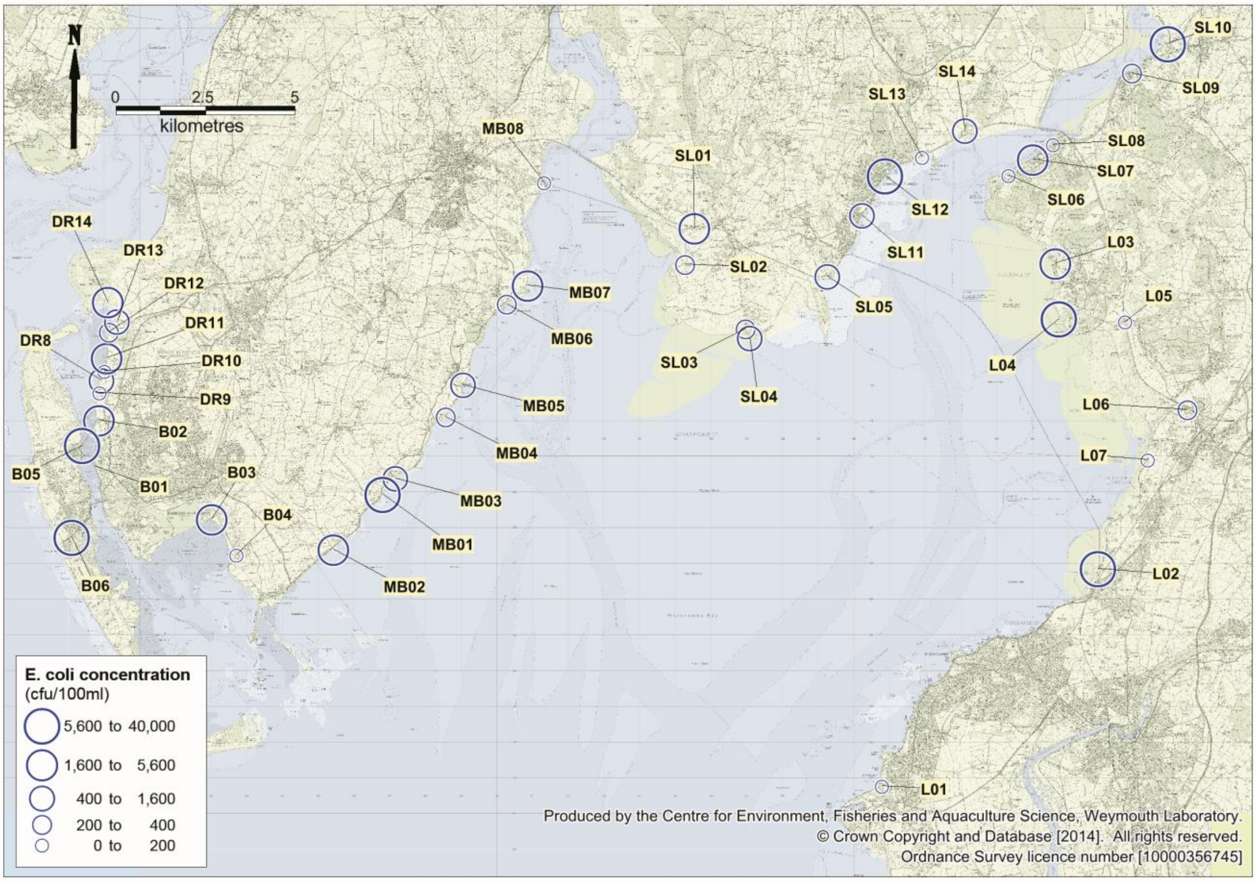

Figure XII.2: Water sample results (Table XII.2 and Table XII.1 for details)

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

Sample ID	Observation number	Date	Description	*E. coli* concentration (cfu/100 ml)	Flow (m^3/s)	*E. coli* loading (cfu/day)
L01	3	02/09/2014	150 mm cast iron pipe	31	$1.82x10^{-5}$	$4.87x10^{5}$
L02	15	02/09/2014	Stream to beach via flap valve outfall	>20,000	0.00308	$>5.31x10^{10}$
L03	30	02/09/2014	Spring on beach	500	0.0439	$1.90x10^{10}$
L04	29	02/09/2014	Spring on beach	5,600	0.0105	$5.07x10^{10}$
L05	24	02/09/2014	Stream	87	0.0214	$1.61x10^{9}$
L06	23	03/09/2014	Stream	270	1.01	$2.36x10^{11}$
L07	19	03/09/2014	Stream discharging via flap valve	87	0.0258	$1.94x10^{9}$
SL01	32	02/09/2014	Stream flowing	2,900	Not measured	
SL02	34	02/09/2014	Stream flowing through sluice gate	220	Not measured	
SL03	39	02/09/2014	Drainage channel, very low flow	220	Not measured	
SL04	40	02/09/2014	Sluice gate flowing. Field drainage behind by caravan site	1,000	0.00613	$5.30x10^{9}$
SL05	43	02/09/2014	Stream with Grange-Over-Sands continuous sewage outfall	1,400	Not measured	
SL06	65	03/09/2014	Stream flowing through marsh	150	0.00331	$4.29x10^{8}$
SL07	63	03/09/2014	Stream flowing	2,500	0.0037	$8.00x10^{9}$
SL08	59	03/09/2014	Pipe flowing	31	Not measured	
SL09	56	03/09/2014	Stream with possible intermittent - very low flow	210	Not measured	
SL10	55	03/09/2014	Milnthorpe STW flowing into River Bela	17,000	Not measured	
SL11	44	03/09/2014	Drainage channel flowing	1,200	0.00821	$8.51x10^{9}$
SL12	48	03/09/2014	1 m pipe flowing, 300 mm valved pipe above not flowing	5,900	0.0979	$4.99x10^{11}$
SL13	53	03/09/2014	Pipe flowing	53	0.0111	$5.10x10^{8}$
SL14	54	03/09/2014	River Winster. Flowing	450	Not measured	
B01	70	04/09/2014	Large pipe with flap flowing	ND	0.00232	
B02	67	04/09/2014	Culverted stream flowing	3,200	0.00474	$1.31x10^{10}$
B03	76	04/09/2014	Large pipe with flap flowing	1,600	0.015	$2.07x10^{10}$
B04	77	04/09/2014	750 mm pipe with flap flowing	53	$8.75x10^{-5}$	$4.01x10^{6}$
B05	79	04/09/2014	Possible private discharge, gently flowing, cloudy, detergent smell	>20,000	Not measured	

B06	83	04/09/2014	Pipe with flat valve and grid - sanitary towel visible in channel	>20,000	0.00162	$>2.81x10^{10}$
DR8	100	21/05/2014	Large pipe flowing (brown water)	1,300	0.00252	$2.83x10^{9}$
DR9	103	21/05/2014	Small pipe to the side of intermittent - flowing	42	0.00137	$4.96x10^{7}$
DR10	104	21/05/2014	Stream (possibly with private discharge)	120	0.000952	$9.87x10^{7}$
DR11	106	21/05/2014	Stream flowing	2,000	Not measured	
DR12	108	21/05/2014	Stream	270	0.000271	$6.31x10^{7}$
DR13	110	21/05/2014	2 x concrete pipes - Flowing fast	1,300	Not measured	
DR14	112	21/05/2014	Red Gutter Stream	2,900	Not measured	
MB01	114	16/10/2014	Culverted stream, flowing	>20,000	0.168	$>2.90x10^{12}$
MB02	119	16/10/2014	Culvert/drainage from fields	5,000	0.00851	$3.68x10^{10}$
MB03	121	16/10/2014	Pipe flowing	420	0.0156	$5.66x10^{9}$
MB04	123	16/10/2014	Broken pipe flowing	200	0.00711	$1.23x10^{9}$
MB05	126	16/10/2014	Stream flowing	450	0.0168	$6.52x10^{9}$
MB06	129	16/10/2014	Stream/intermittent	200	0.00851	$1.47x10^{9}$
MB07	131	16/10/2014	Pipe and stream, flowing	4,300	0.00304	$1.13x10^{10}$
MB08	136	16/10/2014	Canal, no lock, but a couple of overflow pipes	10	Not measured	

Figure XII.3

Figure XII.4


Figure XII.5

Figure XII.6

Figure XII.7

Figure XII.8

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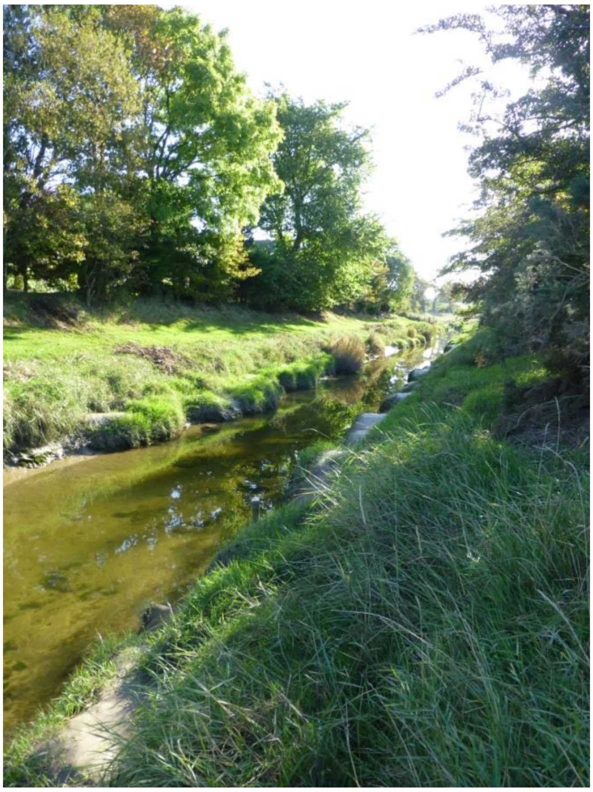
Figure XII.11



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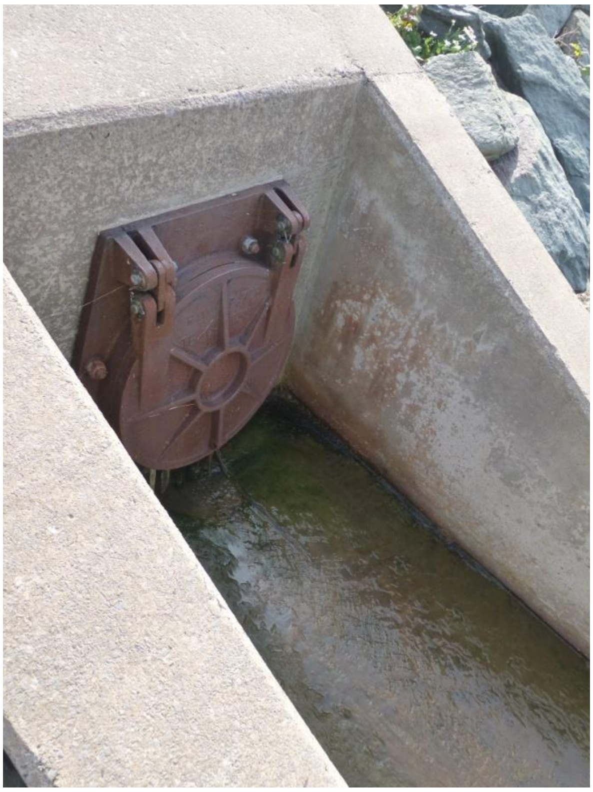

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Figure XII.47

Figure XII.48

Figure XII.49


Figure XII.50

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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
ppt	parts per thousand
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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