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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Duddon

August 2014

Food Standards Agency

Cover photo: View of the estuary from Askam-in-Furness

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Statement of use

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

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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 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 coastalwaters are required in order to establish the appropriate representative monitoring points (RMPs) for the monitoring programme.

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

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

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

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

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

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

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

This report documents the information relevant to undertake a sanitary survey for mussels (*Mytilus* spp.) and cockles (*Cerastoderma edule*) within the Duddon estuary. The area was prioritised for survey in 2014-15 by a shellfish hygiene risk ranking exercise of existing classified areas.

1.2. Area Description

The Duddon estuary is a large estuary, covering an area of approximately 45 km² (Futurecoast, 2002), and is situated on the Cumbrian coast (Figure 1.1).

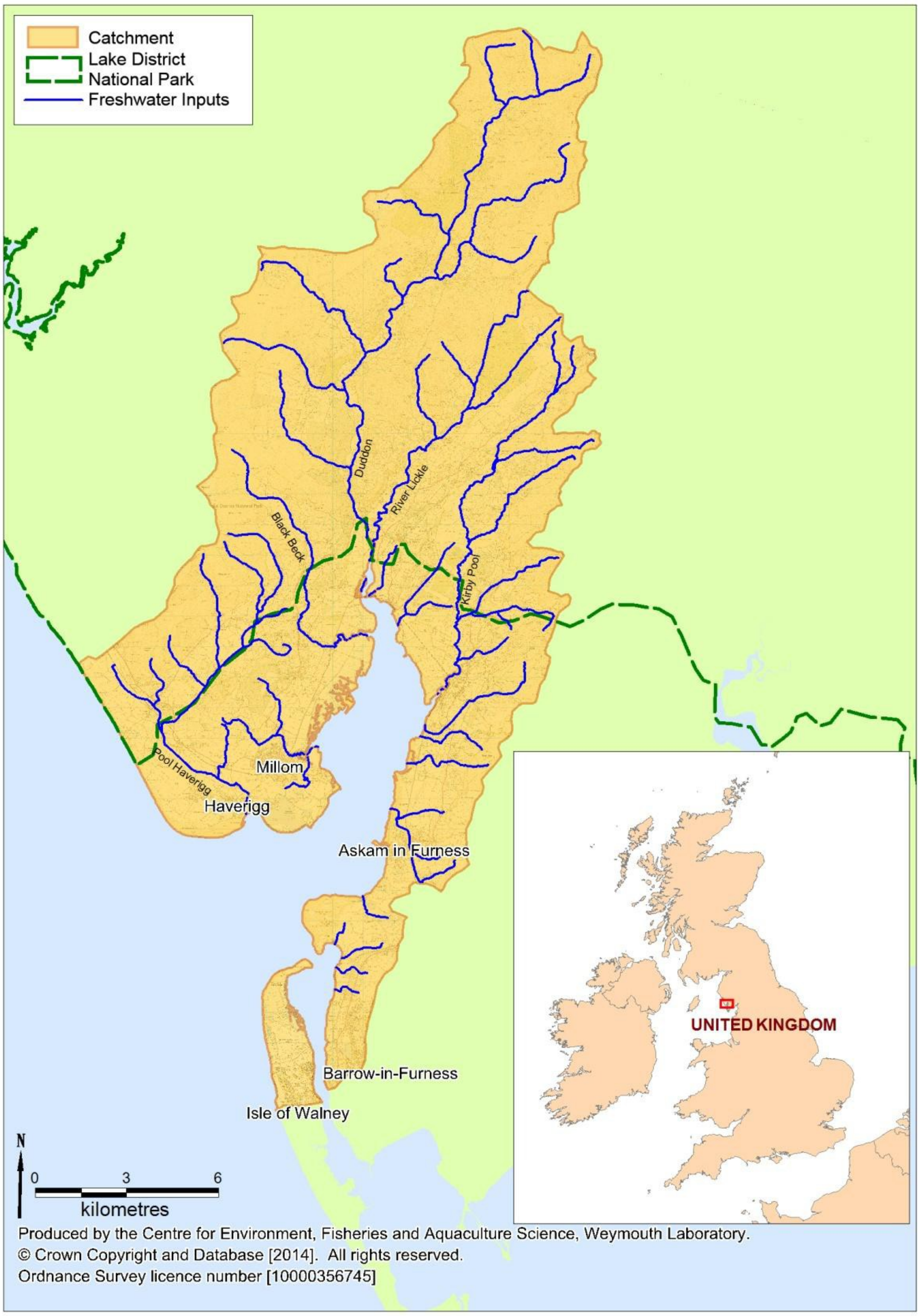


Figure 1.1: Location of the Duddon Estuary

The Duddon estuary lies in a rural setting on the edge of the Lake District National Park. The small towns of Millom and Askam lie opposite one another on the shores of its middle reaches. The local economy is largely based on tourism, farming and fishing. The majority of the estuary comprises of intertidal sandflats, with only a narrow river channel at low tide. Its upper reaches are flanked by extensive areas of saltmarsh. These habitats support significant wildlife populations, and there are several conservation designations within the survey area including a European Marine Site, Special Protection Area (SPA), Special Area of Conservation (SAC), Site of Special Scientific Interest (SSSI), a Ramsar site, three nature reserves and Hodbarrow Lagoon RSPB Nature Reserve.

The estuary receives freshwater inputs from the River Duddon and a number of smaller watercourses. Its mouth faces the Irish Sea to the south west, and there is also a connection to the Morecambe Bay via the Walney Channel. The estuary currently supports a commercially active wild mussel bed in its outer reaches, and every few years there are major settlements of cockles off Askam which attract high levels of commercial harvesting.

1.3. Catchment

Figure 1.2 illustrates land cover within the hydrological catchment which covers an area of approximately 266 km².

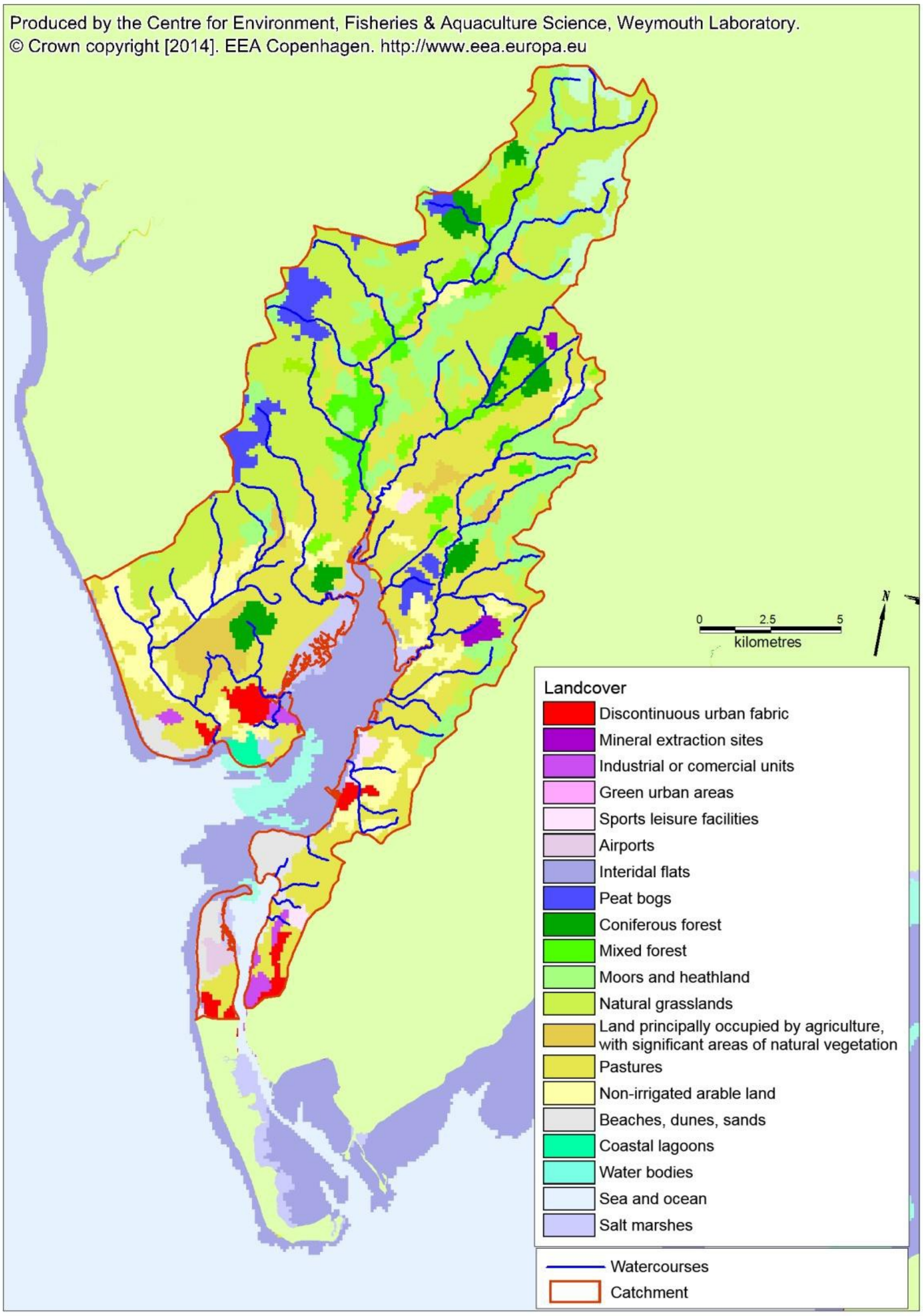


Figure 1.2: Landcover in the Duddon catchment

It is predominantly covered by rural land including moors, heathland and grassland interspersed with woodland and agricultural land in the upper catchment and a mixture of pasture and arable land in the lower catchment. There are some small areas of urbanised land situated close to the coast and these represent the towns of Haverigg, Millom, and Askam-in-Furness. Barrow-in-Furness lies on the mainland shore of the Walney Channel, although most of this town lies to the south of the hydrological catchment considered in this survey.

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

The hydrogeology is described as being of very low permeability throughout most of the catchment, with moderate permeability in the Askam and Millom areas, and higher permeability in the Barrow area (NERC, 2012). Elevations in the upper catchment reach almost 800 m, and the estuary itself lies in a valley flanked by hillsof up to 600 m in height. The relatively steep topography and impermeable geology result in flashy river flows that respond rapidly to rainfall (Environment Agency, 2009).

2. Recommendations

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

2.1. Cockles

The following two zones are proposed for cockles:

Askam. This zone lies to the east of the river channel. It extends from Roanhead in the south through to Dunnerholme Rock in the north, and is where commercial cockle beds form during the occasional years of heavy settlements. Most contaminating influences are up-estuary (e.g. land runoff, Broughton-in-Furness STW). The most significant point source direct to the zone is the Blea Beck, which receives effluent from Askam STW and two intermittent discharges. There are two much smaller freshwater inputs to this zone south of Blea Beck, one of which receives effluent from the (very small) Roanhead STW. There are also a small number of boat moorings off the Askam seafront. It is therefore recommended that the RMP for this zone is located as close to the drainage channel of the Blea Beck, and as far inshore as stocks extend. Aerial photography indicates that this channel lies about 350 m to the north of the edge of the main cockle bed when it was last opened for commercial harvest, although the location of both the channel and the cockles are variable.

Lowsy Point. This area has historically supported settlements of a commercially exploitable density, but over only a small area, and it was not classified when the main bed at Askam was last classified. This area will be under the influence of both the ebb plume from the Walney Channel and that from the main estuary. The northern part of the Walney Channel receives several intermittent discharges, and some minor freshwater inputs. Whilst the main estuary receives contamination from more and larger sources, Lowsy Point is remote from these and in the very outer reaches where there is much more influence from the cleaner waters of the open sea. It is therefore recommended that the RMP be located at the south eastern extremity of this bed, if a classification is ever required here.

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 every 5-10 years, but when it does a high level of effort is anticipated, so classifications must be in place before the fishery opens. Not all beds/zones may require classification when such an event does occur.
- The sampling interval should be monthly. The months of May and June may be omitted assuming all other 10 months are sampled 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. 20 mm minimum landing size).
- Samples should be hand gathered.
- A tolerance of 100 m applies to ensure that there are sufficient stocks for repeated sampling.

2.2. Mussels

Duddon Sands The current zone boundaries adequately cover the mussel bed, whilst not extending into potentially more contaminated areas. As such no changes to the zone boundaries are required. The majority of contamination delivered to this site will originate from up-estuary sources, so the RMP should be moved slightly to the upstream extremity of the bed. The sampling interval should be monthly, and sampling should be undertaken all year round. Samples should be of animals of a harvestable size (45 mm), and should be hand gathered. Given the dense covering of mussels, a tolerance of 10 m should be sufficient to allow for repeated sample collection.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Duddon
Cefas Main Site Reference	M052
Ordnance survey 1:25,000 map	Explorer OL6
Admiralty Chart Nos.	1320

Shellfishery

Species/culture	Mussels	Wild
	Cockles	Wild
Seasonality of harvest	Cockle fishery is currently closed due to low stock levels. Closed season for cockles 1st May to 31st August when fishery is in operation. No closed season for mussels.	

Local Enforcement Authorities

Name	Environmental Health Department Barrow-in-Furness Borough Council Town Hall Duke Street Barrow-in-Furness Cumbria LA14 2LD
Environmental Health Officer	Sue Carey
Telephone number ☎	01229 876378
Fax number 🖷	01229 894217
E-mail 🖃	scarey@barrowbc.gov.uk

3.2. Requirement for Review

The Guide to Good Practice for the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas (EU Working Group on the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas, 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 the Duddon

Classification zone	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Duddon Sands	B052E	Duddon channel upstream end	SD 1706 7656	54° 10.686'N 03° 16.334'W	Mussels	Wild	Hand	Hand	10 m	Monthly	RMP moved slightly to upstream extremity of mussel bed.
Askam	B052F	Blea Beck Channel	SD 2079 7874	54° 11.896'N 03° 12.940'W	Cockles	Wild	Hand	Hand	100 m	10 samples at least 1 week apart for provisional classification. Monthly thereafter	Only requires classification if and when the IFCA identify the prospect of a fishery opening. Both the channel and cockle beds are mobile so exact location may require some adjustment.
Lowsy Point	B052G	Lowsy South East	SD 1803 7417	54° 09.406'N 03° 15.403'W	Cockles	Wild	Hand	Hand	100 m	10 samples at least 1 week apart for provisional classification. Monthly thereafter	Only requires classification if and when the IFCA identify the prospect of a fishery opening. This area may not attract commercial cockle settlements as regularly as the main bed at Askam.

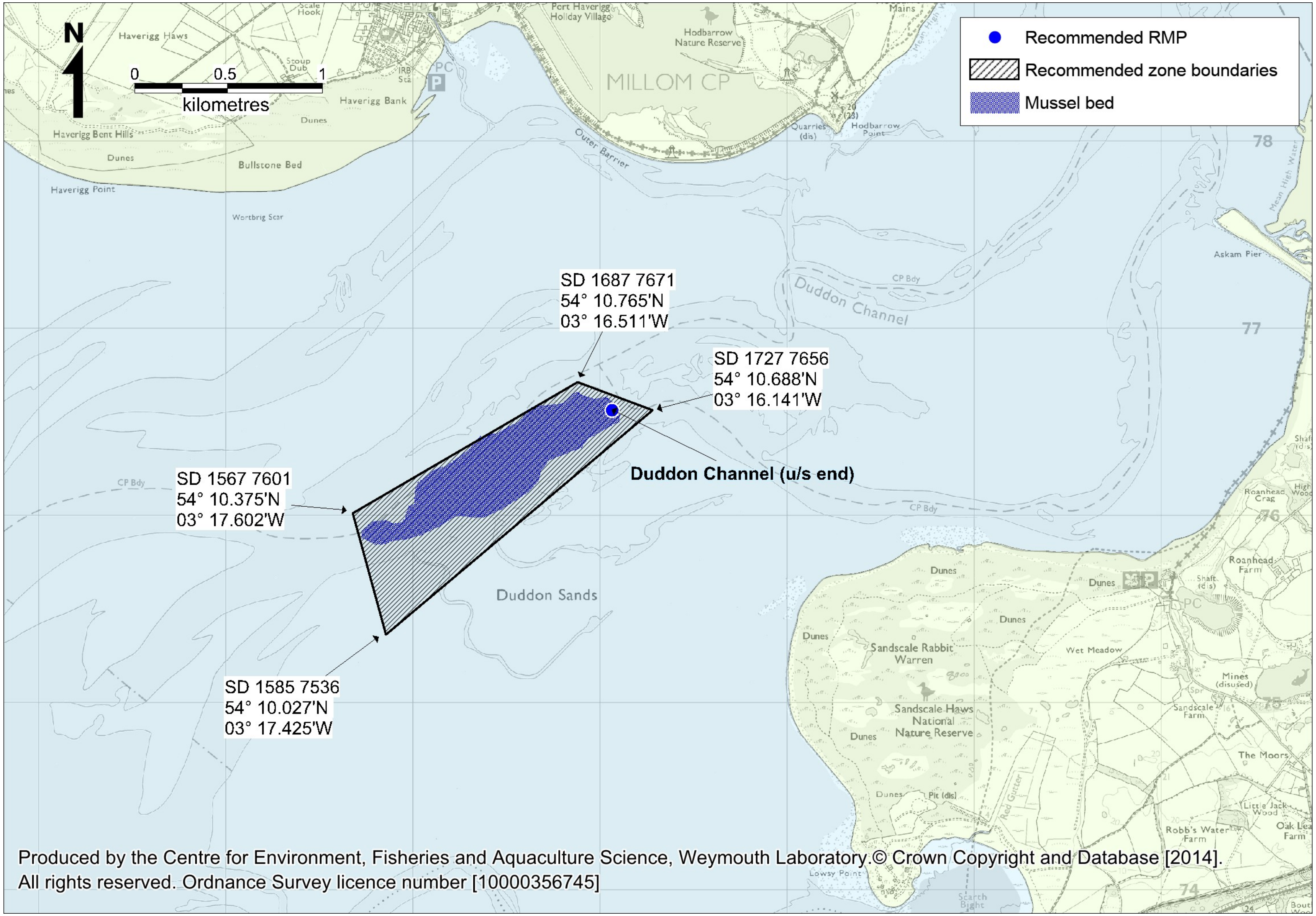


Figure 3.1: Recommended zoning and monitoring arrangements (mussels)

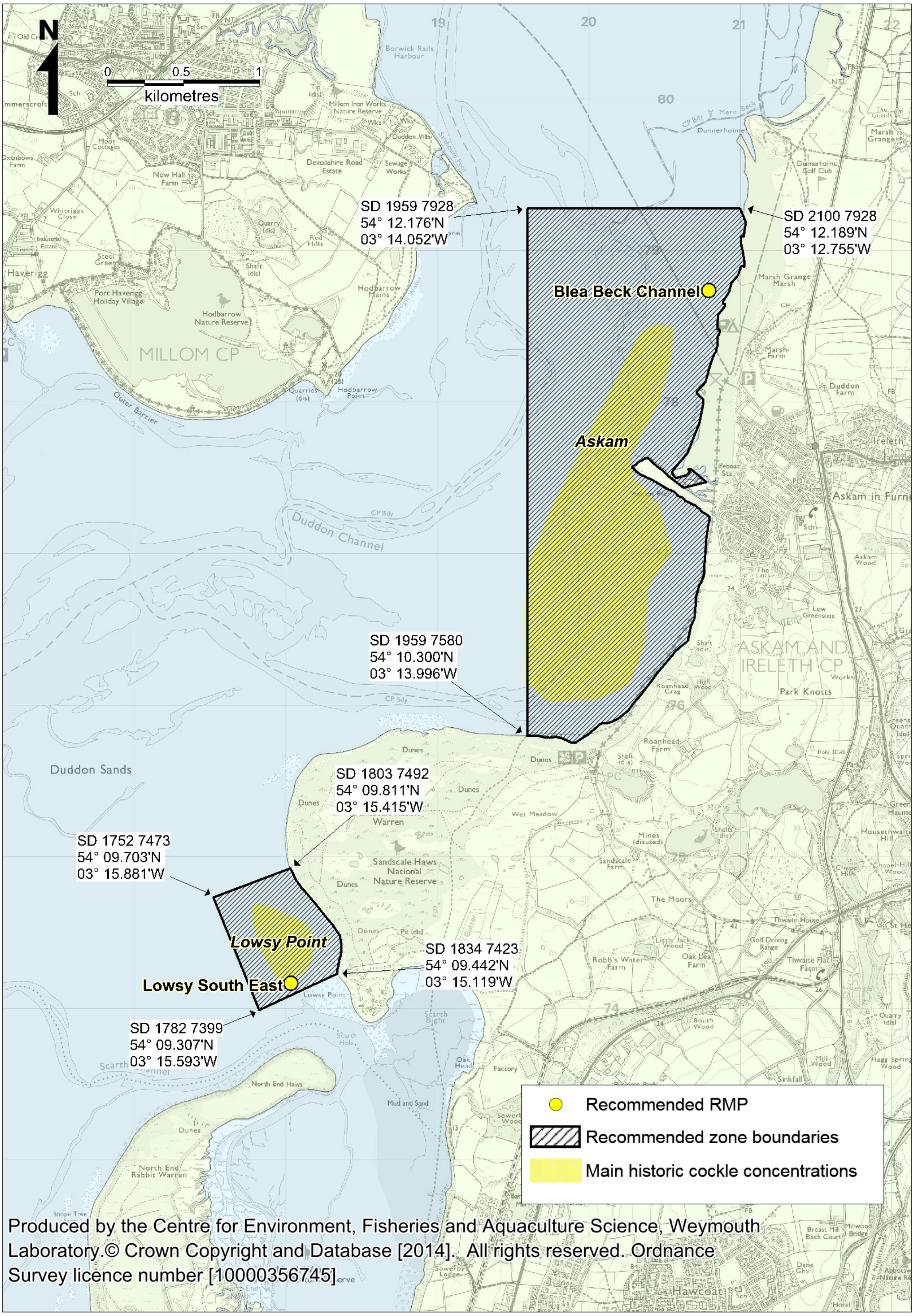


Figure 3.2: Recommended zoning and monitoring arrangements (cockles)

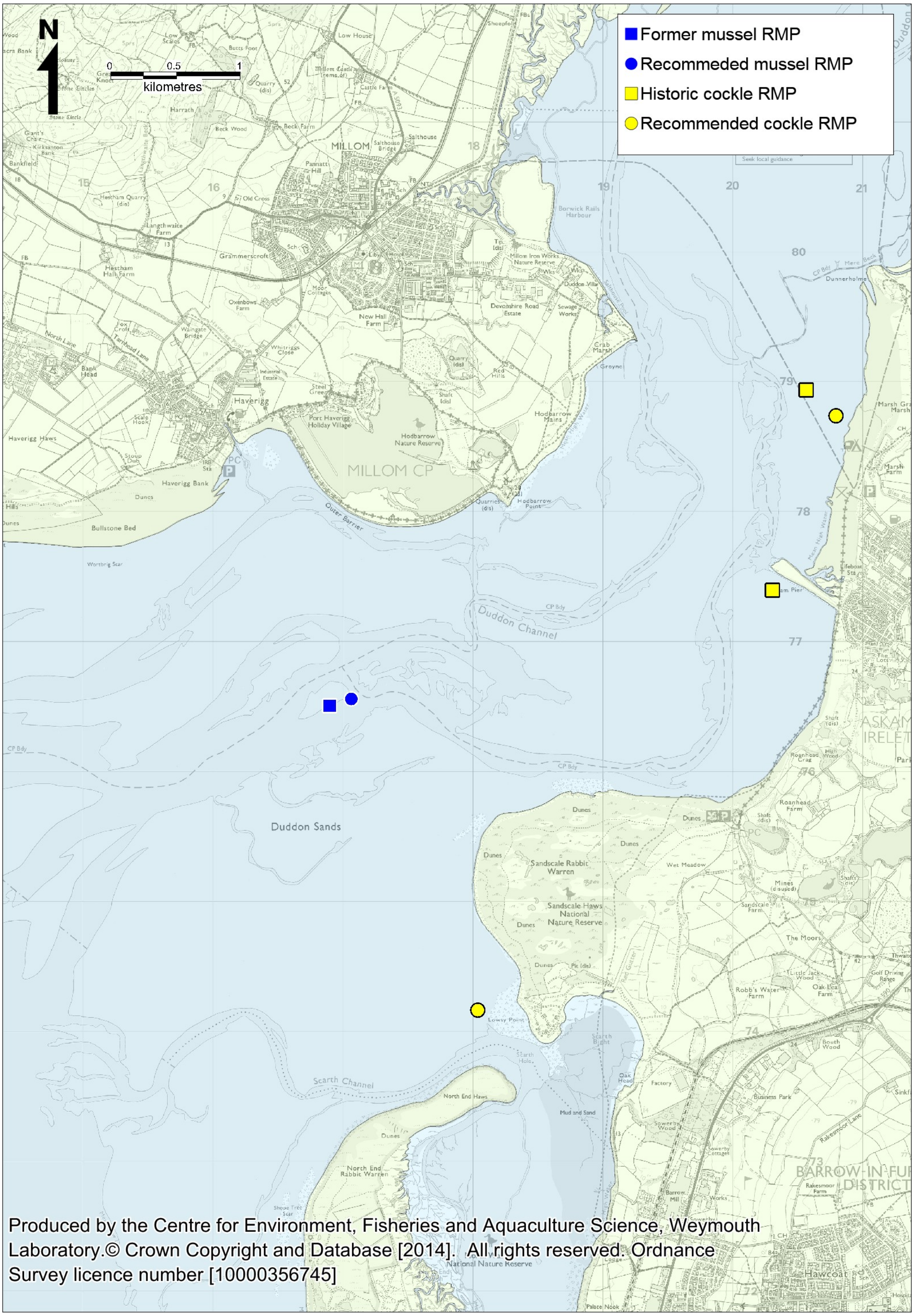


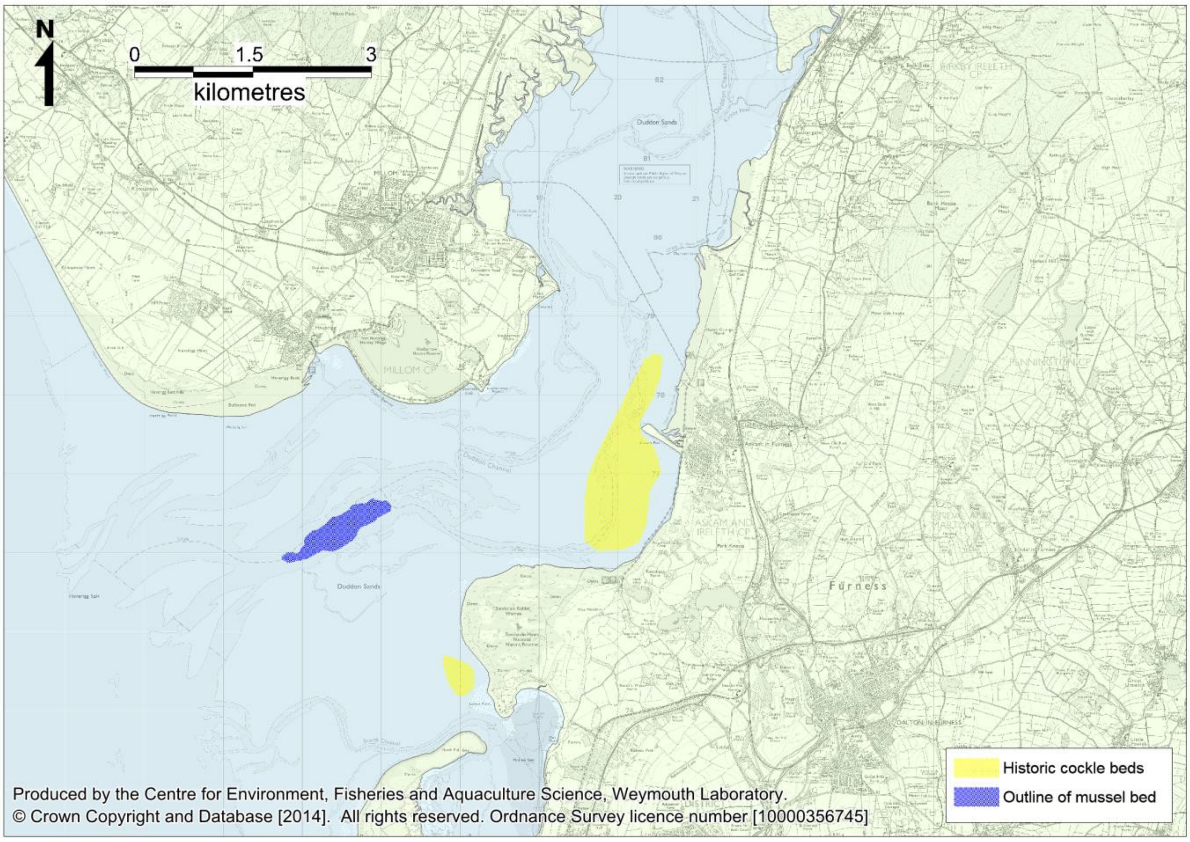
Figure 3.3: Comparison of RMP locations before and after survey (cockle RMPs are not currently active)

4. Shellfisheries

4.1. Species, location and extent

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

Figure 4.1: Historic and current shellfish beds within the Duddon estuary



Currently, there is a significant mussel bed around the Duddon Channel in the outer reaches of the estuary. The bed was surveyed by the NW IFCA in March 2014, and was found to cover an area of about 30 hectares and hold a total of 4,693 tonnes of mussels. They are spread across three small islands in the channel on a sandy substrate interspersed with cobbles and some rocky areas. They are only loosely attached and underlain by a thick layer of mussel mud. They are mainly formed of one year class which has now attained a market size, although there are some smaller individuals at the western end of the bed which settled last year. They are fast growing, meat yields are high (~25%) and they are barnacle free so are readily marketable. Whilst there are usually some mussels in the area shown in Figure 4.1 most years, they are not generally of commercial interest and the current situation is unusual in terms of the numbers and sizes of mussels.

Historically, there have been significant commercially exploitable cockle settlements in the intertidal area off Askam. Additionally, there is a much smaller area off Lowsy Point where they have been present in commercial densities, although this was not classified during the last cockle fishery within the estuary. When there are significant cockle settlements in the estuary, they tend to occur in these areas only. There has not been a commercial cockle fishery in the estuary since 2005/6, and although there are small numbers of cockles still present in these areas there are no beds holding commercial densities at present. The cockle fishery within the estuary (and the wider Morecambe Bay area) is currently closed under byelaw 13a to protect remaining stocks, which are considered to be below safe biological limits for exploitation.

4.2. Growing Methods and Harvesting Techniques

All stocks considered in this report are wild. The intertidal cockles and mussels are exploited by hand gathering. Up to 35 individuals have been observed harvesting the mussels, but generally around 20 harvest the area on suitable tides. Harvesting is restricted to about 5 days around spring tides when the beds are uncovered and accessible. Most are sold to continental markets, although some go to the south west of England and a few are sold locally.

4.3. Seasonality of Harvest, Conservation Controls and Development Potential

Currently, the fishery is managed under the NW IFCA's byelaws. The cockle fishery in this district, when open, operates a closed season running from 1st May to 31st August to protect settling spat[1]. There is no closed season for mussels. Minimum landing sizes apply to cockles (20 mm) and mussels (45 mm) under NWIFCA byelaw. Gear limitations (hand gathering only) apply to the intertidal cockle and mussel fisheries, limiting levels of exploitation and preventing the use of techniques more destructive to the stocks and the habitat. Both cockles and mussels are a public fishery and anyone is allowed to take up to 5 kg of each species per calendar day (unless the fishery is closed under byelaw 13a as is currently the case). 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.

[1] Spat are mollusc larvae ready to settle

Cockle stocks are likely to fluctuate significantly in their overall biomass and their distribution around the area. Success of spatfalls[2] may vary greatly between years and storms, temperature extremes, diseases, predation and of course exploitation can all affect them and mass mortalities may occur at times. A pattern of long periods of low stock levels, with sporadic large recruitment events[3] 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.

Whilst there are usually mussels present in the area occupied by the Duddon channel bed, they are not usually present in commercially viable quantities, sizes and quality. The settlement is not particularly firmly attached and so may be vulnerable to storms and erosion. Movement of the river channel is likely to result in the bed being rapidly sanded over, and the thick underlying layer of mussel mud renders it susceptible to wash out by wave action. As such, it is uncertain how muchlonger this bed will persist for in a commercially viable state, and whether it will regenerate again to such an extent in the future.

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

4.4. Hygiene Classification

Table 4.1: Historical hygiene classifications, 2005 to present

Bed name	Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Askam	Cockles	C	C	-	-	-	-	-	-	-	-
Duddon Channel	Mussels	-	-	-	-	-	-	-	-	-	B

Cockles at Askam have not been classified since 2006, and their most recent classification was C. The mussel bed in the Duddon channel was classified B in May 2014.

[2] Spatfalls are a mass of newly settled larvae
[3] Recruitment events refer to the addition of a new cohort to a population.

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

At present, the only commercially exploited shellfish resource is a mussel bed of about 30 hectares in an area that lies across three islands in the central channel of the outer estuary. This currently supports a hand gathering fishery which usually attracts around 20 harvesters on suitable tides. Whilst there are usually mussels present here, the quality and quantity of the current stock is somewhat exceptional, and its current form is not thought to be particularly stable. It is uncertain how much longer this bed will persist for in a commercially viable state, and whether it will regenerate again to such an extent in the future. It will require continued classification in the meantime whilst it persists in its current form. There are no closed seasons for mussels in the district, and a minimum landing size of 45 mm shell length applies.

Historically there have been large cockle settlements in the Duddon estuary and wider Morecambe Bay area, which have attracted very high levels of commercial gathering. There has not been a major settlement for several years, and these cockle fisheries are currently closed as the IFCA consider stocks to be below safe biological limits for exploitation. Within the Duddon estuary, the main cockle beds occur off Askam, and also within a much smaller patch at Lowsy Point. A sampling plan will be required for these two areas in anticipation of potential future settlements. Some flexibility will be required as it is difficult to predict the spatial extent of future cockle settlements, particularly in an area where the bathymetry is constantly changing. Cockle fisheries in the district are subject to a minimum size of 20 mm and a closed season from 1st May to 31st August.

5.3. Pollution Sources

Freshwater Inputs

All rivers and streams carry some contamination from land runoff and possiblysewage inputs so will require consideration in this assessment. Their impacts will begreatest where they enter the estuary, and within or immediately adjacent to any drainage channels they follow across the intertidal area. The Duddon estuary drains a catchment area of 266 km².

The principle freshwater input is the River Duddon, which drains about a third of this area. There are also a number of other smaller but nevertheless potentially significant watercourses draining to various locations around the estuary. Most of the catchment drains to the estuary upstream of the fisheries. Pasture and arable land dominate the lower catchment, and urban areas are mainly located on thebanks of the estuary. Due to the steep topography and generally impermeable geology the watercourses draining to the estuary respond rapidly to rainfall, a high proportion of which will run off. The bacterial loading delivered by the various watercourses will also fluctuate significantly.

There is only one flow gauging station within the catchment, which is located on the lower reaches of the River Duddon, about 3 km upstream of the tidal limit. Records from this station indicate that flows were higher on average during the colder months. High flow events were recorded in most months of the year, but there tended to be a greater number of higher magnitude events during the autumn and winter. Similar variations are likely to apply to the other watercourses. Whilst high flow events are likely to be associated with the delivery of increased bacterial loadings, it is less certain whether there are major seasonal fluctuations in the average loading delivered.

The only information on the bacteriological content of these watercourses derives from the shoreline survey, which was undertaken in dry conditions in late spring. Water samples were taken from almost all freshwater inputs and they generally contained quite high levels of *E. coli*, with most exceeding 1,000 cfu/100ml and several exceeding 10,000 cfu/100ml.

The majority of land runoff enters the estuary upstream of the fisheries, so to best capture their impacts a general principle of locating the RMP at the up-estuary ends of any shellfish beds should apply. There are however some freshwater inputs in the vicinity of the cockle bed at Askam which may cause localised ‘hotspots’ of contamination in the vicinity of any drainage channels they follow across the intertidal. Three freshwater inputs were observed during the shoreline survey between the Dunnerholme Rock and Roanhead. Two were very small (unnamed) streams at Askam and Roanhead, and the third was the Blea Beck, a much larger watercourse which drains to the shore just north of Askam. The bacterial loadings they were carrying at the time, as estimated from spot flow gauging and water sample results, were $1.7x10^8$, $4.8x10^9$, and $1.0x10^{12}$ cfu/100ml *E. coli* respectively. On the basis of these results it is concluded that the Blea Beck is by far the most significant of these watercourses, and an RMP located by its drainage channel wouldbest capture its impacts. Its outfall has a non return valve so may not discharge around high water.

Human Population

Total resident population within census areas contained within or partially within the catchment area was 50,840 at the time of the last census. The majority of this was located around the shores of the estuary, whereas the more inland areas were sparsely populated. The largest settlement in the area is Barrow-in-Furness, which lies adjacent to the Walney Channel, although only the north-western outskirts of thistown fall within the survey catchment. The towns of Askam-in-Furness and Millom lie opposite one another on the shores of the middle to outer reaches of the estuary, and the town of Broughton-in-Furness lies at its head. Its coastal location and proximity to the Lake District National Park suggests that there will be an increase in local population during the summer holiday period.

Sewage Discharges

There are 11 water company sewage works discharging within the survey area all of which lie in the lower catchment in relatively close proximity to the estuary. The three largest all provide UV disinfection (Millom, Soutergate and Askam STWs). Bacteriological testing results for the final effluent from these works indicate that disinfection is effective, and the average bacterial loading they generate is therefore very small (estimated at $<10^{10}$ *E. coli* per day for all). As such, their impacts will usually be minor and localised. The maximum concentrations of faecal coliforms recorded were however over two orders of magnitude greater than the average indicating that at times their impacts may be significantly higher. Askam and Soutergate are located where they may have some influence on the cockle bed off Askam, whereas Millom may impact on the mussel bed in the outer estuary.

The other relatively large sewage works in the survey area is Broughton-in-Furness STW, which discharges to the head of the estuary and provides secondary treatment only. The estimated loading it generates is much larger than the UV treated works ($2.2x10^{12}$ *E. coli*/day). The remaining seven sewage works are much smaller works providing secondary treatment which may have some localised impacts. Of these, the Greenscoe STW will make some contribution to the *E. coli* loading delivered by Blea Beck to the northern end of the Askam cockle bed, although it is only consentedfor a dry weather flow of 10 m^3/day. Similarly the Roanhead STW (consented for only 3.8 m^3/day) discharges to a small watercourse at Roanhead which may have some influence at the southern end of this bed. Silecroft and Waingate Bridge STWs (combined dry weather flow of 61 m^3/day) both discharge to Haverigg Pool, which may possibly be an influence at the mussel bed, depending on tidal circulation patterns.

There are a small number of intermittent discharges in the survey area. Thisincludes two at Askam (discharging to Blea Beck), four in the Millom area, several to the northern part of the Walney Channel, and a further four to the upper reaches of the estuary. Spill records were only available for Askam and Soutergate STW overflows, and these showed Soutergate had spilled for about 5% of the time and Askam only 2.5% of the time. No spill records were available for any other intermittent discharges so it is difficult to assess their significance aside from noting their location and potential to spill untreated sewage. Spills from the Millom STW aresubject to UV disinfection so should have a reduced bacterial content.

Although the vast majority of properties within the survey area are served by water company sewerage infrastructure, there are also a number of private discharges. 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 ofproperties. Those discharging to soakaway should be of no impact on coastal waters assuming they are functioning correctly. The Haverigg Pool, Black Beck, River Duddon and Grize Beck all receive effluent from a few small private discharges, and these will add to the bacterial loading they deliver to the estuary.

Agriculture

Much of the upper Duddon catchment is used for rough grazing, and there is a mixture of pasture and arable land in the lower reaches of the catchment and aroundthe estuary. The upper estuary is fringed by saltmarsh which is used for grazing livestock. In the most recent detailed livestock census (June 2010) 75,217 sheep, 11,444 cattle, 261 pigs and 60,812 poultry were recorded within this catchment. As such, agriculture is likely to be a significant source of contamination to the estuary.

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 vast majority delivered to the head of the estuary, and potential further hotspots where any smaller watercourses join the lower estuary. 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 particularly a 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. A study undertaken in 1983 indicated that there may be up to 5,000 sheep grazing on saltmarshes in the Duddon estuary, and large numbers are apparent on aerial photography suggesting that this may be a very significant contaminating influence at times. The saltmarshes lie up-estuary from the shellfisheries.

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. Fluxes of faecal matter from grazed saltmarsh are likely to be greatest during spring tides in the summer months.

Boats

Boat traffic within the estuary is light. There are a few moorings for pleasure craft at Askam Pier and at Haverigg. Two suspected houseboats were also seen at Askam Pier during the shoreline survey. Boat traffic to and from the Barrow Docks is much heavier and more varied, but these docks are accessed exclusively from the south as the Walney Channel is not navigable. As such, shipping and other vessels associated with this port should be of no influence to the survey area.

It is concluded that boating activity within the survey area is limited to the occasional leisure craft and fishing vessel in the outer estuary. Private vessels such as yachts, motor cruisers and fishing vessels of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the area. Therefore, the Millom and Askam areas, and the navigation routes to and from these areas are most at risk. Peak pleasure craft activity is anticipated during the summer, so associated impacts are likely to follow this seasonal pattern. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Wildlife

The Duddon estuary encompasses a variety of habitats including intertidal mudflats, sand flats, shallow coastal waters, a freshwater coastal lagoon, saltmarsh, slag and shingle banks and intertidal boulder and cobble skears. These features attract significant populations of birds and other wildlife. The most significant wildlife aggregation of relevance to shellfish hygiene is likely to be the large numbers of overwintering waterbirds (wildfowl and waders) which use the estuary. Over the five winters up until 2011/2012 an average total count of 28,046 overwintering waterbirds were recorded within the Duddon estuary. Large numbers aggregate on North Walney Reserve, Sandscale Haws National Nature Reserve and Hodbarrow Lagoon which are situated close to the shellfisheries. On the shoreline survey flocks of birds were observed throughout, particularly foraging on the sand flats.

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

In addition to overwintering and wildfowl flocks, seabirds such as gulls and terns are also widespread throughout the area all year round. A survey in the early summer of 2000 recorded only 1,859 breeding pairs of gulls and terns. Most of these were in the Hodbarrow Lagoon and Haverigg area. Seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to bemost 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. As the nesting colonies are not in the immediate vicinity of the fishery, their presence will have no influence on the sampling plan.

There is a local population of about 20-50 grey seals, which use the south east shore of Walney Island as their main haul out site. They are also reported to use the sandbanks in the outer Duddon estuary as haul-out sites. Whether they haul out on the actual mussel bed is uncertain. Given their small numbers and the large area they are likely to forage over their impacts are likely to be minor, and unpredictable inspatial terms, so they will have no bearing on the sampling plan. It is likely that the estuary is more attractive to them during the summer and autumn when adultsalmonids are making their upstream migration.

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 Millom and Askam. 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.

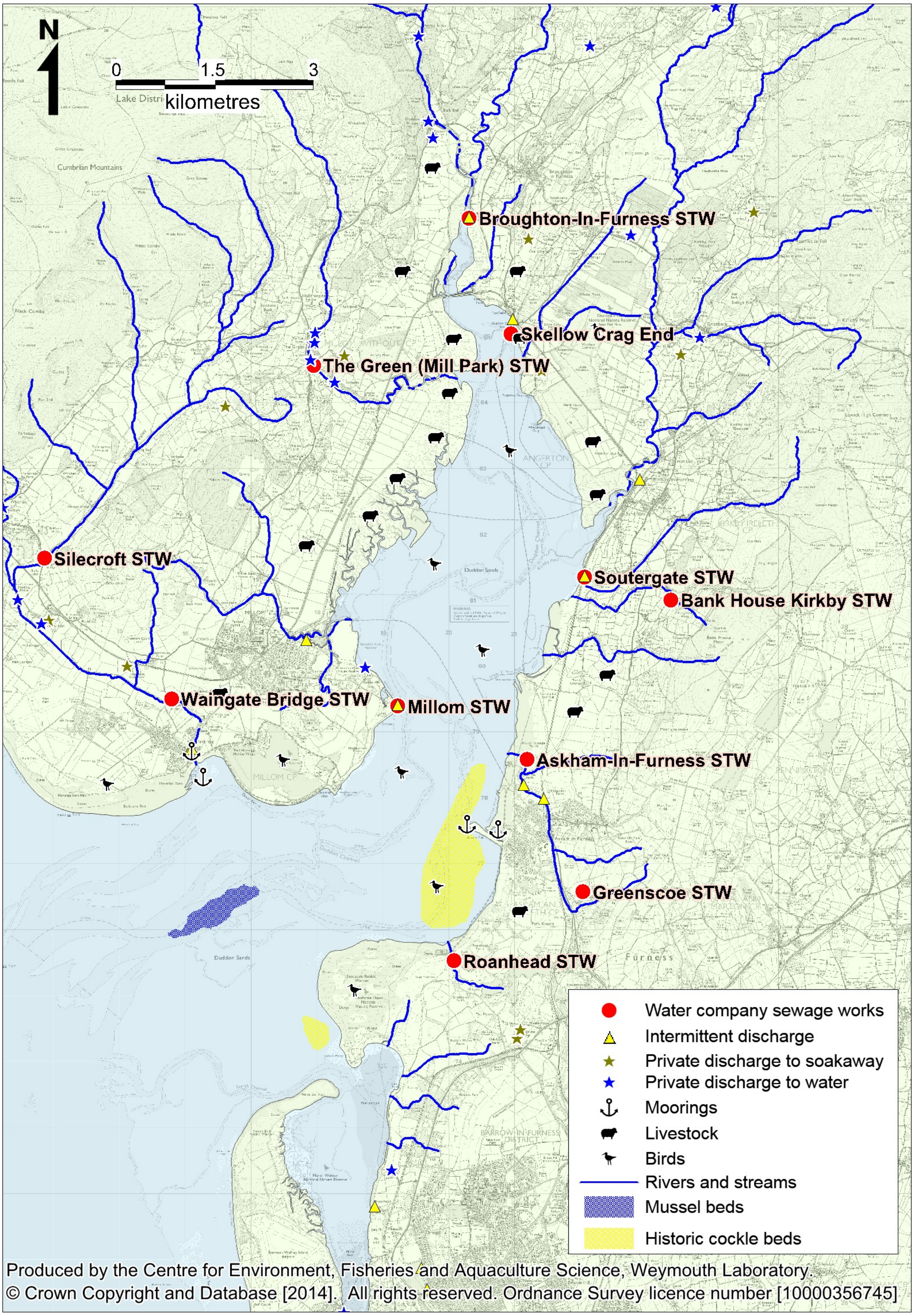


Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The Duddon estuary covers an area of 45 km², around 90% of which is comprised of intertidal sand-flats. It faces south west, towards the Irish Sea, and there is an ebb delta (sandbank) at its mouth which will afford some protection from incoming swells. Dune systems flank the estuary mouth, and there are extensive areas of saltmarsh backed by reclaimed grazing marsh in the inner estuary. The outer and middle reaches are relatively wide, and it narrows significantly near to the tidal limit. The two larger freshwater inputs (Rivers Duddon and Lickle) drain to the head of the Duddon estuary, but there are also several other significant watercourses draining tothe estuary at intervals. The intertidal area is bisected by the river channel, which is meandering and diverges and re-converges in several places. There are numerous other channels which drain from the intertidal areas and carry freshwater inputs towards the main river channel. The layout of these channels is constantly changing. The shallow nature of the estuary will promote tidal exchange, but will limit dilution potential particularly around low water.

Just inside the estuary mouth, there is a channel (Walney Channel) which forms a connection behind Walney Island to the Barrow Dock area and Morecambe Bay. The middle reaches of this channel are intertidal, with the elevation of the channel bed peaking to the north of the Jubilee Bridge around an area called the Walney Meetings. The connection will be limited to higher states of the tide, and may not be made at all on the smallest neap tides. A subtidal channel connects the mouth of theWalney Channel directly to the Irish Sea.

The tidal range is large, at 7.6 m on spring tides and 4.0 m on neap tides, and this drives extensive water movements through the area. The flood tide will convey relatively clean water originating from the open Irish Sea into the estuary, whereas the ebb tide will carry contamination from shoreline sources out through it. The mainflood current is reported to enter the estuary along its southern margin, with the mainebb current leaving the estuary along its northern margin. This may result in increased impacts of up-estuary sources towards the north shore of the outer estuary. During the flood tide, the principal tidal stream will follow the main channel(s). As levels rise, water will spread out across the intertidal, where current velocities will be lower. The reverse will occur on the ebb. Consequently, shoreline sources of contamination will primarily impact up and downstream of their locations along the bank to which they discharge. Around low tide contamination from shoreline sources such as streams will be carried through drainage channels where the dilution potential is low, so high concentrations of faecal indicator bacteria may arise within them at these times.

Tides flood into the Walney Channel from both ends, meeting to the north of the Jubilee Bridge in an area called the Walney Meetings, then drain away in the opposite direction. It is uncertain whether there is a net flow of water in any one direction through this channel, but given the circulation pattern described above it is concluded that it is unlikely that sources south of the Meetings will impact on the survey area. Contamination from sources to the north of the meetings will follow the course of the subtidal channel out into the Irish Sea once they pass through the mouth of the Walney Channel during the ebb tide.

Freshwater inputs are very low relative to tidal exchange, so density effects are unlikely to significantly modify tidal circulation patterns. Repeated salinity measurements taken at high water in the intertidal areas off Askam, Roanhead and Haverigg show an average salinity of around 29-30 ppt with readings of less than 20 ppt occasionally recorded. Lower salinities are likely to be associated with high river flow events, and increased levels of faecal indicator bacteria in the estuary. It is also likely that salinity decreases to some extent around low water. There was a very slight decrease in average salinity from Askam to Roanhead, then to Haverigg, indicating that although there is a salinity gradient through the outer estuary it is very slight.

Wind driven currents may affect tidal circulation patterns at times. South westerly winds will tend to push surface water up the estuary, creating return flows at depth or along any sheltered margins. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action, which may resuspend contamination entrained in sediments. The delta at the estuary mouth will afford some protection from incoming swells, but this will be very limited at higher states of the tide. Given the shape of the estuary and the prevailing wind direction, the east shore of the outerestuary up to around the Askam area is likely to be most vulnerable to wave action.

5.5. Summary of Existing Microbiological Data

The Duddon estuary has been subject to some microbiological monitoring over recent years, deriving from bathing 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.

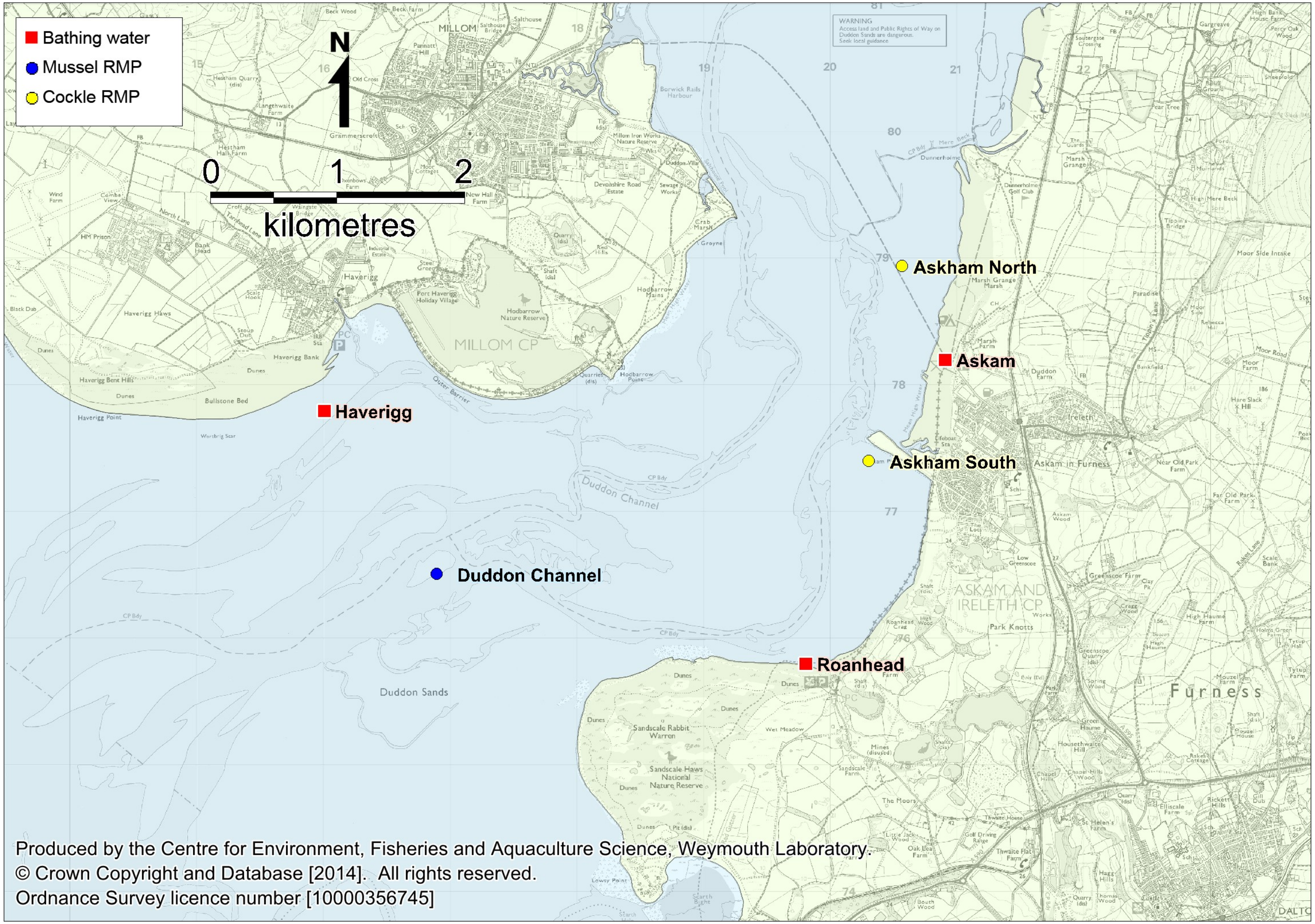


Figure 5.2: Microbiological sampling sites

Bathing Waters

Around twenty water samples were taken from each of three bathing waters sites during each bathing season. Faecal coliforms were enumerated in all of thesesamples. There was a slight drop in geometric mean concentrations of faecalcoliforms from Askam (70.2 faecal coliforms/100ml) through to Haverigg (46.9 faecal coliforms/100ml). This reflects the decreasing influence of up-estuary sources towards Haverigg and increasing influence of cleaner water from the open sea. There was not a statistically significant difference in mean result between the three locations. Comparisons of paired (same day) samples showed that results at all three sites were strongly correlated suggesting that they are under the influence of similar sources of contamination. Through the period 2004 to 2011 no increasing or decreasing trend in average result was apparent. Statistically significant correlations between faecal coliform concentrations and the high/low tidal cycles were found at Askam and Roanhead, but not Haverigg. Sampling was strongly targeted towards high water and no strong patterns were apparent when the data was plotted. All three locations showed significant correlations between faecal coliforms and the spring/neap tidal cycle. Very little sampling was conducted during neap tides, but plots of the data showed faecal coliform concentrations peaked on average during spring tides at all three locations. This may be related to saltmarsh grazing. Faecal coliform levels at all three sites were strongly influenced by antecedent rainfall. The only difference between them was that no influence was found at Roanhead until twodays after a rainfall event, whereas at the other two the influence was apparent after one day. This may be related to their relative proximities to watercourses. There were significant correlations between salinity and faecal coliform concentrations at Askam and Haverigg, but not Roanhead. As with the correlation with rainfall, this also suggests a lesser influence of runoff borne contamination at Roanhead compared to the other two sites.

Shellfish Hygiene Classification Monitoring

Over the past decade, shellfish hygiene flesh monitoring in the area has been limited to around two years of monitoring of cockles at two points off Askam[4], and a recent short series of sample results from the current mussel bed in the outer estuary. Across the two cockle RMPs, the geometric mean result was higher at Askham South than at Askham North (505 and 374 *E. coli* MPN/100g respectively), although this difference was not statistically significant. The proportion of results exceeding 4,600 *E. coli* MPN was however lower at Askham South than at Askham North (3.8%

[4] Historically hygiene monitoring points off Askam-in-Furness have been named Askham South and Askham North.

and 10.7% respectively). This suggests that results from Askham North were more consistent with a C classification, whereas those from Askham South were consistent with a B classification, despite the higher average result at the latter. A comparison of paired (same day) samples showed a significant correlation suggesting they are influenced by similar sources. No statistically significant seasonal variation was found at either of these two RMPs, although there did appearto be a tendency for lower results in the spring when this limited data was plotted. There was insufficient data to undertake analyses of *E. coli* levels against tidal state. There were no significant correlations between rainfall and *E. coli* levels in cockle flesh at Askham North. At Askham South, there were significant correlations between rainfall and *E. coli* levels in cockles five and six days after rainfall. The reasons for this are uncertain.

Only 11 samples were taken from the mussel RMP (Duddon Channel) over a short period of around four months so limited conclusions can be drawn and the effects of environmental variables could not be assessed in a meaningful way. The geometric mean result at the mussel RMP was 327 *E. coli* MPN/100g, and no results exceeding 4,600 *E. coli* MPN/100g were recorded. The range of results recorded here (80 to 1700 *E. coli* MPN/100g) was small.

Bacteriological survey

Whilst a bacteriological survey may potentially have been beneficial, it was not possible to undertake one due to the inaccessible nature of the mussel bed and the current lack of cockle stocks.

Appendices

Appendix I. Human Population

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

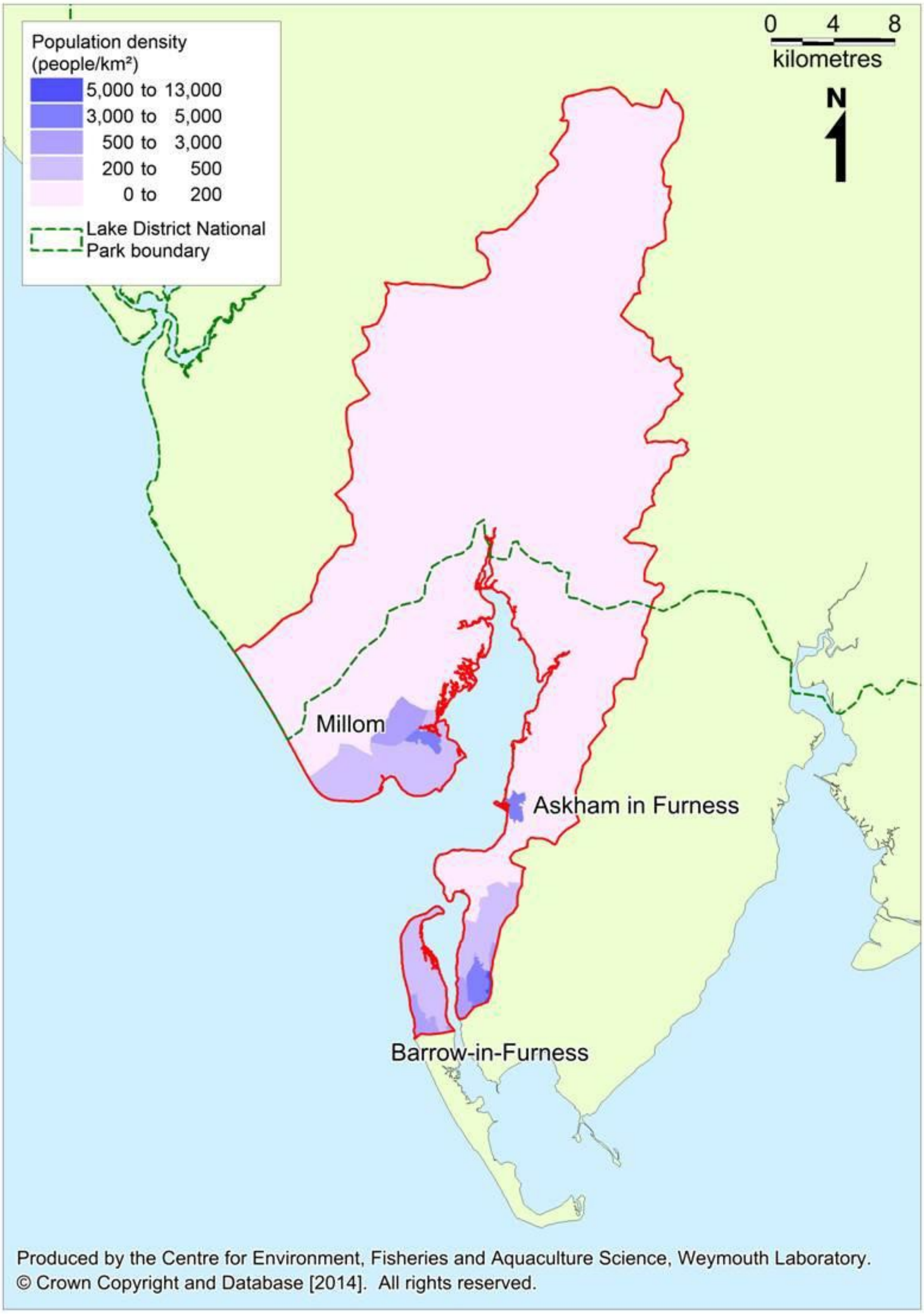


Figure I.1: Human population density in census areas in the Duddon catchment.

Total resident population within census areas contained within or partially within the catchment area was 50,840 at the time of the last census. The largest settlement in the area is Barrow-in-Furness, which had a total population of about 57,000 in 2011, although only the north-west outskirts of this town falls within the survey catchment. The second largest settlement, Millom had a population of approximately 7,000 in 2011. The highest population densities are associated with these settlements. About 60% of the catchment is occupied by the Lake District National ark, and so the upper catchment is sparsely populated. 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.

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

Details of all consented sewage discharges within the Duddon Estuary hydrological catchment were taken from the most recent update of the Environment Agency national permit database (March 2014). These are mapped in Figure II.1.

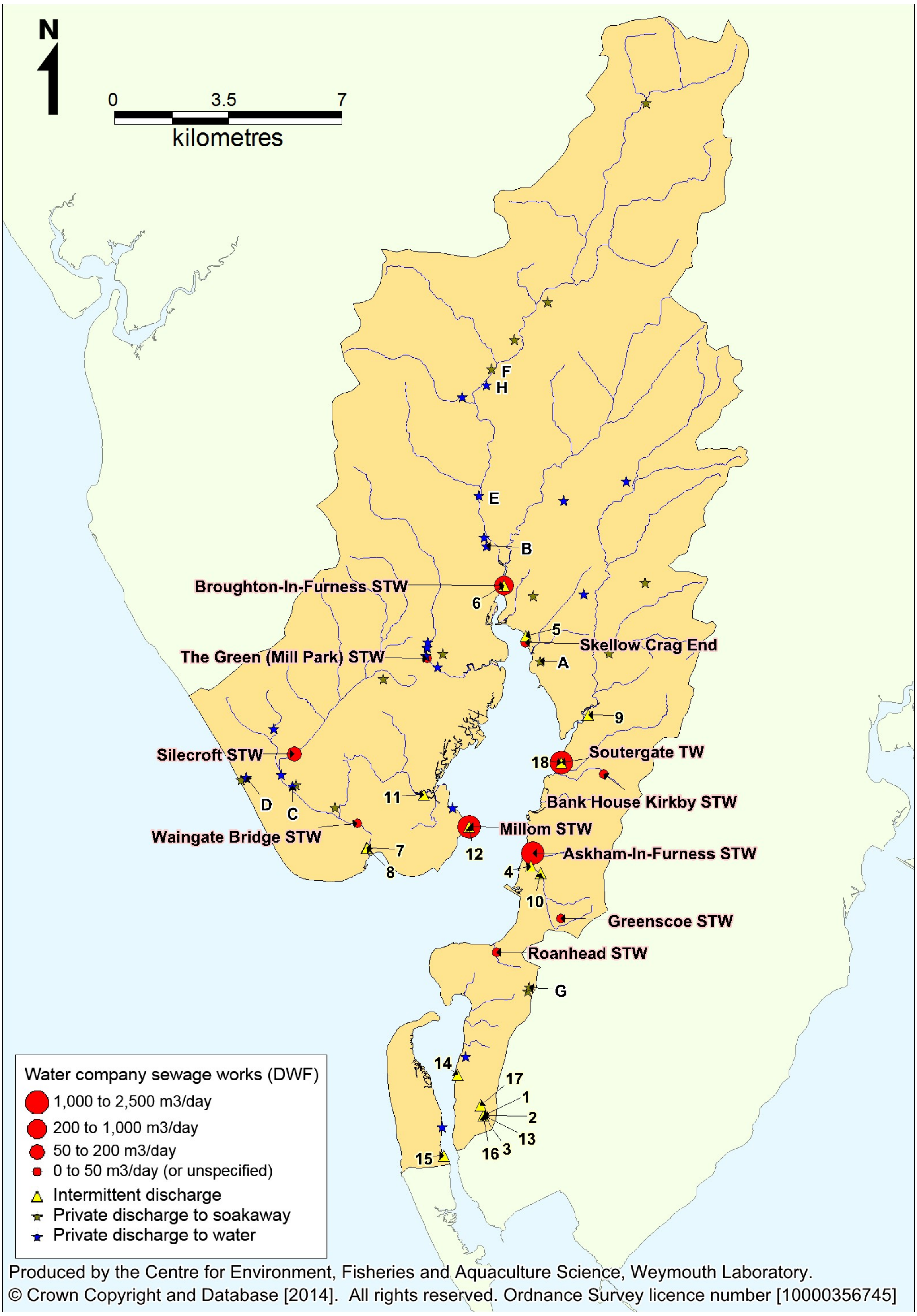


Figure II.1: All permitted sewage discharges to the Duddon catchment

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There are 11 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
Askham-In-Furness STW[5]	SD2118078600	UV Disinfection	1,036	$4.5x10^{9**}$	Blea Beck
Bank House Kirkby STW	SD2336081020	Biological Filtration	4.8	$1.6x10^{10*}$	Soakaway
Broughton-In-Furness STW	SD2030086810	Biological Filtration	799	$2.6x10^{12*}$	Duddon Estuary
Greenscoe STW	SD2203076590	Biological Filtration	10	$3.3x10^{10*}$	Blea Beck trib.
Millom STW	SD1922079410	UV Disinfection	2,799	$7.7x10^{9**}$	Duddon Estuary
Roanhead STW	SD2007075550	Biological Filtration	3.8	$1.3x10^{10*}$	Unnamed watercourse
Silecroft STW	SD1386081650	Package Plant	57	$1.9x10^{11*}$	Haverigg Pool
Skellow Crag End	SD2094085060	Secondary	13.4	$4.4x10^{10*}$	Duddon Estuary
Soutergate STW	SD2205081370	UV Disinfection	1,112	$1.6x10^{9**}$	Soutergate Beck
The Green (Mill Park) STW	SD1794084580	Biological Filtration	29	$9.6x10^{10*}$	Black Beck
Waingate Bridge STW	SD1579079520	Biological Filtration	4	$1.3x10^{10*}$	Haverigg Pool

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*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	$7.2x10^6$
Primary (12)	127	$1.0x10^7$	14	$4.6x10^6$
Secondary (67)	864	$3.3x10^5$	184	$5.0x10^5$
Tertiary (UV) (8)	108	$2.8x10^2$	6	$3.6x10^2$

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

The three largest sewage works within the survey area provide UV disinfection. Table II.3 and Figure II.2 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 the three UV treated works, January 2008 to March 2012

Sewage works	No.	Geometric mean result (cfu/100ml)	Minimum	Maximum
Askham	102	437	0	94,000
Millom	108	274	0	40,000
Soutergate	108	142	0	76,000

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Bacteriological testing results for the final effluent from Askam, Millom and Soutergate STWs 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. The maximum concentrations of faecal coliforms recorded were however over two 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).

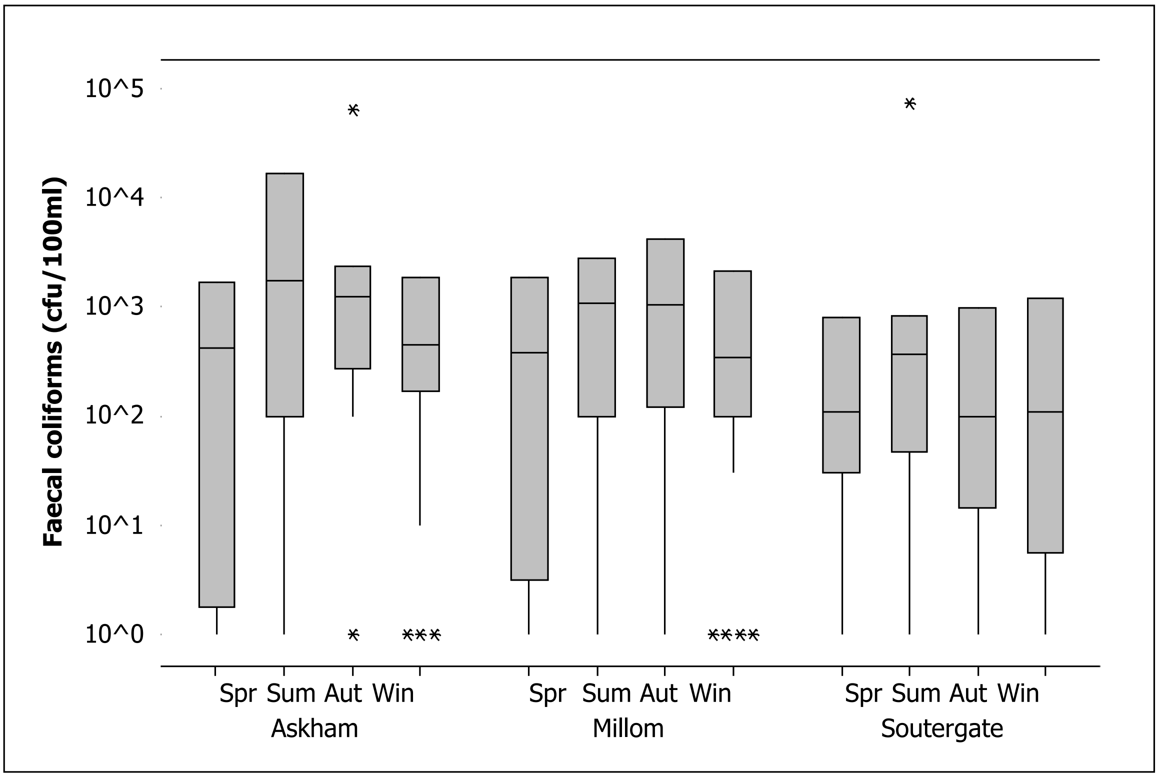

Figure II.2: Boxplot of faecal coliform concentrations in UV treated final effluents by season.
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Some limited seasonality in faecal coliform concentrations was observed at Askam and Millom STWs, where results were lowest on average during the spring. It is uncertain whether this translates to a noticeable seasonal variation in the bacterial loadings delivered, as there is likely to be some seasonality in the volumes of effluent discharged.

The remaining 8 works all provide secondary treatment. The largest by a considerable margin is Broughton-in-Furness STW, which discharges to the very upper reaches of the estuary. The Skellow Crag End STW also discharges to the upper estuary, but is much smaller. Other small works discharge to Black Beck, Haverigg Pool, Cross Beck, Blea Beck, and a small un-named watercourse at Roanhead.

In addition to the continuous sewage discharges, there are several intermittent water company discharges associated with the sewerage networks also shown on Figure II.1. Details of these are shown in Table II.4. Spill event monitoring records were only available for one of these, which is highlighted in yellow.

Table II.4: Intermittent discharges to the survey area

No.	Name	Permit No.	Grid reference	Receiving water
1	Ainslie St/Harrogate St	01BRW0012	SD1966070550	Ormsgill Reservoir
2	Ainslie St/Newport St	01BRW0011	SD1966070550	Ormsgill Reservoir
3	Ainslie St/Oxford St	01BRW0013	SD1966070550	Ormsgill Reservoir
4	Askham-In-Furness STW ST & PS	17470136	SD2113078200	Blea Beck
5	Foxfield PS	17480180	SD2096085270	Duddon Estuary

No.	Name	Permit No.	Grid reference	Receiving water
6	Greety Gate PS	17480364	SD2030086810	Duddon Estuary
7	Haverigg PS	17480403	SD1608078760	Haverigg Pool
8	Haverigg SPS	17480256	SD1609078750	Haverigg Pool
9	Head Cragg PS	17480357	SD2289082830	Trib. Kirkby Pool
10	K Shoes	01BRW0056	SD2143077990	Blea Beck
11	King Street PS	17470009	SD1783080400	Salthouse Pool
12	Millom STW	17470048	SD1922079410	Duddon Estuary
13	Oxford Street SSO	17480304	SD1966070550	Ormsgill Reservoir
14	Palace Nook Sewage PS	17480314	SD1887071800	Walney Channel
15	Promenade/Latona St	01BRW0094	SD1846069310	The Walney Channel
16	Romney Rd SSO	17480303	SD1966070550	Ormsgill Reservoir
17	Schneider Street	17480361	SD1958070871	Ormsgill Reservoir
18	Soutergate STW	17470020	SD2205081370	Soutergate Beck

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There are eight intermittent discharges in the Barrow area, which discharge to the northern end of the Walney Channel. There are also ten intermittent discharges dispersed at intervals around the fringes of the estuary which may impact to some extent on the shellfisheries. Improvements at King Street PS to reduce the frequency and volume of spills from the storm overflow were completed in October 2013 and UV disinfection was installed at Millom STW storm overflow in late October2013. Verified spill records for the Askam and Soutergate STW outfall were availablefor the period October 2011 to March 2013, for which summary statistics are presented in Table II.5.

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

Discharge name	No spill events	Total duration (hrs)	% period active
Askham STW	8	333.6	2.5%
Soutergate STW	17	728.9	5.5%

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The Soutergate STW overflow discharges to the east shore of the estuary about 1km to the north of the cockle bed off Askam. It was active for about 5.5% of the period considered, so its impacts may be captured once on average during about two years of monthly monitoring. The Askam STW storm tanks only spilled for 2.5% of the period. For the other intermittent discharges to the estuary it is difficult to assess their impacts aside from noting their locations and their potential to spill stormsewage. Spills from Millom STW should have a reduced bacterial content due to the additional disinfection step.

Although the vast majority of properties within the survey area are served by water company sewerage infrastructure, there are also a number of private discharges. 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. All permitted private sewage discharges are mapped in Figure

II.1, and Table II.6 presents details of those consented to discharge more than 5 m^3/day.

Table II.5: Details of private sewage discharges >5 m^3/day to the Duddon catchment

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	Angerton Farm	SD2140084490	Reedbed	5	Soakaway
B	Plots 1 - 8	SD1975488020	Biological Filtration	8	Duddon trib.
C	Raceside Farm	SD1381080650	Package Plant	5	Kirksanton Pool
D	Silecroft Holiday Park	SD1238080920	UV Disinfection	41	Unnamed Watercourse
E	Duddon Hall Estate	SD1952989568	Package Plant	8.5	River Duddon
F	The Almshouses	SD1991993451	Septic Tank	6.5	Soakaway
G	The Clubhouse	SD2108074490	Biological Filtration	11	Soakaway
H	Ulpha C.E. School	SD1976092960	Biological Filtration	5	River Duddon

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Those discharging to soakaway should have no impact on coastal waters assuming they are functioning correctly. Of those discharging to water, the vast majority discharge to the various watercourses located throughout the Duddon catchment and as such will contribute to the bacterial loading delivered to the estuary by these watercourses. Of all the private discharges in the catchment there are a few discharging to Haverigg Pool and its tributaries and these may be of local significance, contributing background bacterial load to waters on the northern shore of the Duddon around Haverigg.

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

Land cover within the Duddon catchment is principally grassland in the more inland areas. The upper reaches of the catchment also contain significant natural areas (forest, heathland and peat bogs). There is a mixture of pasture and arable land in the lower reaches of the catchment and around the estuary. The upper estuary is fringed by saltmarsh which is used for grazing livestock.

Table III.1 presents livestock numbers and densities for the catchment. These data were provided by Defra and are derived from the June 2010 census as this provides more detail than censuses undertaken in subsequent years. 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 2010 livestock census for the Duddon catchment

Cattle		Sheep		Pigs		Poultry	
No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)
11,444	43.1	75,171	282.8	261	1.0	60,812	228.8

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 large numbers of sheep within the catchment, as well as significant numbers of cattle and poultry and a few pigs. Sheep and cattle were observed frequently during the shoreline survey, around the perimeter of the estuary.

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 vast majority delivered to the head of the estuary, and potential minor hotspots where any smaller watercourses join the lower estuary. As the primary mechanism for mobilisation of faecal matter deposited on pastures into watercourses is via land runoff, fluxes of agricultural contamination into coastalwaters 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 was reported that the Duddon saltmarshes are grazed by over 2,000 ewes for most of the year, but are removed during the larger spring tides and for a few weeks around lambing time in spring. These produce around 3,000 lambs which also graze the marshes from May to September (Howard, 1983). Whether these numbers have changed significantly since this report was written is uncertain. Aerial photography (Google, date uncertain) showed that the salt marsh on both sides of the estuary was heavily stocked with sheep at the time the images were taken. During the shoreline survey (May) none was recorded on saltmarsh, although this visit may have coincided with lambing.

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. Sources and variation of microbiological pollution: Boats

The discharge of sewage from boats is a potential source of bacterial contamination of shellfisheries within the Duddon estuary. Boat traffic here is limited to recreational craft such as yachts. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources.

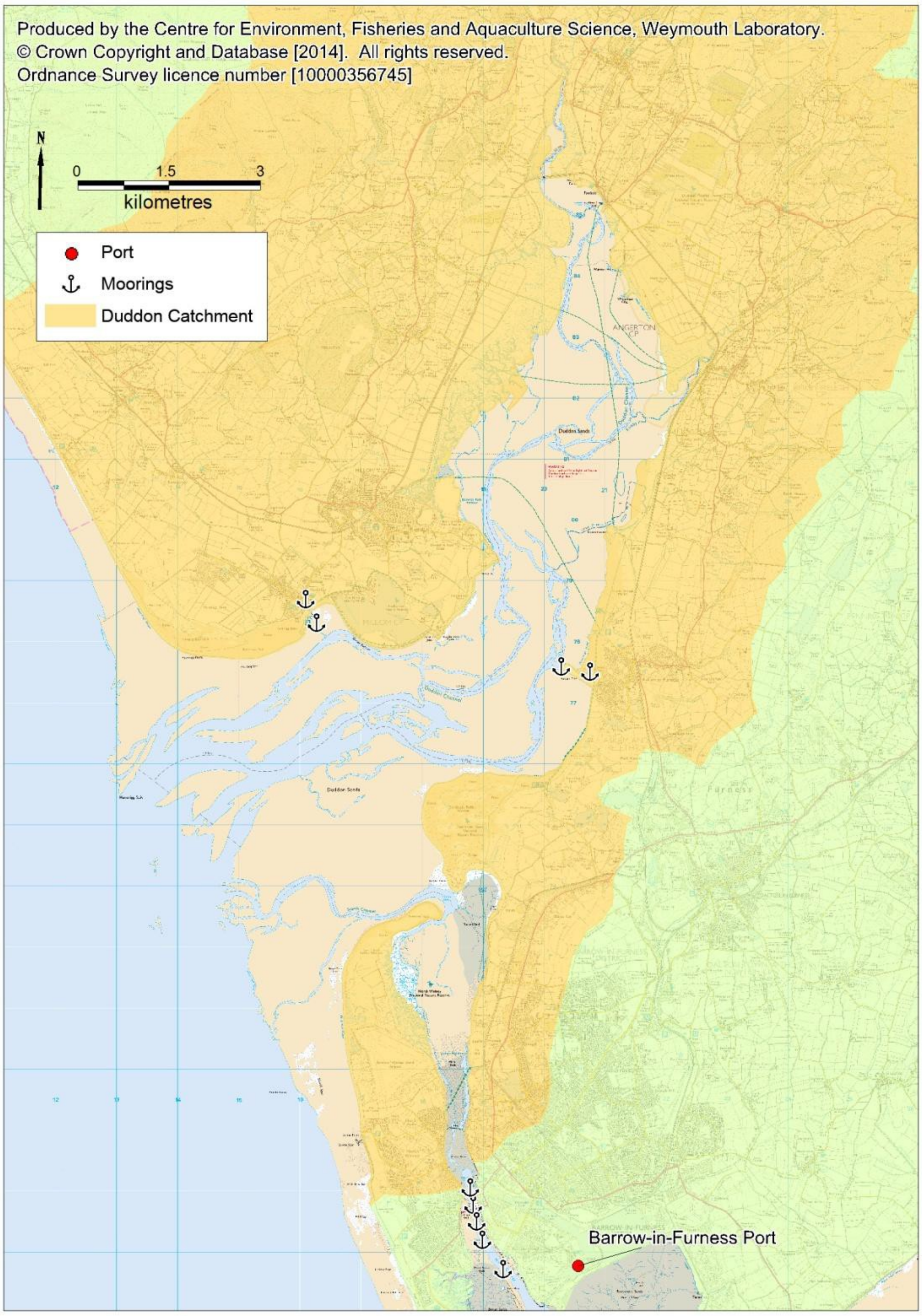

Figure IV.1: Boating activity in the Duddon survey area

There are no commercial ports, marinas or facilities within the Duddon, however there are a few moorings available for pleasure boats at Haverigg, Askam Pier and in the Walney Channel. On the shoreline survey two possible houseboats were observed adjacent to Askam Pier. The closest marina with pump out facilities is Glasson Basin Marina in Morecambe Bay (The Green Blue, 2010). A watersports centre is based on Port Haverigg freshwater lake offering water skiing and wakeboarding over the summer months. Sailing, windsurfing, kitesurfing and kayaking are also popular within the estuary. However, these smaller recreational boats are not large enough to contain onboard toilet facilities and therefore are unlikely to make overboard discharges.

The closest commercial port is located approximately 2.5 km south east at Barrow Port. This is accessed from the south, rather than via the Duddon estuary then the Walney Channel. As such, shipping and other vessels associated with this port should be of no influence to the survey area.

There is a small fishing fleet in the area, of which 6 fishing vessels under 10 metres and 1 vessel over 10 metres are listed as having Barrow-in-Furness as their home port (MMO, 2014). Their fishing patterns are uncertain but in general their use of the Duddon estuary is likely to be very limited.

It is therefore concluded that boat traffic in the estuary is limited to small numbers of pleasure craft and possibly fishing vessels, so the impacts from boat traffic are likely to be minor at most. The locations of piers and moorings at Askam and Haverigg suggest that traffic will generally be limited to the outer estuary. Private vessels such as yachts, motor cruisers and fishing vessels of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the area. Therefore, whilst overboard discharges may be made anywhere within the survey area, it is likely that the moorings and the main navigation routes through the area are most at risk of contamination from thissource. Smaller pleasure craft such as kayaks and sailing dinghies will not have onboard toilets and so are unlikely to make overboard discharges. Peak pleasure craft activity is anticipated during the summer, so associated impacts are likely to follow this seasonal pattern. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Appendix V. Sources and Variation of Microbiological Pollution: Wildlife

The Duddon estuary encompasses a variety of habitats including intertidal mudflats, sand flats, shallow coastal waters, a freshwater coastal lagoon, saltmarsh, slag and shingle banks and intertidal boulder and cobble skears (Duddon Estuary Partnership, 2012). These features attract significant populations of birds and other wildlife. Consequently the Duddon estuary falls under several national and international conservation statuses, including: a European Marine Site, Special Protection Area (SPA), Special Area of Conservation (SAC), Special Site of Scientific Interest (SSSI), a Ramsar site, three nature reserves and Hodbarrow Lagoon RSPB Nature Reserve.

The most significant wildlife aggregation in terms of shellfish hygiene is likely to be the large numbers of overwintering waterbirds (wildfowl and waders) which use the estuary. Studies in the UK have found significant concentrations of microbiological contaminants (thermophilic campylobacters, salmonellae, faecal coliforms and faecal streptococci) from intertidal sediment samples supporting large communities of birds (Obiri-Danso and Jones, 2000). Over the five winters up until 2012/2013 an average total count of 28,046 overwintering waterbirds was recorded within the Duddon estuary (Austin et. al, 2014). Large numbers aggregate on North Walney Reserve, Sandscale Haws National Nature Reserve and Hodbarrow Lagoon which are situated close to the shellfisheries. In exceptional years in excess of 70,000 wintering waterfowl (wildfowl, waders and seabirds) have been recorded (Duddon Estuary Partnership, 2012). Species include pintail, knot, redshank, shelduck, red-breasted merganser, oystercatcher, ringed plover, dunlin and curlew. On the shoreline survey flocks of birds were observed throughout, particularly foraging on the sand flats.

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

In addition to overwintering and wildfowl flocks, seabirds such as gulls and terns are also widespread throughout the area all year round. A survey in the early summer of 2000 recorded only 1,859 pairs of breeding seabirds including European herring gull, Lesser black-backed gull, black-headed gull, great black-backed gull, common tern, little tern and sandwich terns (Mitchell *et al*, 2004). 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. As the nesting colonies are not in the immediate vicinity of the fishery, their presence will have no influence on the sampling plan.

The south east shoreline of Walney Island is the main haul out site for a local population of around 20 to 50 grey seals along the Cumbrian coast (Cumbria Wildlife website). They are also reported to haul out on the sand banks offshore from the north of Walney Island, in the entrance to the Duddon estuary (Wildzone, 2011). It is quite likely that they haul out on mid estuary sandbanks on occasion, and if this coincides with the cockle and mussel beds there is the potential for them to create a localised hotspot of contamination. However, no firm information on regular haul-out sites within the Duddon estuary could be found. Given their small numbers and the large area they are likely to forage over their impacts are likely to be minor, and unpredictable in spatial terms, although it is likely that the estuary is more attractive to them during the summer and autumn when salmon and sea trout are making their return migration.

There is evidence of otters on both the Haverigg Pool and Black Beck watercourses discharging to the northern shore of the estuary (Cumbria Wildlife Trust). No information on numbers was available but the population is likely to be small. Otters generally tend to favour the more secluded areas with access to watercourses. However, given their likely wide distribution and very small numbers, otters have no material bearing on the sampling plan.

Appendix VI. Meteorological Data: Rainfall

The Duddon weather station, located on the banks of the middle reaches of the River Duddon, received an average of 1020 mm per year between 2004 and 2013. Figure VI.1 presents a boxplot of daily rainfall records by month from this weather station.

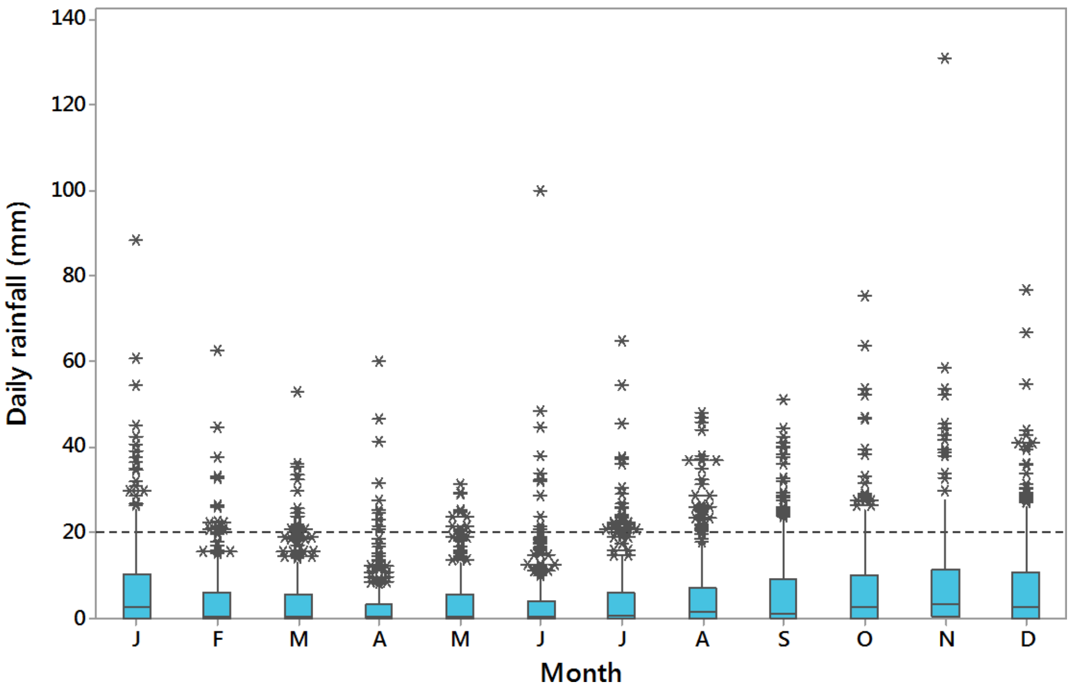

Figure VI.1: Boxplot of daily rainfall totals at the Duddon weather station, January 2004 to December 2013.

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Rainfall records from the Duddon weather station, which is representative of conditions in the hydrological catchment indicate significant seasonal variation, with higher average rainfall from September through to January, peaking in November. It was lowest on average in April and May. Daily totals of over 20 mm were recorded on 8% of days and 36% of days were dry. High rainfall events (>20 mm/day) occurred in all months. Annual rainfall in coastal parts of the catchment is on average roughly half that experienced in the higher elevations of its very upper reaches, where it typically exceeds 3000 mm (NERC, 2012).

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. Meteorological Data: Wind

NW England and the Isle of Man are among the more exposed parts of the UK, being relatively close to the Atlantic and containing large upland areas. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest in the winter half of the year, especially from December to February, and this is when mean speeds and gusts (short duration peak values) are strongest (Met Office, 2012).

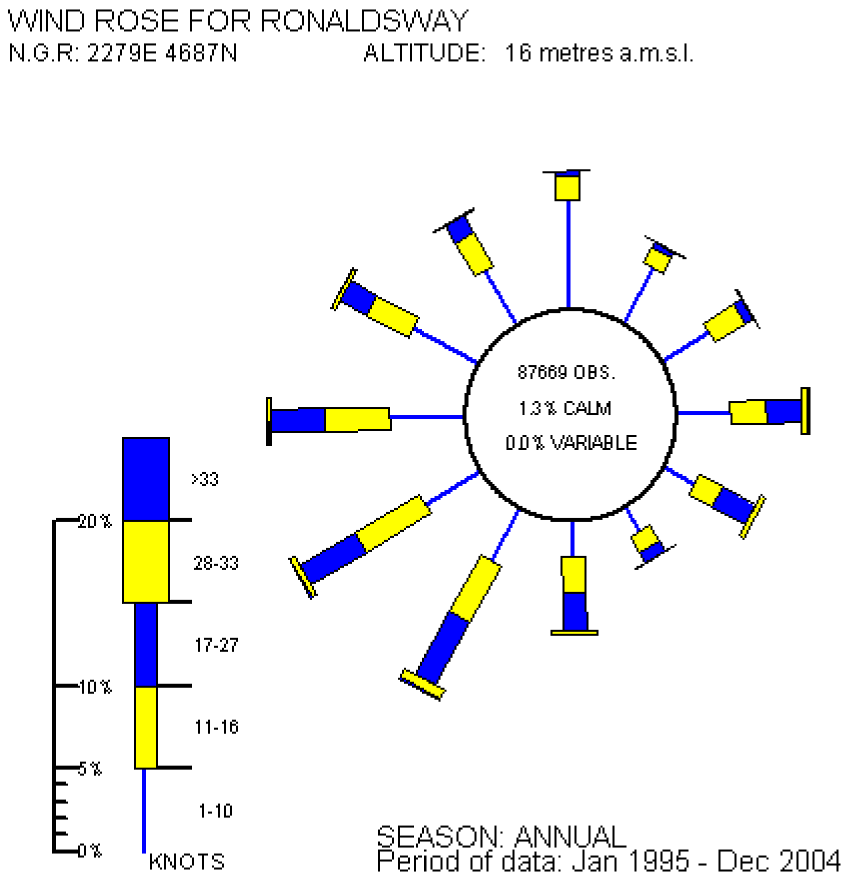

Figure VII.1 Windrose for Ronaldsway, Isle of Man
Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

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 highfrequency of winds from the north east in the spring. The Duddon estuary is relatively exposed to the prevailing winds as it faces south west, and has a relatively wide mouth.

Appendix VIII. Hydrometric Data: Freshwater Inputs

The Duddon estuary has a hydrological catchment of 266 km². The principle freshwater input is the River Duddon, which drains about a third of this area. There are also anumber of other smaller, but nevertheless potentially significant, watercourses draining to various locations around the estuary (Figure VIII.1).

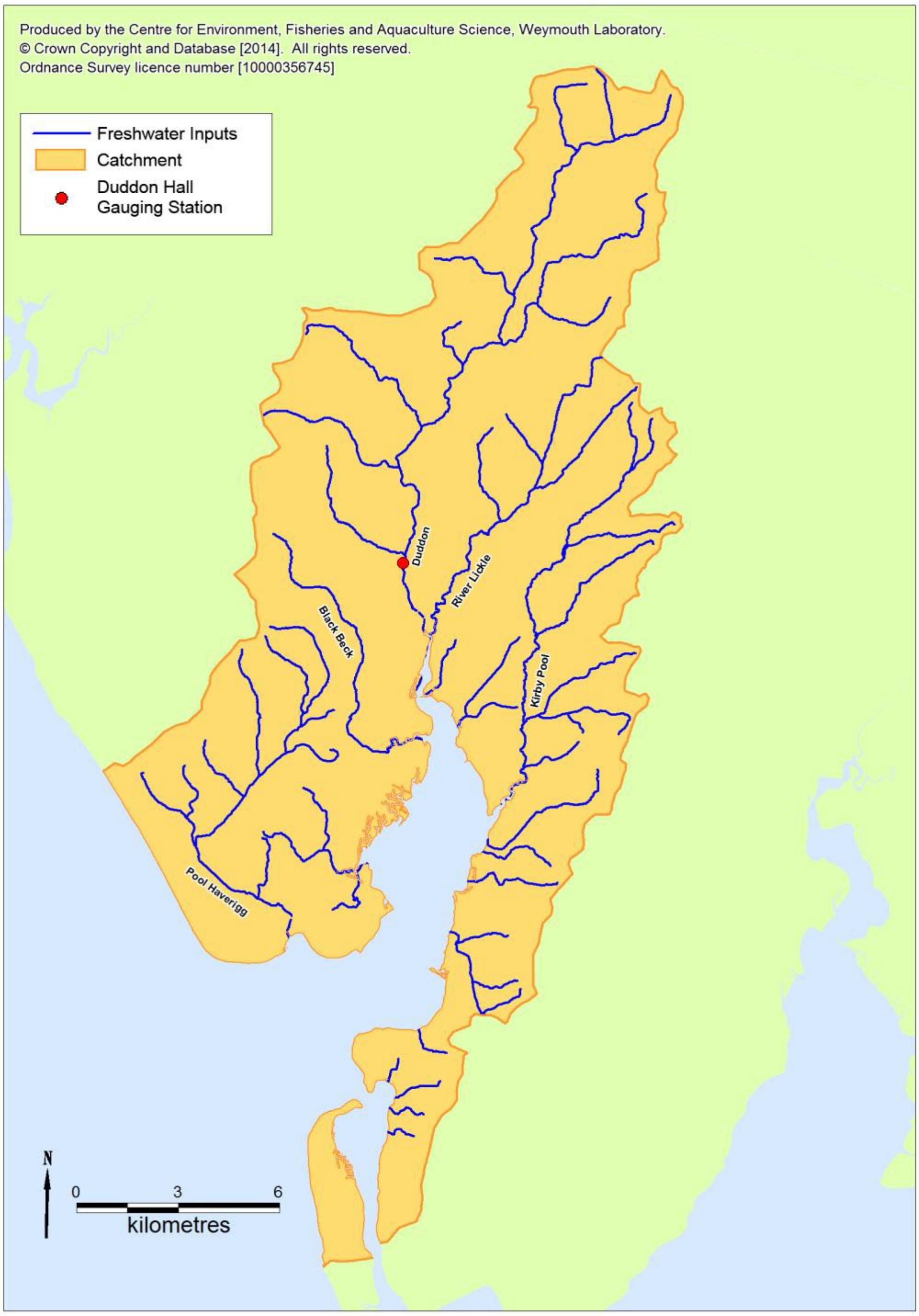

Figure VIII.1: Freshwater inputs into the Duddon estuary

The River Duddon is a spate river of about 23 km in length that originates in uplands of the Lake District. Other significant watercourses include the River Lickle, the Black Beck, the Kirby Pool and the Haverigg Pool. Most of the catchment drains via watercourses which enter the estuary upstream of the fisheries. Land cover in the inland areas is mixture of grassland, heathland and woodland. Pasture and arable land dominate the lower catchment, and urban areas are mainly located on the banks of the estuary. The catchment is hilly throughout, reaching a maximum elevation of almost 800 m. The hydrogeology is described as being of very low permeability throughout most of the catchment, with moderate permeability in the Askam and Millom areas, and higher permeability in the Barrow area (NERC, 2012). Due to the generally steep topography and impermeable geology the watercourses draining to the estuary respond rapidly to rainfall,a high proportion of which will run off. As such, the bacterial loading they deliver to the estuary is likely to vary greatly with rainfall.

There is only one flow gauging station within the catchment, which is located on the lower reaches of the River Duddon, about 3 km upstream of the tidal limit. Table VIII.1 presents summary statistics, and Figure VIII.2 presents boxplots of mean daily flows by month.

Table VIII.1: Summary flow statistics for the Duddon Hall flow gauging station

Watercourse	Station Name	Catchment Area (km²)	Mean Annual Rainfall 1961-1990 (mm)	Mean Flow (m³s-1)	Q95[1] (m³s-1)	Q10[2] (m³s-1)
Duddon	Duddon Hall	85.7	2265	5.717	0.515	13.700

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).

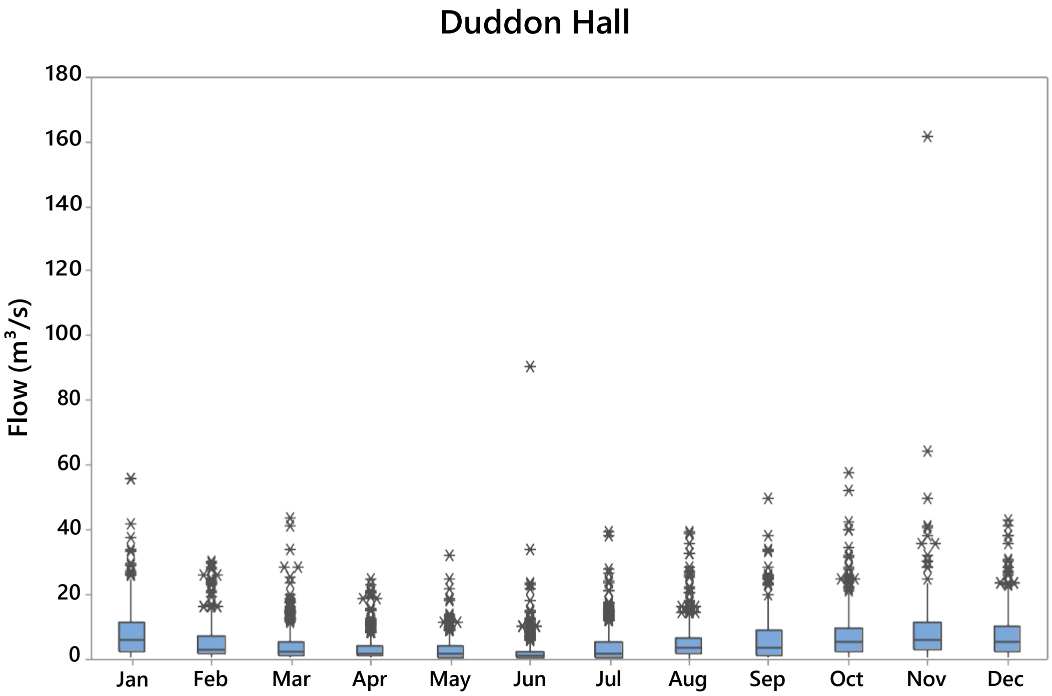

Figure VIII.2: Boxplots of mean daily flow records from the Duddon Hall gauging station (2004-2014)
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Flows were higher on average during the colder months. High flow events were recorded in most if not all months of the year, but there tended to be 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.

There are also numerous smaller streams, marsh drains and surface water outfalls discharging at intervals along the shore of the estuary. The only information on flow and bacterial content of these derives from the shoreline survey, where samples were taken and spot flow measurements made if it was possible to safely access them. The survey was undertaken in dry conditions in late spring. These measurements should be treated with some caution as they only relate to conditions on the day, and a significant proportion were not measured, including most of the larger ones (e.g. Duddon, Lickle).

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

Ref	Observation	*E. coli* (cfu/100ml)	Discharge (m^3/day)	*E. coli* loading (cfu/day)
1	Blea Beck outfall (flap valve)	11,000	9,224	$1.0x10^{12}$
2	Pear Tree Beck	14,000	Inaccessible (flowing)	
3	Cross Beck (flap valve)	13,000	Inaccessible (flowing)	
4	Soutergate Beck (pipe with flap valve)	4,100	Inaccessible (flowing)	
5	Pipe with flap valve	310	Inaccessible (flowing)	
6	Grize Beck (culverted)	12,000	Inaccessible (flowing)	
7	Galloper Stream	3,400	Inaccessible (flowing)	
8	Large pipe outfall (brown water)	1,300	218	$2.8x10^9$
9	Small pipe to the side of intermittent - flowing	42	118	$5.0x10^7$
10	Stream (possibly with private discharge)	120	82	$9.9x10^7$
11	Stream	2,000	Flow readings suspect	
12	Stream	270	23	$6.1x10^7$
13	Double concrete pipe outfall	1,300	Inaccessible (flowing)	
14	Red Gutter Stream	2,900	Flow readings suspect	
15	Stream	590	810	$4.8x10^9$
16	Stream	450	37	$1.7x10^8$
17	Salthouse Pool Stream	>20,000	2,048	$>4.1x10^{11}$
18	Small Stream	12,000	Not flowing at the time	
19	Black Beck	9,500	Inaccessible (flowing)	
20	Field drainage	7,400	330	$2.4x10^{10}$
21	Stream	3,400	6,648	$2.3x10^{11}$
22	Field drainage	7,400	425	$3.1x10^{10}$
23	Field drainage	5,300	64	$3.4x10^9$
24	Field drainage (flap valve)	4,800	622	$3.0x10^{10}$
25	Small stream (flap valve)	2,700	507	$1.4x10^{10}$
26	River Duddon	5,900	Inaccessible (flowing)	
27	River Lickle	14,000	Inaccessible (flowing)	
28	Stoup Dub Cut outfall (pipe)	99	1,331	$1.3x10^9$
29	Haverigg Pool River	700	Inaccessible (flowing)	

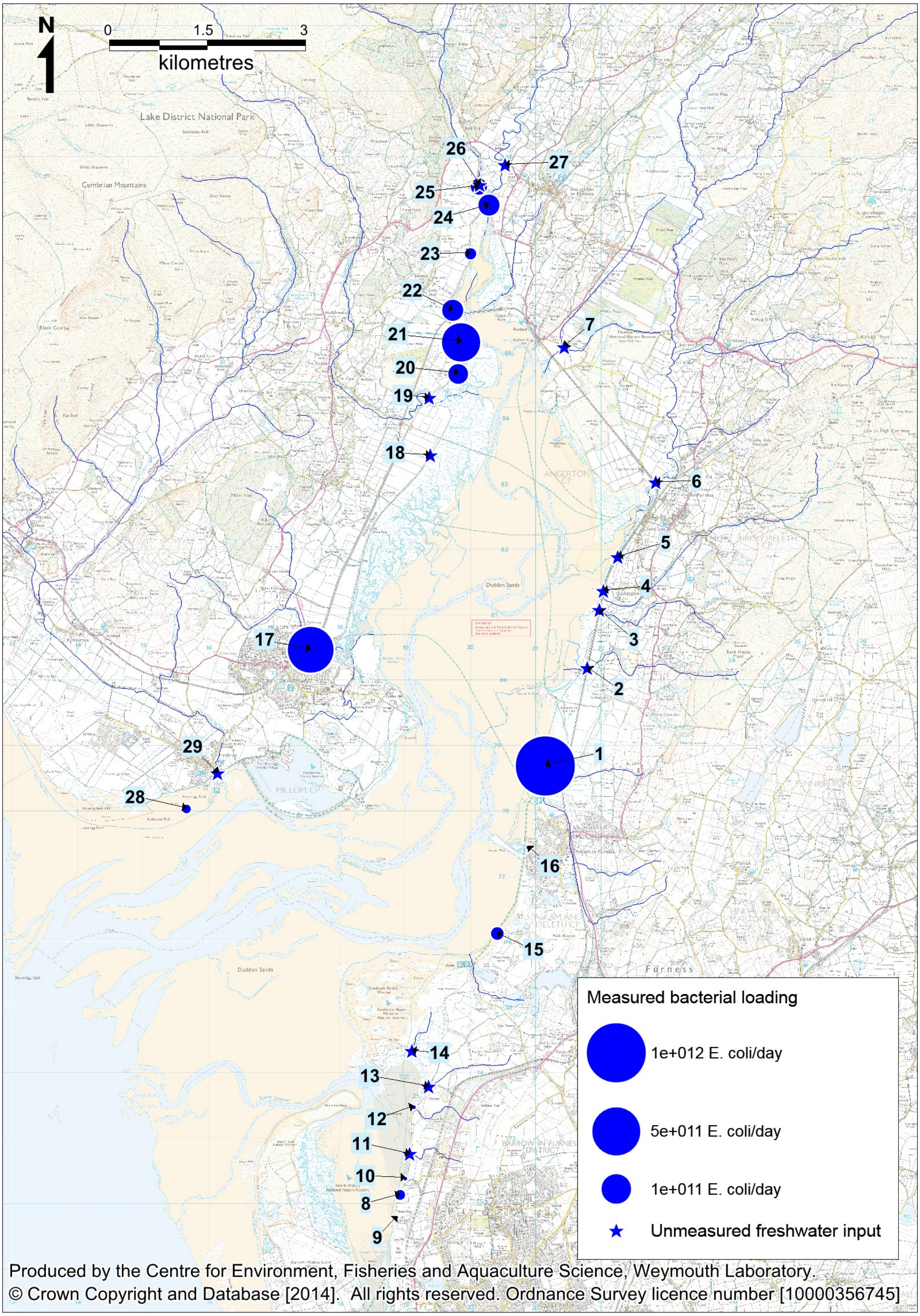

Figure VIII.3: Locations of shoreline survey bacteriological samples and spot flow measurements

Many of these watercourses were carrying relatively high concentrations of *E. coli*. The majority of those carrying larger bacterial loadings (and of the larger streams which were not measured) enter the estuary upstream of the fisheries. The Blea Beck may represent a significant local source of contamination to cockle settlements off Askam as it drains just to the north of where these usually occur. Freshwater inputs to the northern end of the Walney Channel were minor. Many of the freshwater inputs from the lower lying areas had non-return valves, so will only discharge at lower states of the tide.

Appendix IX. Hydrography

IX.1. Bathymetry

There are no detailed bathymetric charts of the area, so an aerial photograph taken at low water is presented instead (Figure IX.1).

The survey area is a spit enclosed estuary which covers an area of 45 km², around 90% of which is comprised of undulating intertidal sand-flats, with only a river channel at low water. Its shallow nature and the high proportion of its area which is intertidal will promote exchange of water, but limit the dilution potential. It faces south west, towards the Irish Sea, and there is an ebb delta (sandbank) at its mouth which will afford some protection from incoming swells. Dune systems flank the estuary mouth, and there are extensive areas of saltmarsh backed by reclaimed grazing marsh in the inner estuary. The outer andmiddle reaches are relatively wide, and it narrows significantly near to the tidal limit. The two larger freshwater inputs (Rivers Duddon and Lickle) drain to the head of the Duddon estuary, but there are also several other significant watercourses draining to the estuary at intervals. The main river channel is meandering and diverges and re-converges in several places. There are numerous other channels which drain from the intertidal areas and carry freshwater inputs towards the main river channel. The layout of these channels is constantly changing.

Just inside the estuary mouth, there is a channel (Walney Channel) which forms a connection behind Walney Island to the Barrow Dock area and Morecambe Bay. The middle reaches of this channel are intertidal, with the elevation of the channel bed peaking to the north of the Jubilee Bridge around an area called the Walney Meetings. 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. Either way, the connection will be limited to higher states of the tide, and may not be made at all on the smallest neap tides. A subtidal channel connects the mouth of the Walney Channeldirectly to the Irish Sea.

Figure IX.1: Aerial photograph of the Duddon Estuary
Bing Maps

IX.2. Tides and Currents

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 estuary.

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

Port	Height above chart datum (m)				Range (m)	
	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Duddon Bar	8.5	6.6	2.6	0.9	7.6	4.0

Data from Admiralty TotalTide©

Advection of pollutants by tidal currents is likely to be the main mode of contaminant transport in the Duddon estuary. The flood tide will convey relatively clean water originating from the open Irish Sea into the estuary, whereas the ebb tide will carry contamination from shoreline sources out through it. Tidal stream atlases indicate that offshore tidal streams flood in a southerly direction parallel to the coast here, with weaker ebb streams flowing in the opposite direction. Contamination from sources discharging to the Irish Sea coast to the north of the estuary may therefore be carried in during the flood.

There are no tidal diamonds within the Duddon estuary, nor could any detailed observational or modelling results be found during a literature search. It was therefore not possible to present detailed information on circulation patterns within the estuary, or to make estimates of the distances over which sources of contamination may impact during the course of a flood or ebb tide (tidal excursion). The main flood current is reported to enter the estuary along its southern margin, with the main ebb current leaving the estuary along its northern margin (Halcrow, 2013). This may result in increased impacts of up- estuary sources around the northernmost of the main channels running through the outer estuary.

As levels rise, water will spread out across the intertidal, where current velocities will be lower. Consequently, shoreline sources of contamination will primarily impact up and downstream of their locations along the bank to which they discharge. Around low tide contamination from shoreline sources such as streams will be carried through drainage channels where the dilution potential is low, so high concentrations of faecal indicator bacteria may arise within them at these times.

Tides flood into the Walney Channel from both ends, meeting to the north of the Jubilee Bridge in an area called the Walney Meetings, then drain away in the opposite direction. Itis uncertain whether there is a net flow of water in any one direction through this channel, but given the circulation pattern described above it is concluded that it is unlikely that sources south of the Meetings will impact on the survey area. Contamination from sourcesto the north of the Meetings will be carried in a westerly direction once they pass through the mouth of the Walney Channel during the ebb tide.

In addition to tidally driven currents are the effects of freshwater inputs and wind. Freshwater inputs are very low relative to tidal exchange, with mean and maximum flow rations of 0.001 and 0.016 respectively (Futurecoast, 2002). As such, the estuary is considered well mixed and density effects are unlikely to significantly modify tidal circulation patterns. Repeated salinity measurements taken between 2004 and 2014 at the three bathing water sites within the estuary (Figure IX.2).

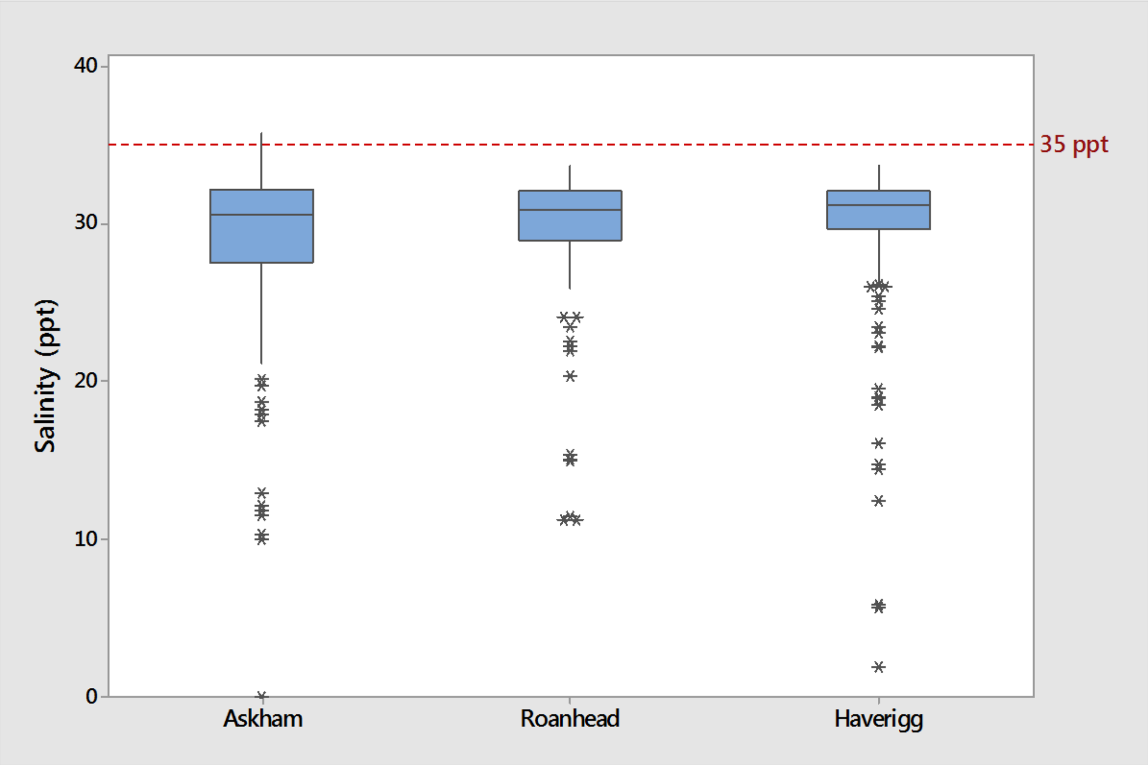

Figure IX.2: Boxplot of salinity measurements 2004-2014

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These measurements confirm that freshwater influence in the outer estuary in the vicinity of the shellfisheries is generally low, with average salinities between 29 and 30 ppt at all three locations. There was a very slight decrease in salinity from Askam to Roanhead, then to Haverigg, as may be expected. Salinities of less than 20 ppt were recorded on occasion at all three locations, indicating that at times of high river flow a significant proportion of the water in the outer estuary derives from land runoff. As land runoff will contain higher levels of faecal indicator bacteria than seawater, there are likely to be higher levels of *E. coli* in the water column at such times. The decrease in freshwater influence through the lower reaches towards the mouth is very slight, as indicated by the very small increase in average salinities from Askam to Haverigg. It must however be noted that these salinity measurements were taken around high water, whereas aroundlow water salinity is likely to be lower.

Strong winds will modify surface currents. Winds typically drive surface water at about 3% of the wind speed (Brown, 1991) so a gale force wind (34 knots or 17.2 m/s) would drive surface water currents of about 0.5 m/s. These create return currents which may travel lower in the water column or along sheltered margins. South westerly winds will tend to push surface water up the estuary. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great numberof scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action. Where these waves break contamination held in intertidal sediments may be re-suspended. The delta at the estuary mouth will afford some protection from incoming swells, but this will be very limited at higher states of the tide. Given the shape of the estuary, swells may penetrate past Askam.

Appendix X. Microbiological Data: Seawater

There are three bathing waters within the Duddon estuary designated under the Directive 76/160/EEC (Council of the European Communities, 1975), the locations of which are shown in Figure X.1. Due to changes in the analyses of bathing water quality by the Environment Agency from 2012, only data produced up to the end of 2011 were used in these analyses.

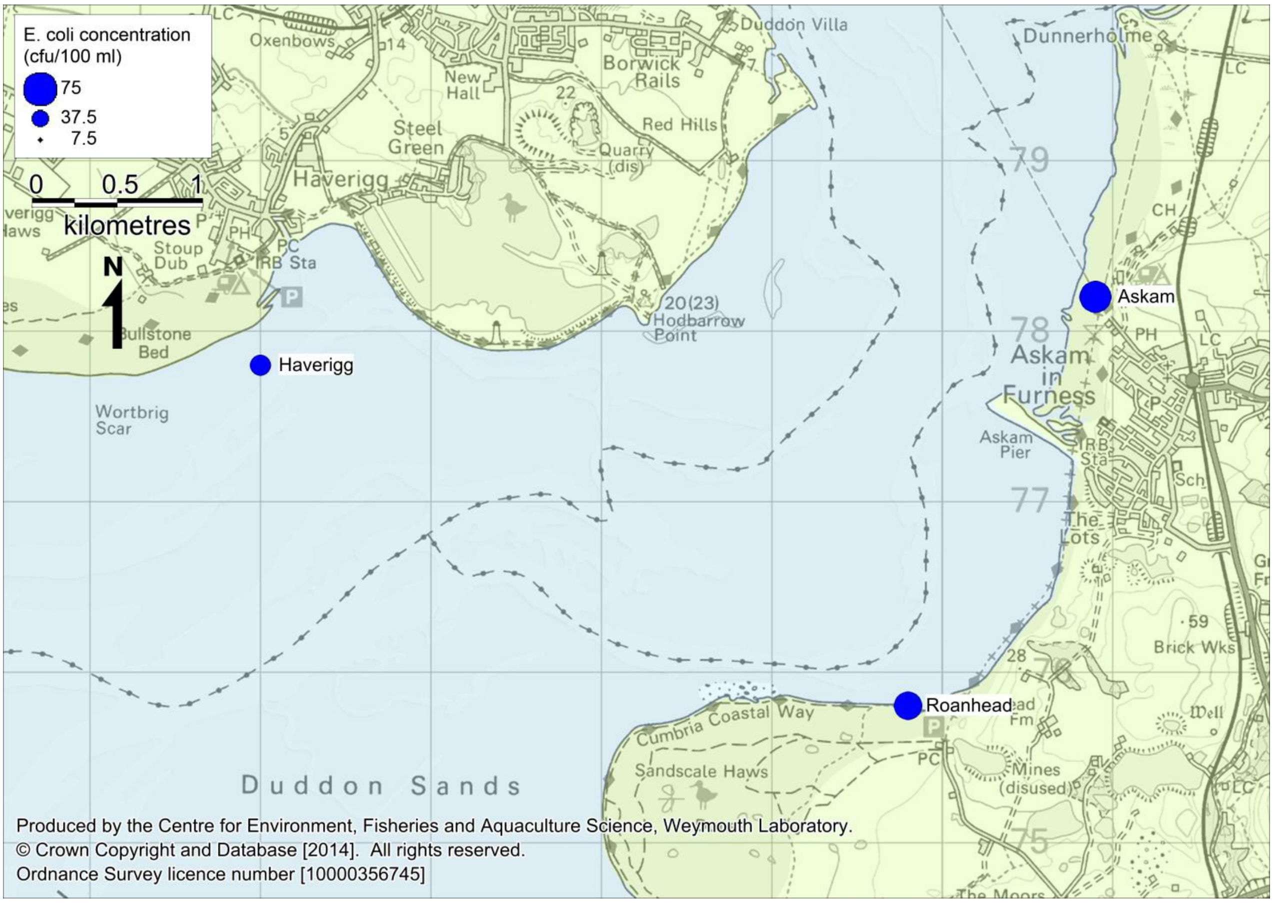

Figure X.1: Location of designated bathing waters monitoring points in the Duddon Estuary
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Around twenty water samples were taken from each of the bathing waters sites during each bathing season, which runs from the 15th May to the 30th September. Faecal coliforms 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 faecal coliforms results, 2004-2011 (cfu/100ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000	% over 10,000
Askam	160	06/05/2004	19/09/2011	70.2	<2	5,000	46.9	8.8	0.0
Roanhead	160	06/05/2004	19/09/2011	61.6	<2	2,880	45.0	8.8	0.0
Haverigg	161	05/05/2004	19/09/2011	46.9	<2	61,000	36.6	6.8	1.9

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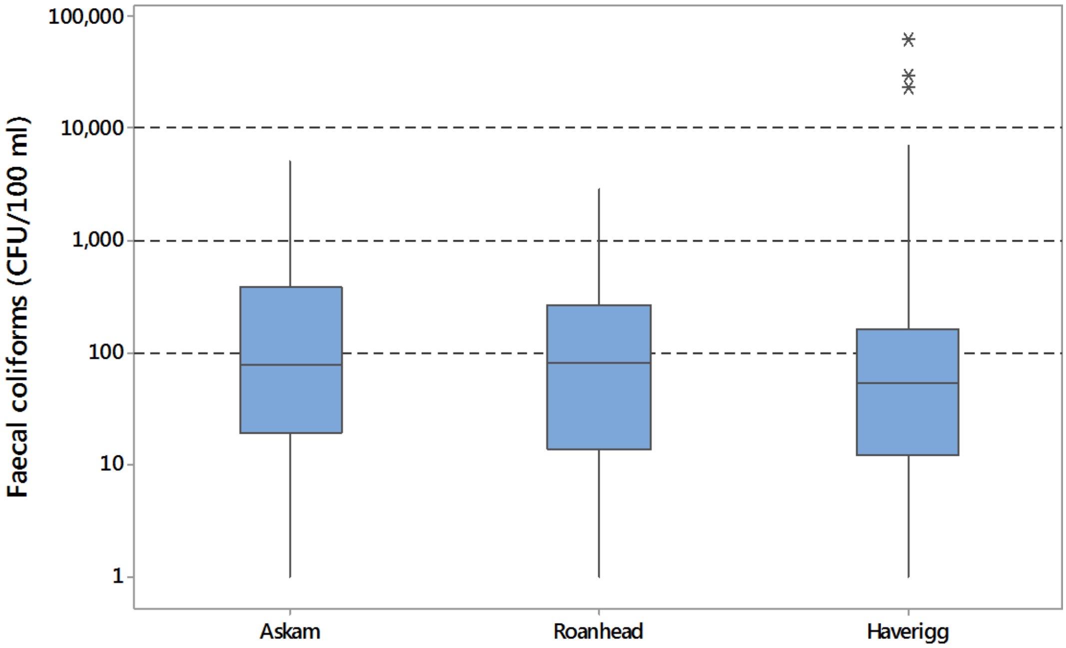

Figure X.2: Box-and-whisker plots of all faecal coliforms results by site
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There was a slight drop in geometric mean concentrations of faecal coliforms from Askam through to Haverigg. All sites had results exceeding 1,000 faecal coliforms/100 ml, but only Haverigg had any samples exceeding 10,000 faecal coliforms/100 ml. A one-way ANOVA test showed that there were no significant differences in faecal coliform concentrations between sites (p=0.235). Correlations (Pearson's) were run between samples at the sites that shared sampling dates, and therefore environmental conditions. There were significant correlations between all site pairings (r=0.695-0.819, p<0.001 in all cases) indicating that the sites are probably affected by similar sources.

Overall temporal pattern in results

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

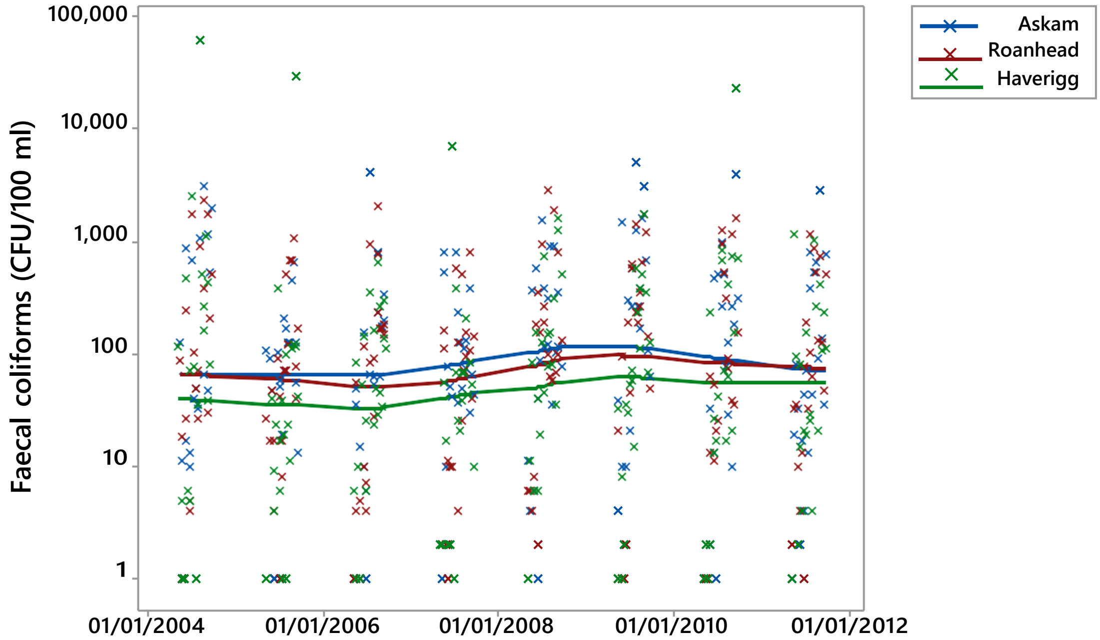

Figure X.3: Scatterplot of faecal coliform results for bathing waters in the Duddon Estuary overlaid with loess lines.

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Although they fluctuate significantly from week to week, faecal coliform levels have remained fairly stable on average since 2004.

Influence of tides

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of these bathing waters sampling points. Correlation coefficients are presented in Table X.2 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

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

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Askam	0.190	0.003	0.161	0.017
Roanhead	0.189	0.004	0.230	0.000
Haverigg	0.111	0.142	0.217	0.001

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Figure X.4 presents polar plots of log_{10} faecal coliform results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Duddon Bar Point is at 0° and low water is at 180°. Results of 100 faecal coliform 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.

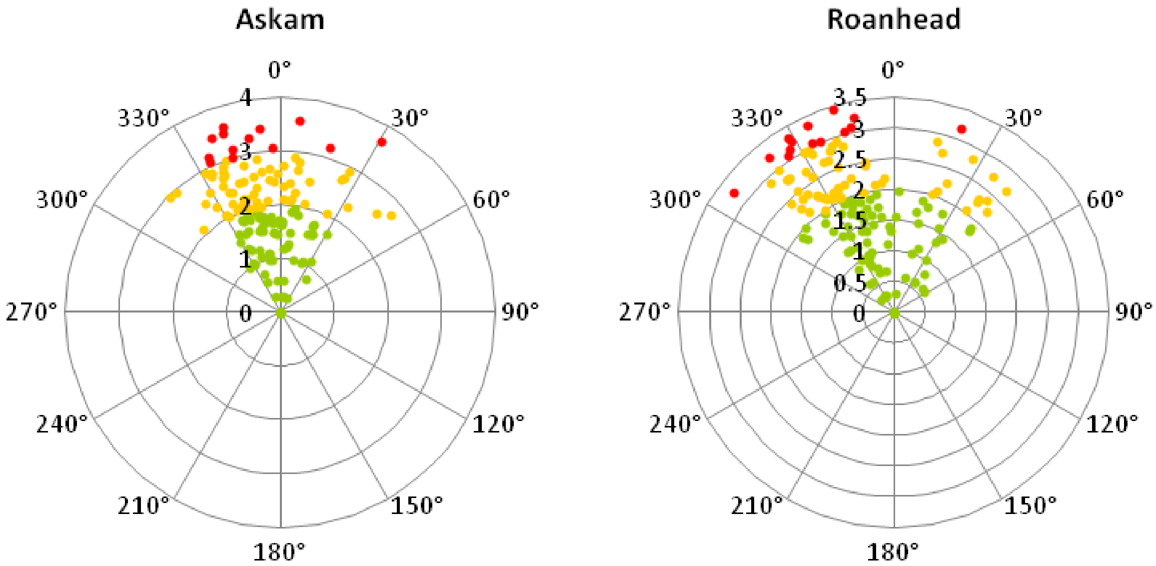

Figure X.4: Polar plots of log10 faecal coliform results (cfu/100 ml) against high/low tidal state.
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Most of the sampling effort at both Askam and Roanhead was concentrated around high water. Only a small proportion of the tidal cycle was represented, and no strong patterns are apparent in the polar plots.

Figure X.5 presents polar plots of log_{10} faecal coliform results against the spring neap tidal cycle for each RMP. 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 100 faecal coliform 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.

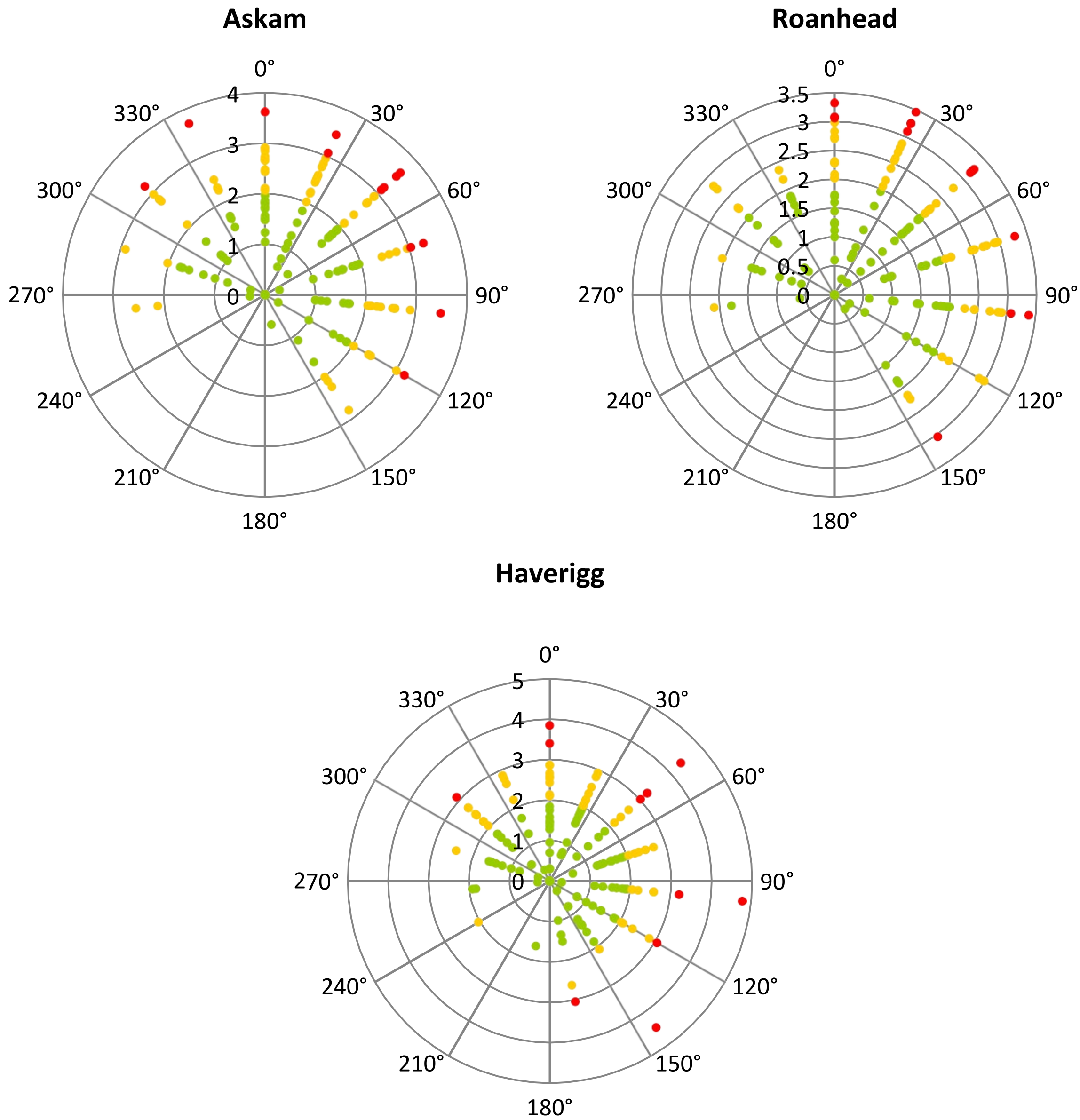

Figure X.5: Polar plots of log10 faecal coliform results (cfu/100 ml) against spring/neap tidal state.
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At all three sites, very little sampling was conducted during neap tides. Faecal coliform concentrations appear to peak on average during spring tides at all three locations.

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

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

	Site	Askam	Roanhead	Haverigg
	n	160	160	161
24 hour periods prior to sampling	1 day	0.219	0.063	0.237
	2 days	0.370	0.321	0.345
	3 days	0.215	0.225	0.161
	4 days	0.198	0.174	0.213
	5 days	0.138	0.156	0.203
	6 days	0.071	0.069	0.046
	7 days	0.110	0.151	0.142
Total prior to sampling over	2 days	0.354	0.227	0.338
	3 days	0.374	0.268	0.345
	4 days	0.404	0.300	0.373
	5 days	0.412	0.328	0.400
	6 days	0.403	0.334	0.383
	7 days	0.403	0.348	0.393

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All three sites were strongly influenced by rainfall. However, while Askam and Haverigg had increased faecal coliforms 1 day after rainfall, Roanhead was not affected until 2 days after a rainfall event.

Salinity

Salinity was recorded on most sampling occasions. Figure X.6 shows scatter-plots between faecal coliforms and salinity. Pearson's correlations were run to determine the effect of salinity on faecal coliforms at the bathing waters site.

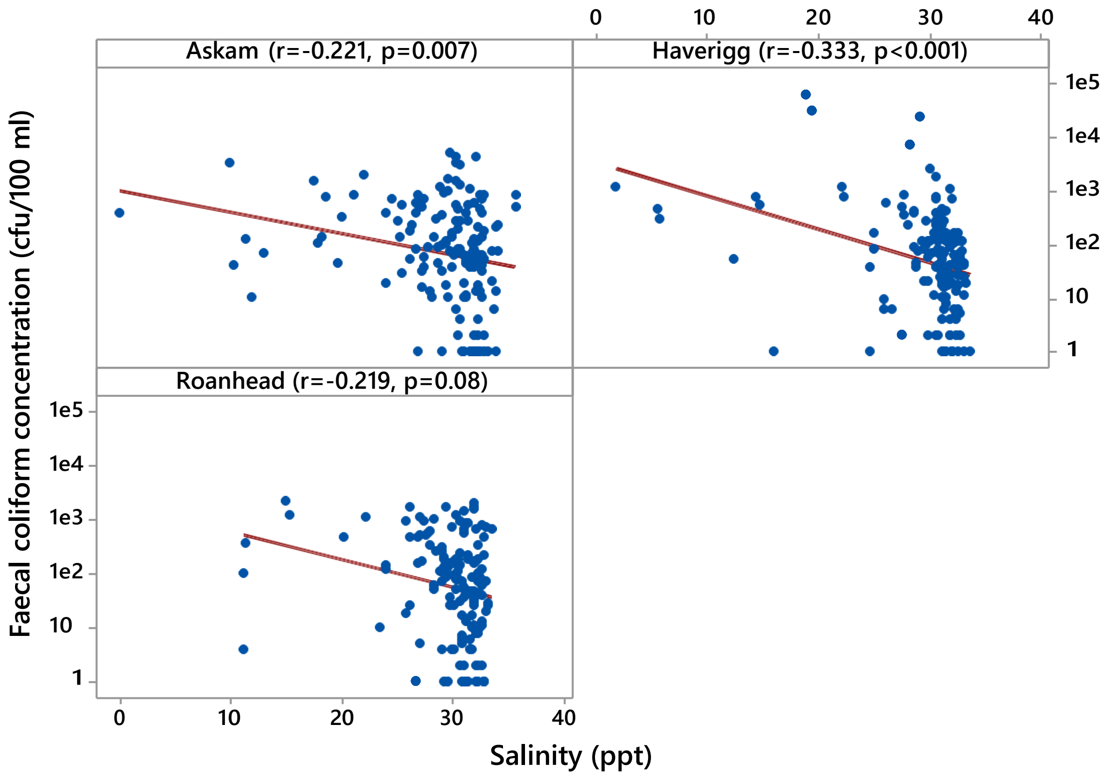

Figure X.6: Scatter-plots of salinity against faecal coliform concentration.
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For most of the time salinities were around 30 ppt at all three locations probably reflecting a bias to sampling around high water. There were significant correlations between salinity and faecal coliform concentrations at Askam and Haverigg. In combination with the lack of effect of rainfall after 1 day at Roanhead, this suggests that land runoff has a more important influence on faecal coliforms at Askam and Haverigg than at Roanhead.

Appendix XI. Microbiological Data: Shellfish Flesh

XI.1. Summary statistics and geographical variation

There are a total of three RMPs in the Duddon production area that have been sampled between 2004 and 2014. One of these RMPs is for mussels and two are for cockles. The geometric mean results of shellfish flesh monitoring from all RMPs sampled from 2004 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.3.

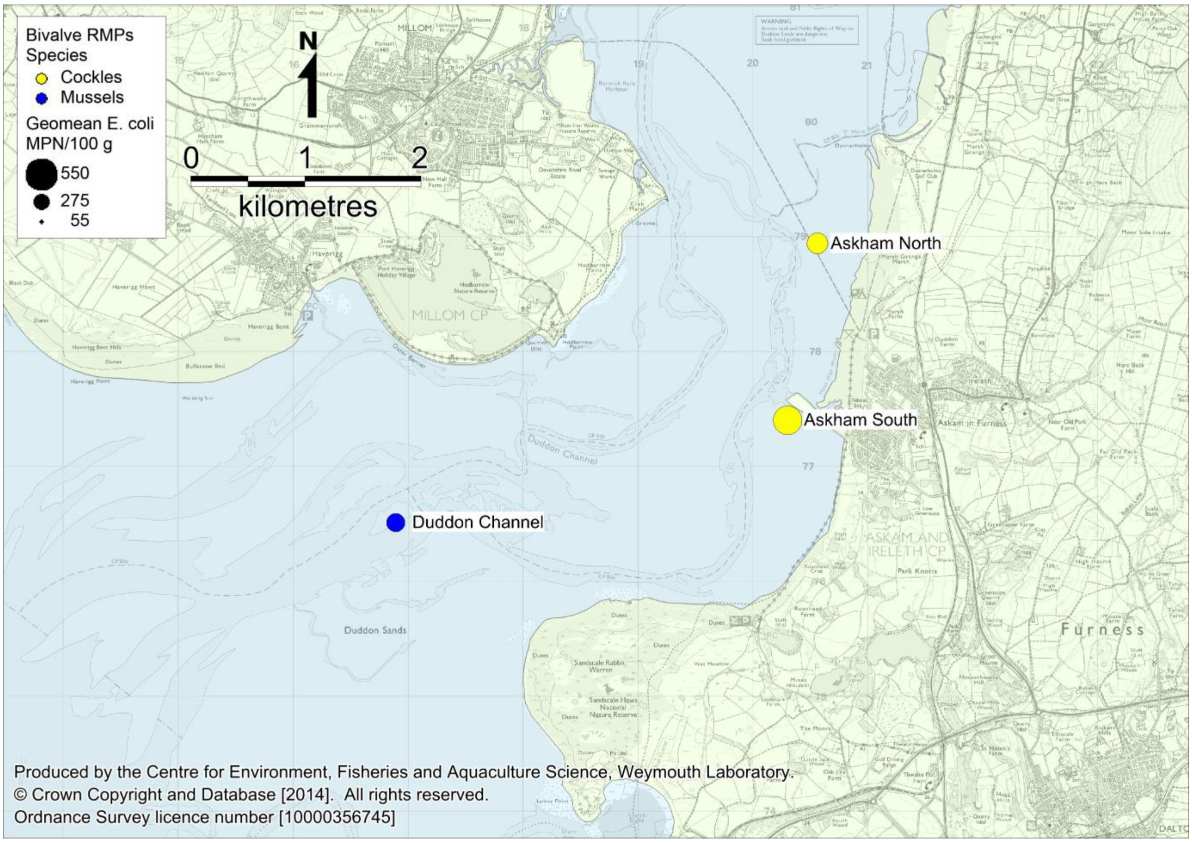

Figure XI.1: Bivalve RMPs active since 2004.

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) from RMPs sampled from 2004 onwards.

Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600
Askham North	Cockle	28	19/01/2004	13/09/2005	373.9	<20	16,000	60.7	10.7
Askham South	Cockle	26	19/01/2004	07/02/2006	505.4	20	11,000	69.2	3.8
Duddon Channel	Mussel	11	29/01/2014	30/04/2014	327.1	80	1,700	63.6	0.0

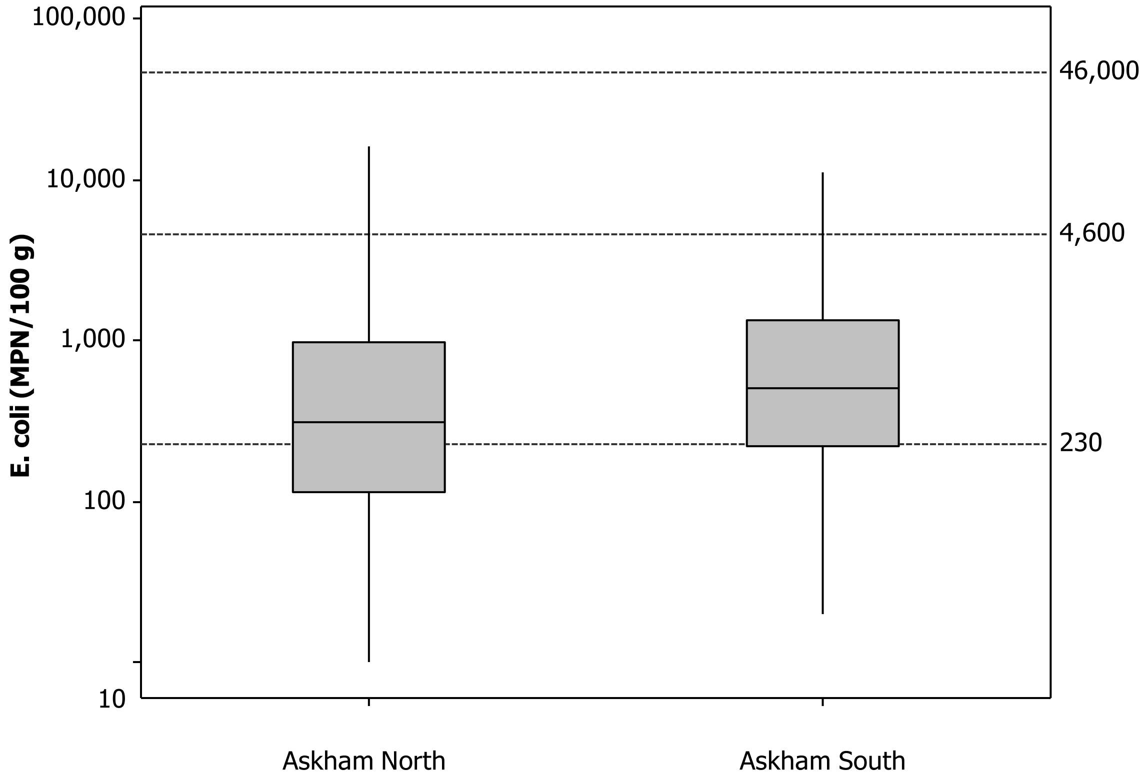

Figure XI.2: Boxplots of *E. coli* results from cockle RMPs from 2004 onwards.

E. coli levels exceeded 230 MPN/100 g in 60.7% and 69.2% of samples respectively at Askham North and Askham South cockle RMPs. *E. coli* levels exceeded 4,600 MPN/100g in 10.7% of samples at Askham North, and 3.8% of samples at Askham South. Although these results indicate marginally higher levels of contamination at Askham South, a two sample T-test showed that there were no significant differences in *E. coli* levels between the two (p=0.471). Pair-wise comparisons were made by running a correlation (Pearson's) between samples taken on the same day and hence under similar environmental conditions. There was a significant correlation between Askham North and Askham South (r=0.425, p=0.028) indicating that the RMPs are probably affected by similar sources.

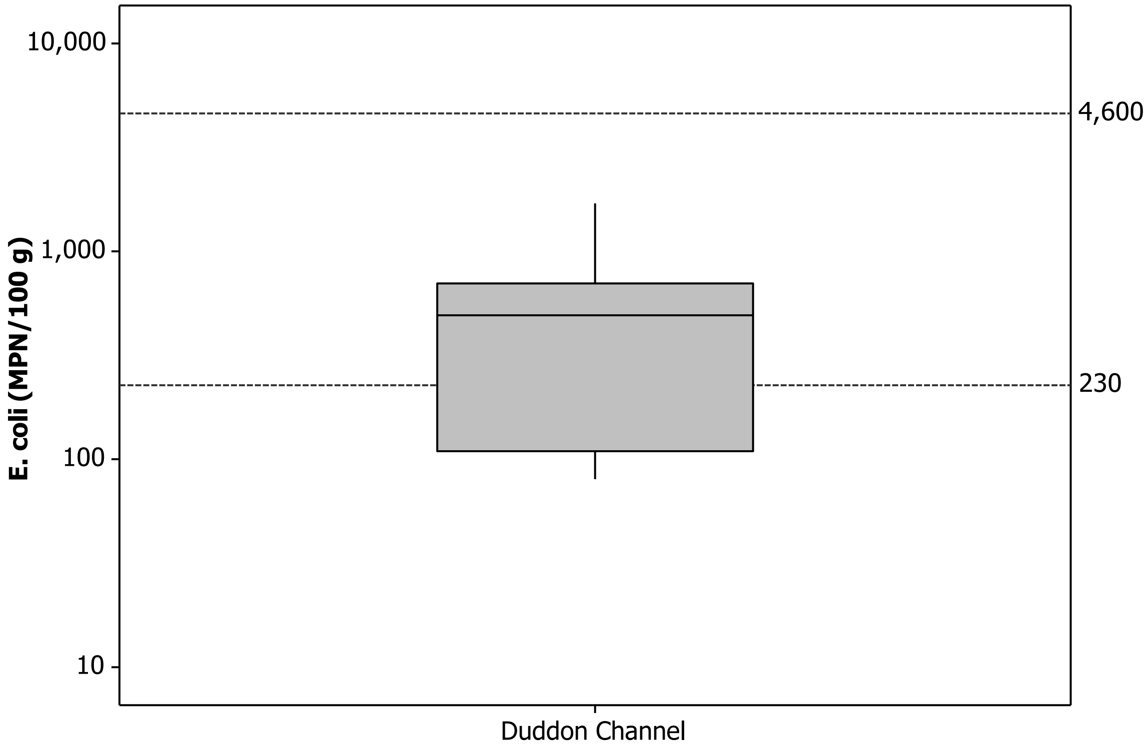

Figure XI.3: Boxplot of *E. coli* results from the Duddon channel mussel RMP.

E. coli levels at Duddon Channel exceeded 230 MPN/100 g in 63.6% of samples and no samples exceeded 4,600 MPN/100 g. The range of results recorded here (80 to 1700 *E. coli* MPN/100g) was small.

XI.2. Overall temporal pattern in results

The overall variation in *E. coli* levels found in cockles is shown in Figure XI.4. Mussels have only been sampled over three months and so it was not feasible to analyse temporal patterns in these data.

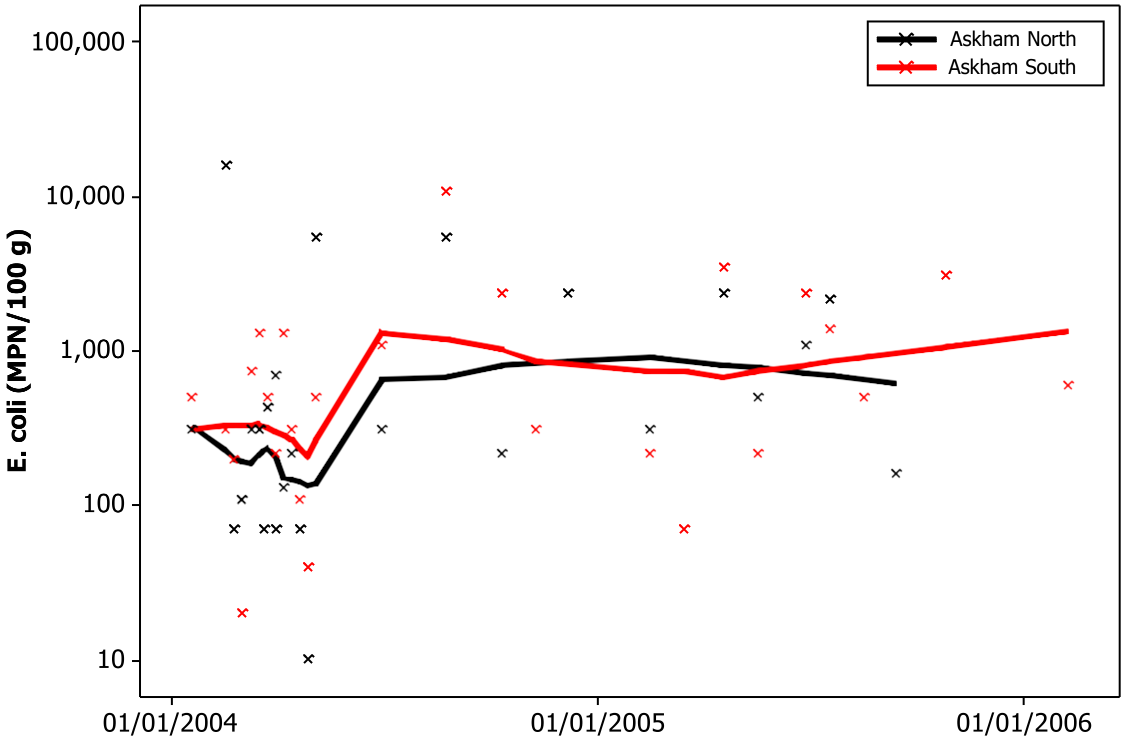

Figure XI.4: Scatterplot of *E. coli* results for cockles overlaid with loess line.

Figure XI.4 indicates that there has been little overall change in average levels of contamination observed through the two-year sampling period. The initial cluster of samples which were taken on a more frequent basis in early 2004 appears to contain a higher proportion of low results.

XI.3. Seasonal patterns of results

The seasonal patterns of results from 2004 to 2014 were investigated by RMP. Figure XI.5 shows box plots of *E. coli* levels at each cockle site by season.

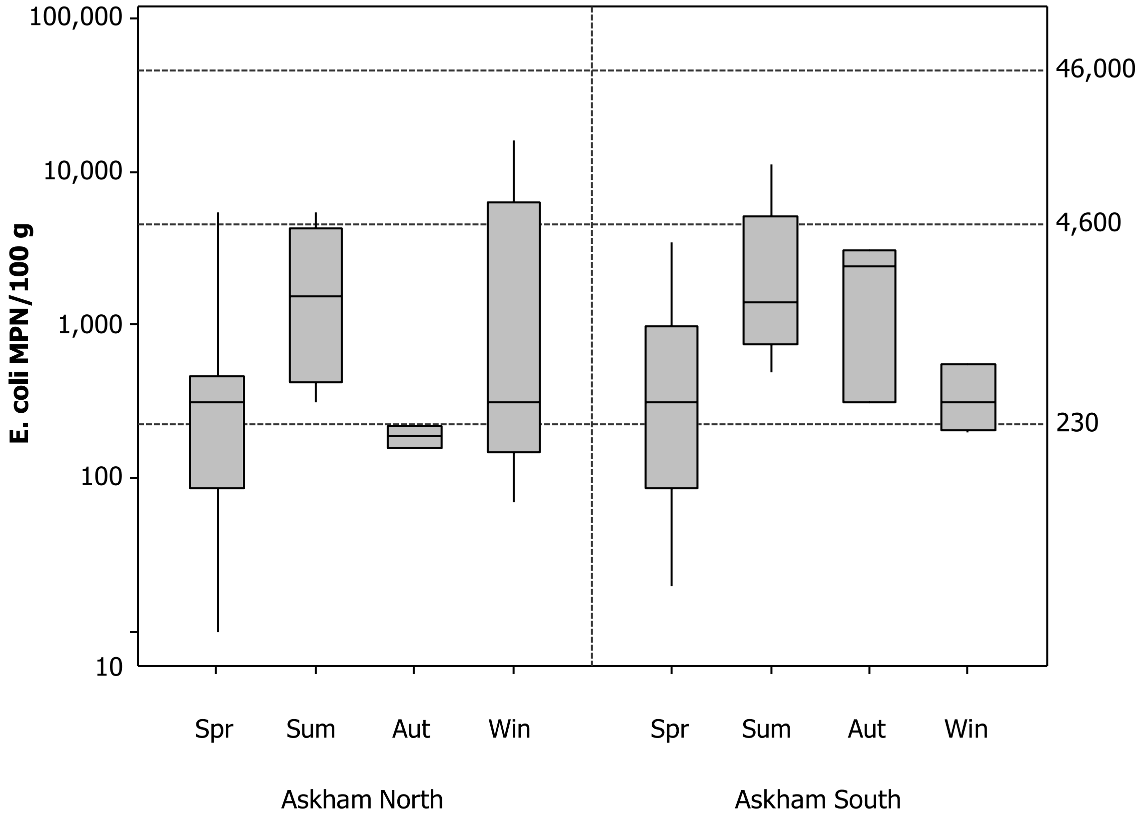

Figure XI.5: Boxplot of *E. coli* results for cockles by RMP and season

One-way ANOVAs showed that there were significant variations in *E. coli* levels between seasons at the Askham South cockle RMP (p=0.041) but not Askham North (p=0.143). A post ANOVA Tukey tests revealed no pairwise differences between seasons at Askham South.

XI.4. Influence of tide

Not enough data were available to carry out meaningful tidal analyses.

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 Duddon weather station (Appendix II for details) over various periods running up to sample collection. These are presented in Table XI.2, and statistically significant correlations (p<0.05) are highlighted in yellow.

Table XI.2: Spearman's Rank correlations between rainfall recorded at Duddon and shellfish hygiene results

	Site	Askham North	Askham South
	Species	Cockle	Cockle
	n	24	26
24 hour periods prior to sampling	1 day	0.111	0.301
	2 days	-0.033	0.276
	3 days	0.030	0.290
	4 days	0.195	0.065
	5 days	0.219	0.499
	6 days	-0.069	0.367
	7 days	-0.267	0.324
Total prior to sampling over	2 days	0.069	0.361
	3 days	0.115	0.366
	4 days	0.087	0.281
	5 days	0.127	0.315
	6 days	0.101	0.377
	7 days	0.036	0.453

There were no significant correlations between rainfall and *E. coli* levels in cockle flesh at Askham North. At Askham South, there were significant correlations between rainfall and *E. coli* levels in cockles five and six days after rainfall.

Appendix XII. Shoreline Survey Report

Date (time):
20 May 2014 (08.30 – 15:30)
21 May 2014 (08.30 – 15:30)

Cefas Officer:
Rachel Parks, Owen Morgan

Survey Partner:
Sue Carey (Sampling Officer, Barrow-in-Furness District Council)
Peter Jackson (Barrow-in-Furness District Council)

Area surveyed:
Track 1: Duddon Road car park, Askam-in-Furness to Foxfield railway station
Track 2: Palace Nook, Barrow-in-Furness to Duddon Road car park, Askam-in-Furness
Track 3: Salthouse Pool, Millom to Low Lickle Bridge, near Broughton-in-Furness
Track 4: Haverigg Bank to Salthouse Pool, Millom

Weather:
20 May 2014, overcast followed by sunny spells, 21.5°C, wind bearing/speed 135°/7.24 km/h
21 May 2014, sunny spells and overcast, 17.7°C, wind bearing/speed 314°/11.10 km/h

Tides:
Admiralty TotalTide© predictions for Duddon Bar (54°09'N 3°20'W). All times in this report are BST.

20/05/2014			21/05/2014		
			Last Quarter		
High	03:49	8.0 m	High	04:50	7.7 m
High	16:22	7.5 m	High	17:28	7.2 m
Low	10:35	1.2 m	Low	11:36	1.5 m
Low	22:56	1.7 m			

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 shownin Figure XII.1.

XII.1. Fishery

Shellfish within the Duddon estuary are harvested all year round by hand from natural stocks. At present there is one active mussel classification zone in the outer Duddon

Channel. Historically cockles have been harvested west of Askam and south of Lowsy Point but due to a lack of commercially viable stock they been closed since 2008. An abundance of dead cockle shells were observed along the intertidal area adjacent to Sandscale Haws Nature Reserve.

There are three main companies that harvest the mussels in the Duddon Channel and at the time of the shoreline survey, mussels in the outer Duddon Channel were beingharvested by hand, with fishermen reaching the stocks via quad bikes.

XII.2. Sources of contamination

Sewage discharges

Palace Nook intermittent discharge (observation 25) and Millom STW continuous and intermittent (observation 58) sewage discharges were identified on the shoreline survey. Palace Nook Intermittent was not flowing at the time. A high *E. coli* concentration was recorded at the Millom Borwick Rails discharge (>20,000 cfu/100ml), with the calculated *E. coli* loading exceeding 4.10×10^{11} cfu/day.

A water sample (DR 4, observation 13) taken from a large pipe which was thought to receive the Soutergate intermittent and continuous discharge points showed a relatively low concentration of *E*. coli 4100 cfu/100ml.

Haverigg Pool River (observation 56) with Haverigg Sewage Pumping Station and intermittent discharge located upstream showed a relatively low *E. coli* concentration of 700 cfu/100ml and therefore suggests the intermittent was not spilling at the time of the survey, however this cannot be confirmed.

United Utilities Foxfield Pumping Station and United Utilities Broughton in Furness STW Sewage Works (observation 21 & 22) were observed but were inaccessible and their outfalls were not located.

Freshwater inputs

The three larger watercourses observed on the survey were the Haverigg Pool (observation 56), the River Duddon (observation 53) and the River Lickle (observation 54).In addition to these, numerous other streams, marsh drains, and surface water outfalls were observed (see Table XII.1). In some cases these freshwater inputs could not be safely accessed, but where possible water samples were taken and spot flowmeasurements made.

Most of the freshwater inputs contained *E.* coli concentrations between 2,000 – 9,500 cfu/100ml, which is relatively high for rural streams. Five freshwater inputs were carrying *E.* coli concentrations exceeding 10,000 cfu/100ml (observation 11, 17, 42, 44 and 54).

Livestock

Sheep and cattle were observed throughout the survey area, predominantly grazing on land adjacent to the shoreline and close to freshwater inputs (observation 6; 7; 9; 18; 24; 30; 34; 43; 48; 53 and 54). The largest livestock aggregation (observation 43; around 200 sheep and 20 cows) was observed on the western shore north of Millom. A flock of 12 sheep were observed along the beach opposite Walney Island Airport.

Wildlife

Birds were observed throughout the survey area (observations 5, 28 and 37). The largest aggregation, around 50, was observed on sandflats close to the mouth of the estuary (observation 37). Dog walking was observed at two locations on the eastern shore, on the beach at Askam-in-Furness and at Sandscale Haws National Nature Reserve.

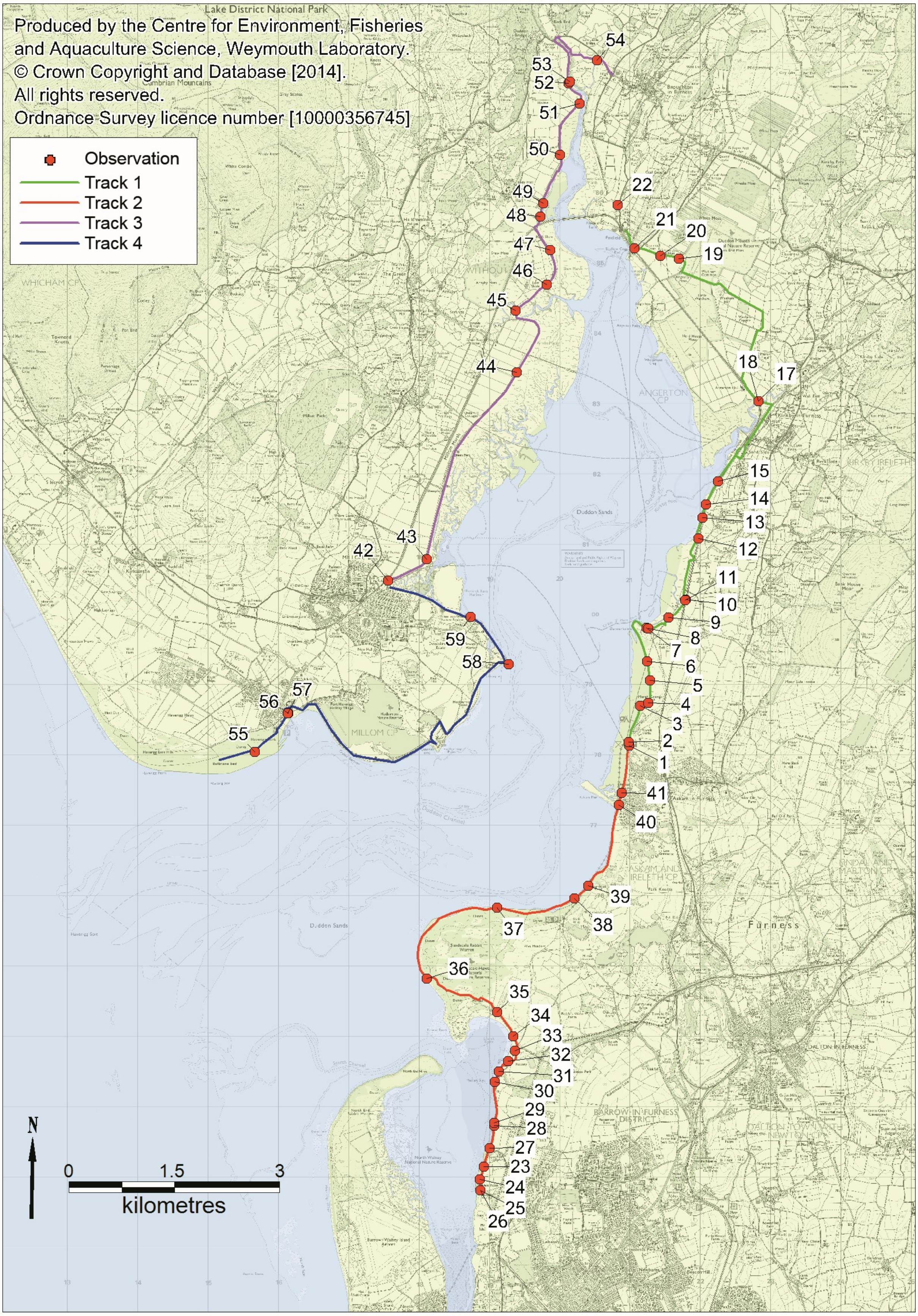

Figure XII.1: Locations of shoreline observations (Table XII.1 for details).

Table XII.1: Details of Shoreline Observations

Observation No.	Date	Time	NGR	Observation	Photo
1	20/05/2014	09:22	SD2098578139	2 Pipes - not flowing	
2	20/05/2014	09:24	SD2097578181	Dog walkers	
3	20/05/2014	09:37	SD2114278701	Culverted stream with flap valve (Blea Beck) (water sample DR1)	Figure XII.3
4	20/05/2014	09:57	S D2125278741	Marsh Farm Caravan site next to golf course	
5	20/05/2014	10:05	SD2127779060	~ 5 birds	
6	20/05/2014	10:10	SD2124279333	~ 10 sheep grazing	Figure XII.4
7	20/05/2014	10:28	SD2123279810	Sheep excrement	
8	20/05/2014	10:30	SD2125279799	Marsh drainage - not flowing	
9	20/05/2014	10:42	SD2154779957	~ 40 sheep	
10	20/05/2014	10:55	SD2178880210	Large pipe with wooden flap - not flowing	Figure XII.5
11	20/05/2014	10:58	SD2178480202	Pear Tree Beck (water sample DR2)	
12	20/05/2014	11:29	SD2197181087	Large pipe with flap & drainage channel - gentle flow (water sample DR3)	Figure XII.6
13	20/05/2014	11:47	SD2203081379	Large pipe with metal flap - Fast flowing (water sample DR4)	Figure XII.7
14	20/05/2014	11:59	SD2207581569	Pipe with flap running under railway - not flowing	
15	20/05/2014	12:16	SD2224781899	Pipe with flap - flowing (water sample DR5)	Figure XII.8
17	20/05/2014	13:13	SD2282783039	Large beck flowing - culverted (water sample DR6)	Figure XII.9
18	20/05/2014	13:13	SD2282783039	~ 40 Sheep in field either side of beck	
19	20/05/2014	14:17	SD2169485068	Otter Pool Stream - not flowing	
20	20/05/2014	14:34	SD2142985106	Galloper Stream - gentle flow (water sample DR7)	Figure XII.10
21	20/05/2014	14:45	SD2105685213	Foxfield Pumping Station	
22	20/05/2014	15:09	SD2082085831	Broughton in Furness STW – outfall not accessible	
23	21/05/2014	09:56	SD1891872142	Large pipe flowing (brown water) (water sample DR8)	Figure XII.11
24	21/05/2014	10:09	SD1885971959	~ 12 sheep on beach	
25	21/05/2014	10:14	SD1887171804	Palace Nook Intermittent - Not flowing	Figure XII.12
26	21/05/2014	10:14	SD1887171804	Small pipe to the side of intermittent - flowing (water sample DR9)	
27	21/05/2014	10:33	SD1899972402	Stream (water sample DR10)	Figure XII.13
28	21/05/2014	10:45	SD1906372726	~30 birds on the sandflats in the middle of the channel	

Observation No.	Date	Time	NGR	Observation	Photo
29	21/05/2014	10:47	SD1906272767	Stream flowing (water sample DR11)	Figure XII.14
30	21/05/2014	11:08	SD1907673353	1 cow seen in field	
31	21/05/2014	11:12	SD1913273494	Stream - Flowing (water sample DR12)	Figure XII.15
32	21/05/2014	11:32	SD1926573644	Sanitary debris along HW mark	
33	21/05/2014	11:40	SD1935873794	2 x concrete pipes - Flowing fast (water sample DR13)	Figure XII.16
34	21/05/2014	11:52	SD1933474002	~50 sheep in field	
35	21/05/2014	11.58	SD1910274341	Red Gutter Stream - Flowing (water sample DR14)	Figure XII.17
36	21/05/2014	13:00	SD1810274815	Lots of cockle shells	
37	21/05/2014	13:30	SD1910975827	~ 50 birds on sandflats in the middle of the estuary	
38	21/05/2014	13:48	SD2020675964	Dog walkers	
39	21/05/2014	13:53	SD2040576137	Stream across the beach - Flowing (water sample DR15)	Figure XII.18
40	21/05/2014	14:20	SD2083677292	~14 boats moored on marsh (2 possible houseboats)	Figure XII.19
41	21/05/2014	14:24	SD2087677463	Stream (water sample DR16)	Figure XII.20
42	20/05/2014	08:41	SD1755580483	Salthouse Pool Stream Millom (water sample DO1)	Figure XII.21
43	20/05/2014	09:00	SD1810080787	~20 cows & ~200 sheep	Figure XII.22
44	20/05/2014	09:40	SD1938383451	Small Stream - Not flowing (water sample DO2)	Figure XII.23
45	20/05/2014	10:03	SD1936784329	Black Beck (steep sided) - Flowing (water sample DO3)	Figure XII.24
46	20/05/2014	10:16	SD1981284695	Small stream - unable to sample or measure - surrounded by sheep	
47	20/05/2014	10:25	SD1981284696	Field drainage & sheep (water sample DO4)	Figure XII.25
48	20/05/2014	10:45	SD1985985185	Small stream fenced off from sheep (water sample DO5)	Figure XII.26
49	20/05/2014	10:58	SD1972485664	Field drainage (water sample DO6)	Figure XII.27
50	20/05/2014	11:15	SD1999786539	Field drainage (water sample DO7)	Figure XII.28
51	20/05/2014	11:33	SD2028387276	Field drainage with non return flap (water sample DO8)	Figure XII.29
52	20/05/2014	11:48	SD2012487561	Small stream with non return valve (water sample DO9)	Figure XII.30
53	20/05/2014	11:53	SD2013787581	River Duddon (too deep to measure) & sheep (water sample DO10)	Figure XII.31
54	20/05/2014	12:25	SD2052487887	River Lickle (too deep to measure) & sheep (water sample DO11)	Figure XII.32
55	21/05/2014	09:19	SD1565778049	Large Pipe (1m) - flowing from hole in side & broken pipe opposite (20cm) (water sample DO12) & dog walking on the beach	Figure XII.33
56	21/05/2014	10:00	SD1613078593	Haverigg Pool River with ~ 10 moored boats (water sample DO13)	Figure XII.34

Observation No.	Date	Time	NGR	Observation	Photo
57	21/05/2014	10:05	SD1612978593	Pipeline - possibly electric cable housing	
58	21/05/2014	11:20	SD1926879297	Millom Borwick Rails Continuous and Intermittent Sewage outfall 70 cm pipe (water sample DO14)	Figure XII.35
59	21/05/2014	11:44	SD1872679965	Large Pipe - Flowing unable to access, situated in Millom Ironwork Nature Reserve	

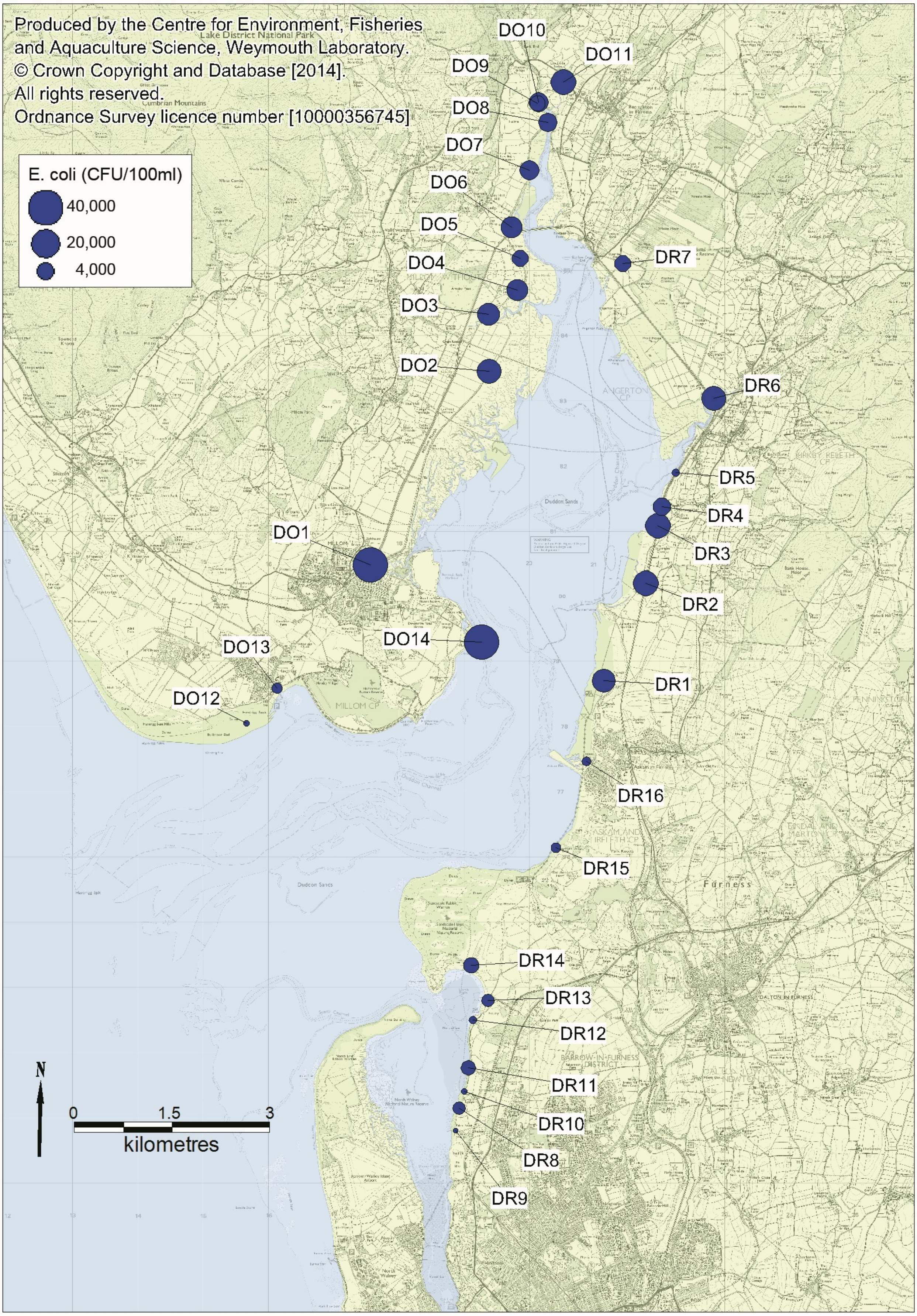

Figure XII.2: Water sample results (Table XII.2 for details)

Table XII.2: Freshwater sample *E. coli* results and spot flow measurements

Sample ID	Observation number	Observation	*E.* coli (cfu/100 ml)	Flow (m^3/day)	*E.* coli (cfu/day)
DR1	3	Blea Beck outfall (flap valve)	11,000	9224	1.0×10^{12}
DR2	11	Pear Tree Beck	14,000	Inaccessible	
DR3	12	Cross Beck (large pipe with flap - gentle flow)	13,000	Inaccessible	
DR4	13	Soutergate Beck (large pipe with metal flap - fast flowing)	4,100	Inaccessible	
DR5	15	Pipe with flap - flowing	310	Inaccessible	
DR6	17	Grize Beck (culverted, flowing)	12,000	Inaccessible	
DR7	20	Galloper Stream - gentle flow	3,400	Inaccessible	
DR8	23	Large pipe flowing (brown water)	1,300	218	2.8×10^{9}
DR9	26	Small pipe to the side of intermittent - flowing	42	118	5.0×10^{7}
DR10	27	Stream (possibly with private discharge)	120	82	9.9×10^{7}
DR11	29	Stream flowing	2,000	Flow readings suspect	
DR12	31	Stream	270	23	6.1×10^{7}
DR13	33	2 x concrete pipes - Flowing fast	1,300	Inaccessible	
DR14	35	Red Gutter Stream	2,900	Flow readings suspect	
DR15	39	Stream across the beach	590	810	4.8×10^{9}
DR16	41	Stream	450	37	1.7×10^{8}
DO1	42	Salthouse Pool Stream	>20,000	2048	$>4.1 \times 10^{11}$
DO2	44	Small Stream - Not flowing	12,000	Not flowing	
DO3	45	Black Beck (steep sided) - Flowing	9,500	Inaccessible	
DO4	47	Field drainage	7,400	330	2.4×10^{10}
DO5	48	Small fenced of stream from sheep	3,400	6648	2.3×10^{11}
DO6	49	Field drainage	7,400	425	3.1×10^{10}
DO7	50	Field drainage	5,300	64	3.4×10^{9}
DO8	51	Field drainage with non return flap	4,800	622	3.0×10^{10}
DO9	52	Small stream with non return valve	2,700	507	1.4×10^{10}
DO10	53	River Duddon	5,900	Inaccessible	
DO11	54	River Lickle	14,000	Inaccessible	

Sample ID	Observation number	Observation	*E.* coli (cfu/100 ml)	Flow (m^3/day)	*E.* coli (cfu/day)
DO12	55	Stoup Dub Cut outfall (~1m diameter pipe)	99	1331	$1.3x10^9$
DO13	56	Haverigg Pool River	700	Inaccessible	
DO14	58	Millom Borwick Rails Continuous & Intermittent Sewage outfall (70 cm pipe)	>20,000	1025	$>2.0x10^{11}$

Figure XII.3

Figure XII.4

Figure XII.5

Figure XII.6

Figure XII.7

Figure XII.8

Figure XII.9

Figure XII.10

Figure XII.11

Figure XII.12

Figure XII.13

Figure XII.14

Figure XII.15

Figure XII.16

Figure XII.17

Figure XII.18


Figure XII.19


Figure XII.20

Figure XII.21

Figure XII.22

Figure XII.23

Figure XII.24

Figure XII.25

Figure XII.26


Figure XII.27


Figure XII.28


Figure XII.29


Figure XII.30

Figure XII.31

Figure XII.32

Figure XII.33

Figure XII.34

Figure XII.35

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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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