Scottish Sanitary Survey Project

Sanitary Survey Report

East Firth and Firth

SI 379 and SI 363

March 2008

Cefas

FOOD STANDARDS AGENCY SCOTLAND

Buidheann Inbhe-Bìdhe an Alba

Report Distribution – The Firth

Date	Name	Agency*
	Linda Galbraith	Scottish Government
	Judith White	Scottish Government
	Ewan Gillespie	SEPA
	Douglas Sinclair	SEPA
	Stephan Walker	Scottish Water
	Alex Adrian	Crown Estate
	Dawn Manson	Shetland Islands Council
	Sean Williamson	NAFC
	Steven Hawkins	Shetland Mussels Ltd.**
	Alan Manzie	Demlane-Isle of Shuna Plc.**

* Distribution of both draft and final reports to relevant agency personnel is undertaken by FSAS.

** Distribution of draft and final reports to harvesters in undertaken by the relevant local authority.

Table of Contents

Acknowledgements

We are thankful to the following persons and agencies who provided assistance and information used in the following report.

Shetland Islands Council
Sean Williams, NAFC
Mr. Robert Anderson
Demlane – Isle of Shuna Plc
Mr. Steven Hawkins
SEPA Registry Office Dingwall
The Shetland Sea Mammal Group
Scottish Water
Dr. Alan Lilly, Macaulay Land Research Institute

1. General Description

The Firth and East Firth are located in the southwest of Shetland main island and lie between Tresta Voe to the east, Bixter Voe to the west and Sandsound Voe to the south (Figure 1.1). A relatively sheltered water, it receives freshwater from several burns, most notable of which are the Burn of Quarsdale and Burn of Tumblin to the west and Burn of Tresta and Stouri Gill to the east.

The settlement of Tresta lies along the eastern shore of Tresta Voe, approximately 1.5 km from the Tresta North mussel site.

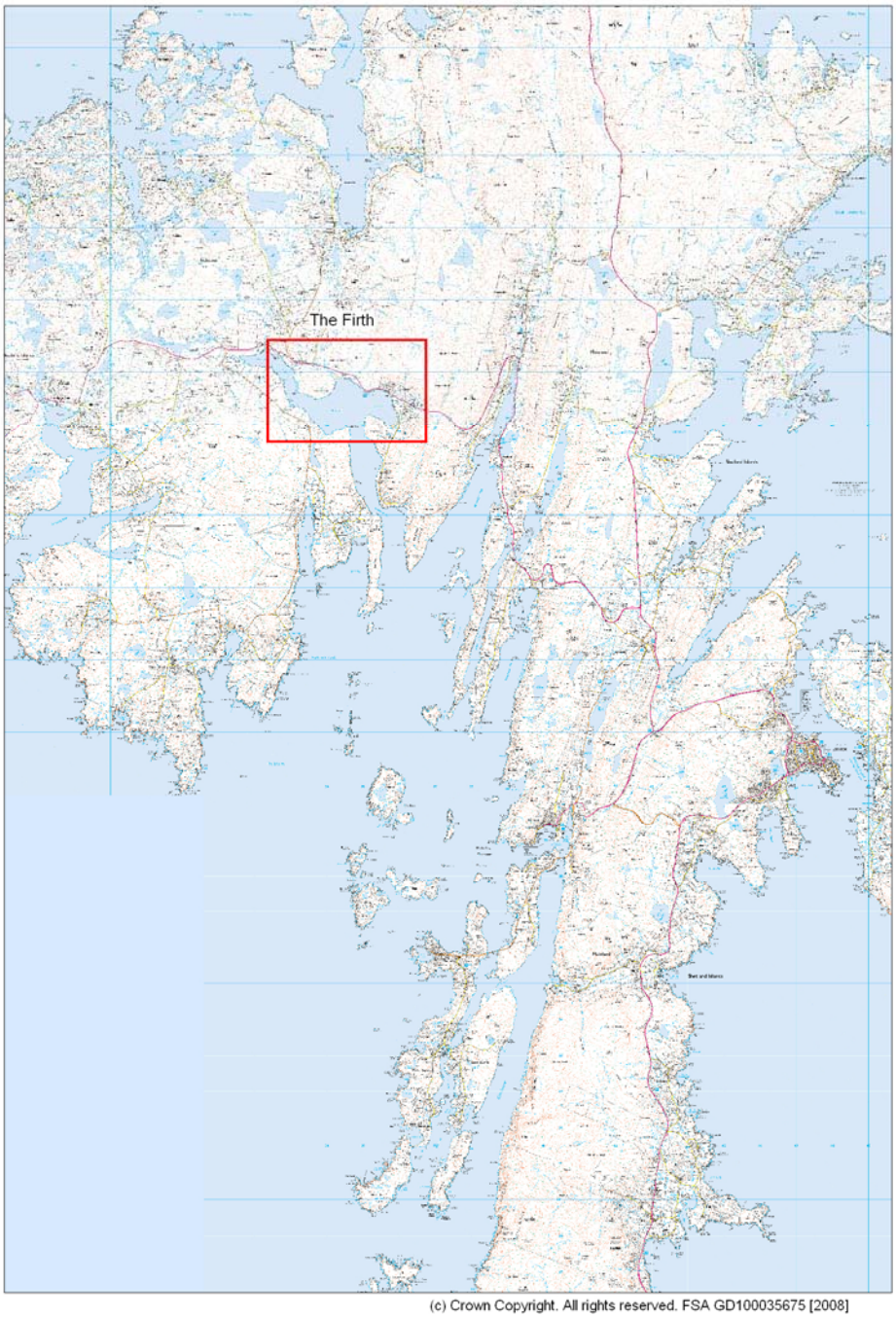


Figure 1.1 Location of the Firth

2. Fishery

The fishery consists of two separate production areas: The Firth (SI 363) and East Firth (SI 379) each of which contains a single mussel site. The site Ness of Bixter (SI 363 751 08) lies within The Firth production area and the Tresta North site (SI 379 769 08) lies in the East Firth. There is an additional seabed lease not currently in use located to the south of Tresta North.

On both sites, mussels are rope grown. Long lines attached to floats are laid out in parallel lines anchored at either end within the approved lease area. Vertical lines containing plastic pegs (droppers) are attached to the long lines. New lines are placed before or during spawning between May and early June and spat settle on to the droppers from the surrounding water. The spat are then left to grow for up to three years before reaching marketable size.

Mature mussels are harvested by stripping the attached mussels from the droppers using a system of brushes mounted to a funnel. In some cases, harvested mussels are cleaned and sorted on the barge and in others they are taken back to a central facility for scrubbing and sorting.

Harvesting is done in rotation with different lines set out in different years to allow harvesting of some stock every year. Mussels from the Ness of Bixter site were only just coming on to harvestable size at the time of survey.

Spawning occurs in May, during which time the meat yield declines substantially. Blooms of toxic algae typically occur during the summer months, resulting in fishery closures during the remaining summer months that usually clear up for harvesting in September or October.

As pressure from supermarkets to supply mussels year-round increases, some of the larger Shetland producers are harvesting during the May to August time frame. While this does not currently affect the sites in Weisdale Voe, this could change in the future if the leases are sold or harvesters change practices to take advantage of market opportunities.

The Ness of Bixter site was classified earlier this year and was in production at the time of survey. It consisted of 4 long lines with droppers to a depth of 5 meters. The stated RMP for this site is HU 335 513. As mapped in Figure 2.1, it does not appear to lie on the fishery but this is due to the fact that the grid reference is only stated to 100 m accuracy. Due to scheduling conflicts, this site was visited and sampled by the OC sampling officer, Sean Williamson. One sample was collected at this site from the recorded RMP.

Two lines were in place at the Tresta North site at the time of the shoreline survey and both lines were virtually empty of mussels. Samples were taken from the bottoms of the floats. It is not likely that there will be sufficient stock to harvest from this site in the near future. The harvester's representative indicated that the lines had been in for over a year and that they had anticipated harvesting them in a year's time.

Figure 2.1 shows the relative positions of the mussel farms, Food Standard Agency Scotland designated Production Area and the Crown Estate lease areas.

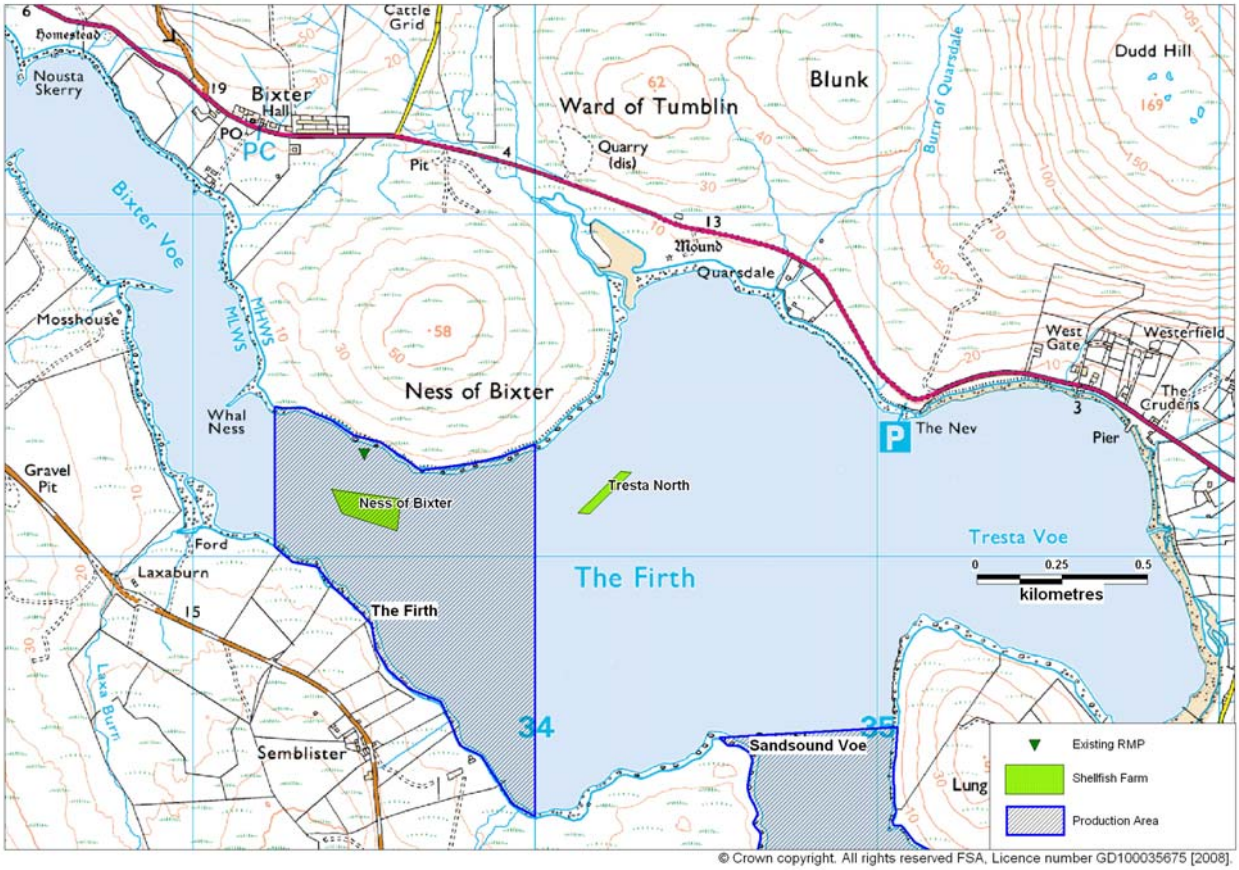


Figure 2.1 Fishery locations within the Firth

3. Human Population

The figure below shows information obtained from the General Register Office for Scotland on the population within the census output in the vicinity of the Firth.

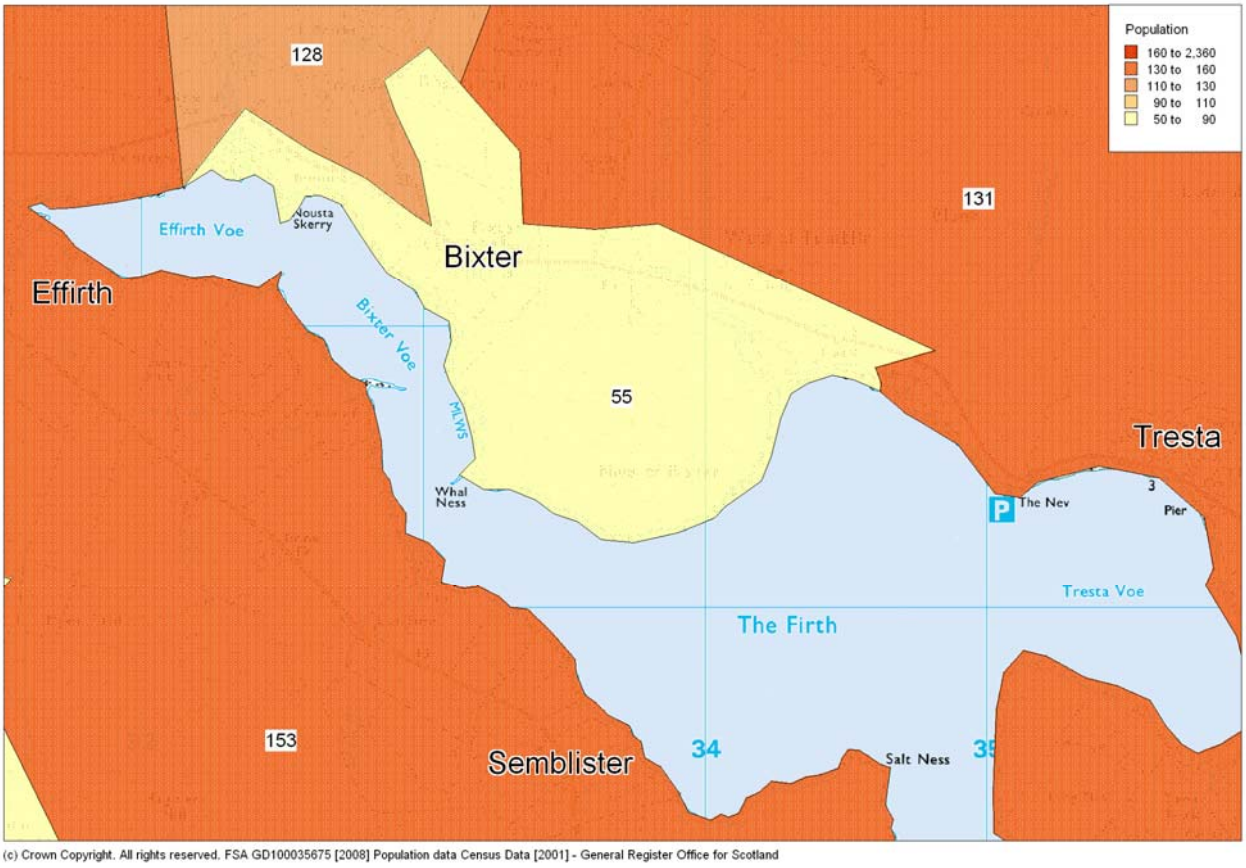


Figure 3.1 Population of the Firth

The population for the four census output areas bordering immediately on the Firth are:

60RD000033	131
60RD000035	128
60RD000136	55
60RD000032	153
Total	467

On the eastern side of the Firth are the settlements of Effirth and Bixter. On southwestern side of the Firth is the settlement of Semblister and east of Tresta Voe is the larger settlement of Tresta. Most of the population is concentrated towards the eastern shore of the Firth and any associated faecal pollution from human sources will be concentrated in this area.

For Shetland as a whole, the total number of holiday travellers in 2006 was estimated as 24,744 (compared to the 2001 census population of 21, 988) with the majority of tourists (66%) visiting during the peak summer season of June to

September (Shetland Enterprise, Shetland Visitor Survey 2005/2006). There is no explicit information on the number of visitors to this specific area. There are no known holiday parks or caravan sites in the immediate area of the voe. There could therefore be an increase in faecal contamination from human sources during the summer months but there is not sufficient information on which to base an estimate for this area.

4. Sewage Discharges

Scottish Water have provided information on the following discharges from community septic tanks to the firth:

Table 4.1

Production Area	NGR of discharge	Discharge Name	Discharge Type	Level of Treatment	Consented flow (DWF) m3/d	Consented/ design PE	Q&S III Planned improvement?
Firth	HU 3300 5200	Bixter	Continuous	Septic Tank	3.6	20	N
Firth	HU 3570 5140	Tresta	Continuous	Septic Tank		10	N

No sanitary or microbiological data were available for these discharges. The locations of these discharges are illustrated in Figure 4.1.

A number of the homes around the area appeared to have private septic tanks. It has not historically been obligatory to register private septic tanks in Scotland. Currently, this must be done upon installation of a new tank or sale of the property thereby leaving many older tanks unrecorded.

As of the date of this report, there were no known SEPA registered discharges from private septic tanks directly to the Firth. However, it was apparent upon survey that habitations around the area were not connected to a public septic system and had private septic tanks. Further information on these can be found in Appendix 16.1, Shoreline Survey.

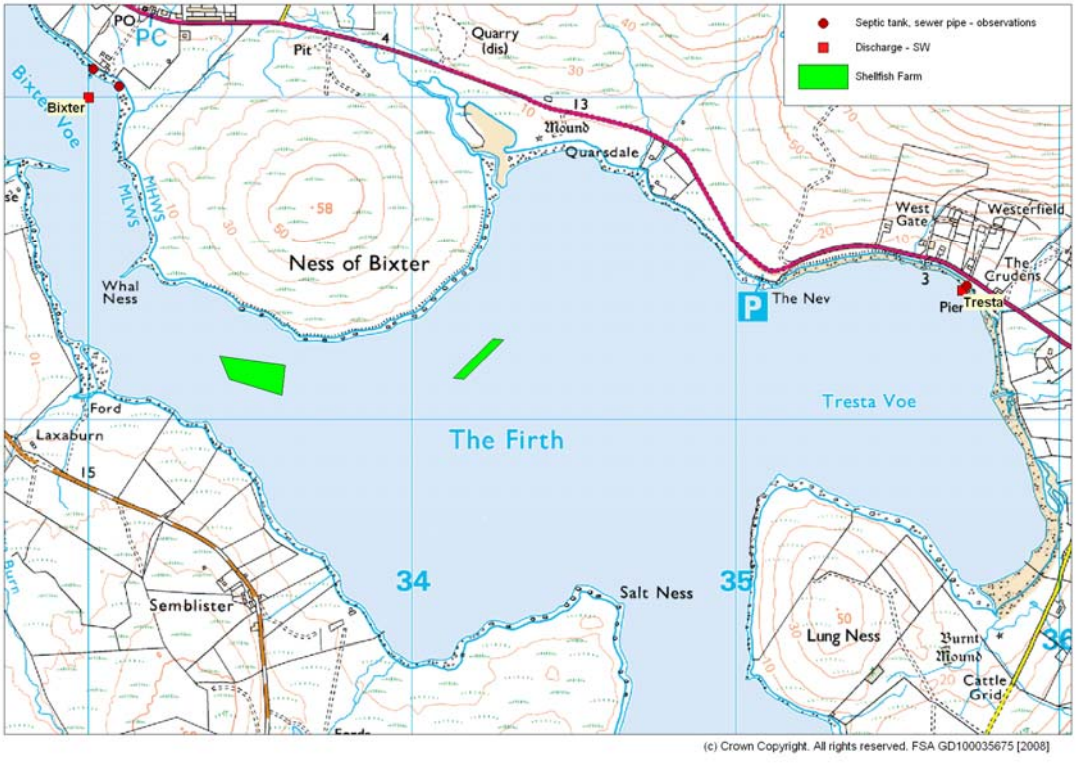


Figure 4.1 Sewage discharges to the Firth

5. Geology and soils

Component soils and their associations were investigated using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute. The relevant soil associations and component soils were then researched to establish basic characteristics. From the maps seven main soil types were identified: 1) humus-iron podzols, 2) brown forest soils, 3) calcareous regosols, brown calcareous regosols, calcareous gleys, 4) peaty gleys, podzols, rankers, 5) non-calcareous gleys, peaty gleys: some humic gleys, peat, 6) organic soils and 7) alluvial soils (see the glossary at the end of this section).

Humus-iron podzols are generally infertile and physically limiting soils for productive use. In terms of drainage, depending on the related soil association they generally have a low surface % runoff, of between 14.5 – 48.4%, indicating that they are generally freely draining.

Brown forest soils are characteristically well drained with their occurrence being restricted to warmer drier climates, and under natural conditions they often form beneath broadleaf woodland. With a very low surface % runoff of between 2 – 29.2%, brown forest soils can be categorised as freely draining (Macaulay Institute, 2007).

Calcareous regosols, brown regosols and calcareous gleys are all characteristically freely draining soils containing free calcium carbonate within their profiles. These soil types have a very low surface % runoff at 14.5% and can be classified as freely draining soils.

Peaty gleys, peaty podzols and peaty rankers contribute to a large percentage of the soil composition of Scotland. They are all characteristically acidic, nutrient deficient and poorly draining. In addition, they also have a very high surface % runoff of between 48.4 – 60%, confirming that they are poorly draining.

Non-calcareous gleys, peaty gleys and humic gleys are generally developed under conditions of intermittent or permanent water logging. In Shetland, non-calcareous gleys within the Arkaig association are most common and have an average surface % runoff of 48.4%, indicating that they are generally poorly draining.

Organic soils often referred to as peat deposits and are composed of greater than 60% organic matter. Organic soils have a surface % runoff of 25.3% and although low, due to their water logged nature, results in them being poorly draining.

Alluvial soils are confined to principal river valleys and stream channels, with a wide soil textural range and variable drainage. However, the alluvial soils encountered within the regions mapped have an average surface % runoff of 44.3%, so it is likely that in this case they would be poorly draining.

Maps were produced using these seven soil type groups and whether they are characteristically freely or poorly draining (Figure 5.1).

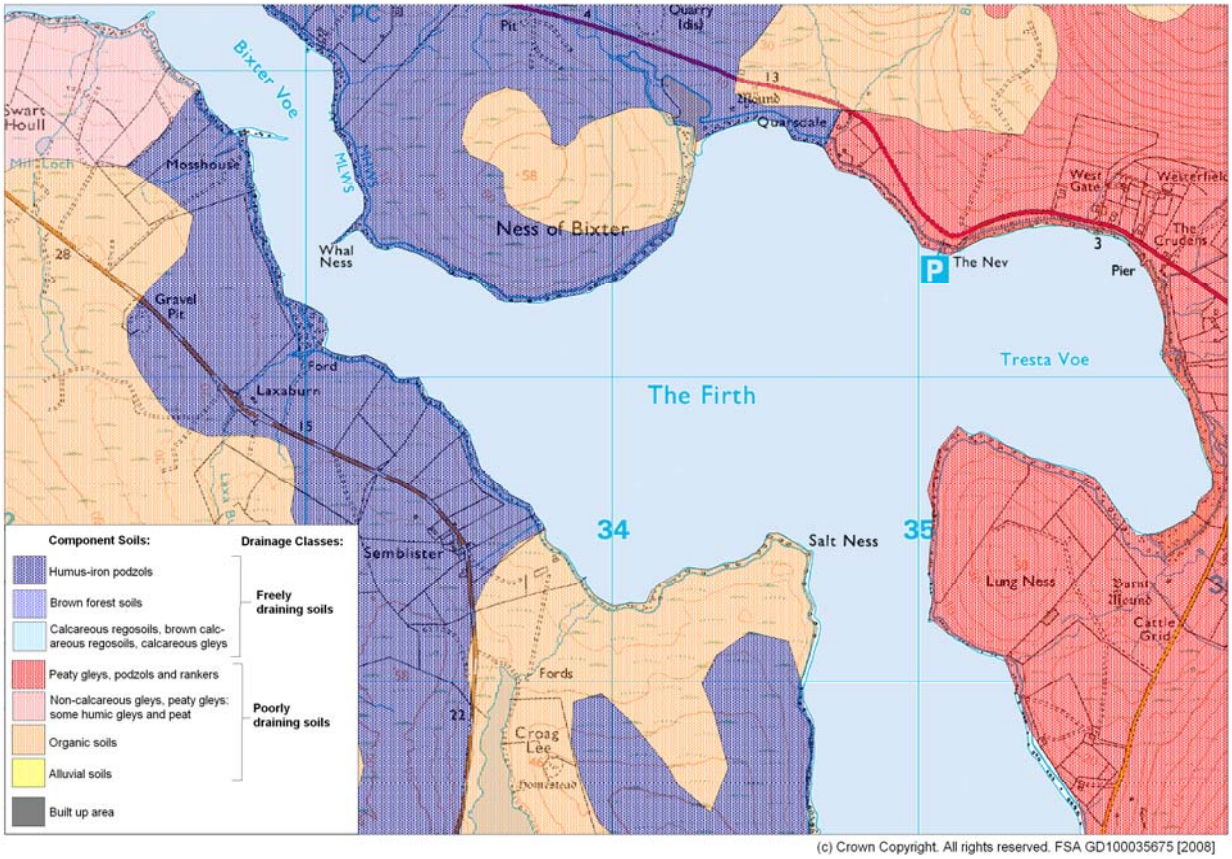


Figure 5.1 Component soils and drainage characteristics

There are three main types of component soils visible in this area. The most dominant is composed primarily of peaty gleys, (peaty) podzols and (peaty) rankers. This soil type dominates much of the eastern coast of The Firth.

The other two types of dominant soils; humus-iron podzols and organic soils, occur on the western coastline and are fairly intertwined. However, the humus-iron podzols seems to dominate more of the coastline whereas the organic soils are more frequent inland.

In poorly draining soils found along the eastern coastline of The Firth, surface run off is likely to be high, as peaty gleys, podzols and rankers are often waterlogged. On the Western coastline however, the drainage will be variable as it is covered partly by the freely draining humus-iron podzols and partly by the poorly draining organic soils. The humus-iron podzols will have a lower surface runoff, as the permeability of the soil will be greater. The organic soils, which are often waterlogged, will have a greater surface runoff. This provides an indication as to the potential for contamination due to diffuse pollution from livestock and whether it is higher in certain areas.

The potential for land runoff contaminated with *E. coli* from various sources is possible on all land surrounding The Firth, however it is likely to be higher on the eastern side.

Glossary of Soil Terminology

Calcareous: Containing free calcium carbonate.

Gley: A sticky, bluish-grey subsurface layer of clay developed under intermittent or permanent water logging.

Podzol: Infertile, non-productive soils. Formed in cool, humid climates, generally freely draining.

Rankers: Soils developed over noncalcareous material, usually rock, also called 'topsoil'.

Regosol: coarse-textured, unconsolidated soil lacking distinct horizons. In Scotland, it is formed from either quartzose or shelly sands.

6. Land Cover

The Land Cover Map 2000 data for the area is shown in Figure 6.1 below:

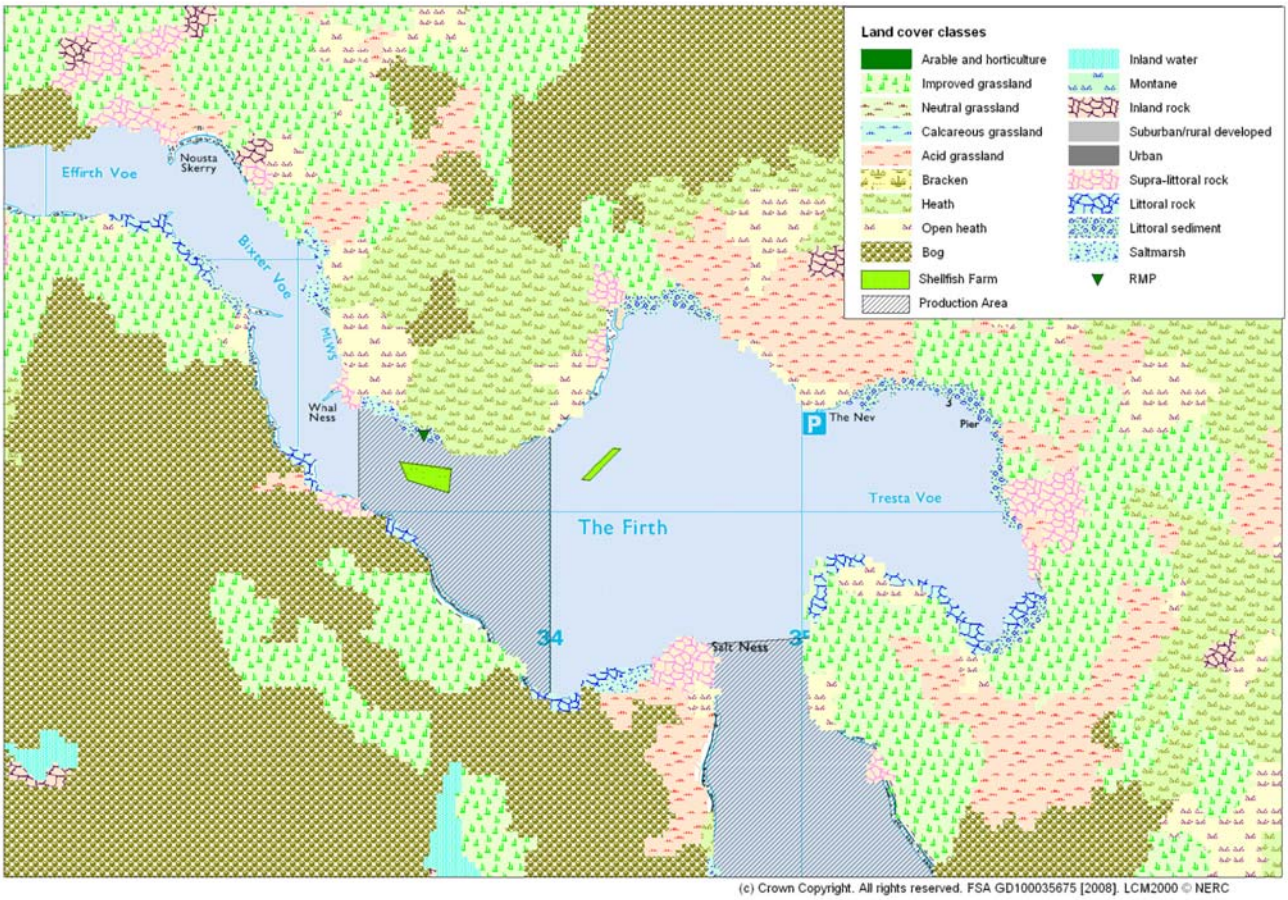


Figure 6.1 LCM2000 class data for the Firth

Most of the land on the west side of the Firth is shown as bog, improved grassland or heath. The land cover on the east side of the Firth is more mixed with patches of acid grassland, open heath and inland rock, amongst improved grassland and heath. Along much of the coastline of the Firth there are areas of littoral rock and littoral sediment. There is also some supra-littoral sediment on the northern and southern parts of the Firth coastline.

The faecal coliform contribution would be expected to be highest from developed areas, like at Tresta, which is located southeast of Tresta Voe (approx 1.2 – 2.8×10^9 cfu km^{-2} hr^{-1}), with intermediate contributions from the improved grassland (approximately 8.3×10^8 cfu km^{-2} hr^{-1}) and lowest from the other land cover types (approximately 2.5×10^8 cfu km^{-2} hr^{-1}) (Kay *et al*. 2008). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, this being expected to be highest, at more than 100-fold, for the improved grassland. Areas of improved grassland border the existing production area along its southern shoreline and are also found around much of the shoreline bordering Tresta Voe and the southern shore of Effirth Voe. Contributions of faecal bacteria from these areas would be most likely to impact the shellfish farm at Ness of Bixter.

7. Farm Animals

Regulation (EC) No. 854/2004 requires the competent authority to:

(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.

With regard to potential sources of pollution of animal origin, agricultural census data to parish level was requested from the Scottish Government. The request was denied on the grounds of confidentiality because there were so few farms present in the parish that it would have been possible to determine specific data for individual farms.

The only significant source of information was therefore the shoreline survey (see Appendix), which only relates to the time of the site visit on 11-13th and the 16th May 2007.

The shoreline survey identified that there is no arable agriculture surrounding the Firth. Much of the land is used for sheep grazing with livestock having free access to the shoreline throughout. Sheep were observed throughout the area surveyed. The geographical spread of sheep and therefore contamination at the shores of the Firth is considered to be even over time and therefore it is assumed that this factor does not have to be taken into account when identifying the location of a routine monitoring point (RMP).

Local information (Shetland Agricultural Centre, personal communication) indicated that numbers of sheep in the period May to September was approximately double that in other periods. Any contamination due to this source is therefore likely to be increased during this period.

The spatial distribution of livestock observed and noted during the shoreline survey is illustrated in Figure 7.1. It should be noted animal numbers were recorded on the day of shoreline survey from the observer's point of view. This does not necessarily equate to total numbers present as natural features may obscure individuals and small groups of animals from view.

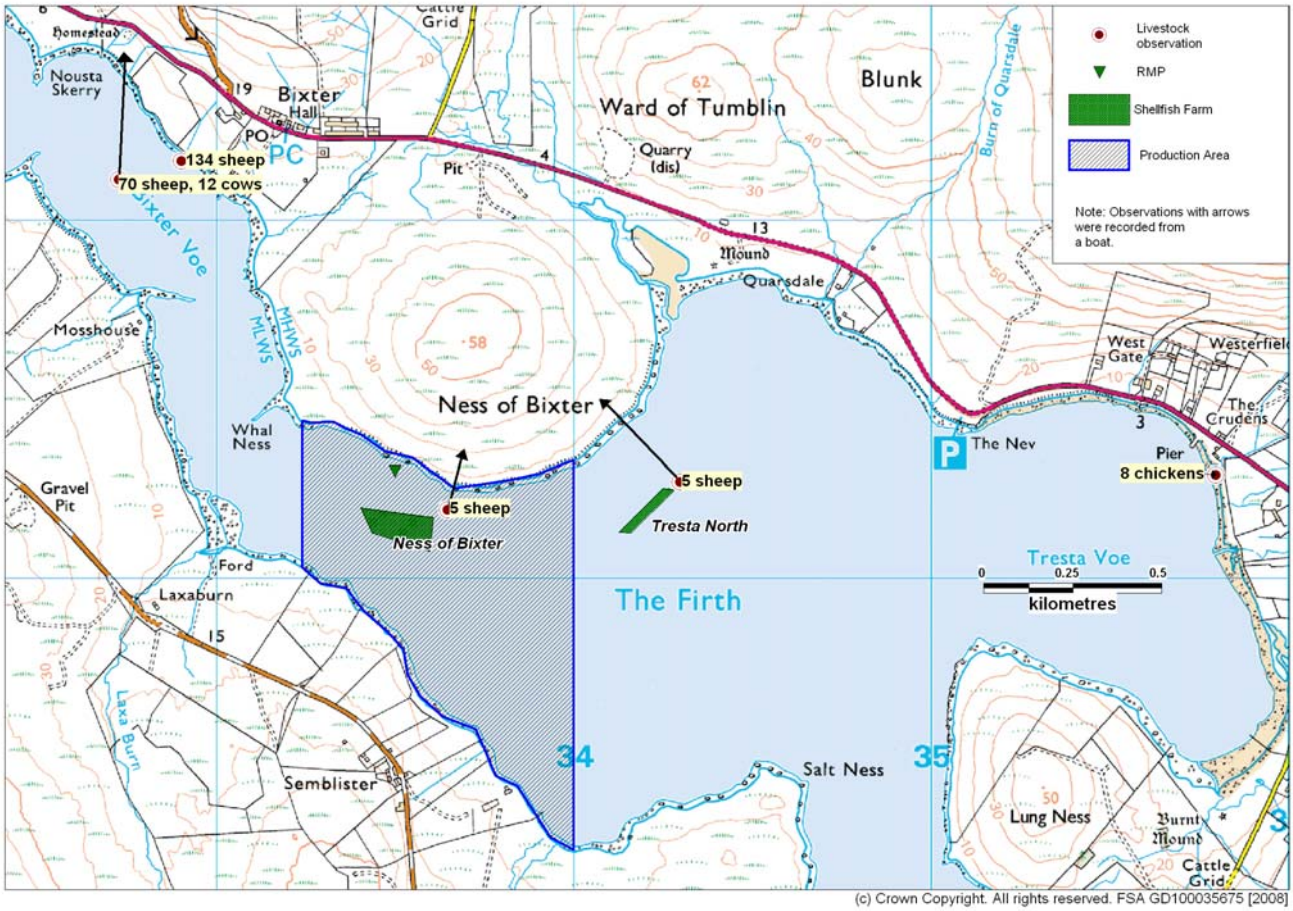


Figure 7.1 Livestock observations at the Firth

8. Wildlife

8.1 Pinnipeds

Two species of pinniped (seals, sea lions, walruses) are commonly found around the coasts of Scotland: These are the European harbour, or common, seal (*Phoca vitulina vitulina*) and the grey seal (*Halichoerus grypus*). Shetland hosts significant populations of both species.

The amount of *E. coli* and other faecal indicator bacteria contained in seal faeces has been reported as being similar to that found in raw sewage, with counts showing up to 1.21 x 104 CFU (colony forming units) *E. coli* per gram dry weight of faeces (Lisle et al 2004).

Common seals surveys are conducted every 5 years and an estimate of minimum numbers is available through Scottish Natural Heritage. The Shetland-wide count in 2001 was 4883 harbour seals, though this was anticipated to be an underestimation of the total population (Sea Mammal Research Unit 2002). A further survey was to have been conducted in 2006, however the populations observed in Shetland had declined by approximately 40% on the 2001 survey and so detailed figures have been withheld pending further survey. A final report was expected in late 2007, though at the date of this report was not yet available for inclusion here.

According to the Scottish Executive, in 2001 there were approximately 119,00 grey seals in Scottish waters, the majority of which were found in breeding colonies in Orkney and the Outer Hebrides. While no mention was made of populations in Shetland in 2001, in 1996, the Shetland grey seal population was estimated to be around 3,500 (Brown & Duck 1996).

Seals have been observed lying between mussel floats in and around the Firth (R. Anderson, personal communication) so it is anticipated that there could be some impact to the fisheries though this may be spatially and temporally limited. A known haulout site lies to the west of the Firth fisheries, in Effirth Voe. During the shoreline survey, seals were observed on the shoreline though numbers were indeterminate as they were difficult to see clearly against the grey of the shoreline and disappeared into the water as the boat drew near enough to gain a better view.

Adult Grey seals weigh 150-220 kg and adult common seals 50-170kg. They are estimated to consume between 4 and 8% of their body weight per day in fish, squid, molluscs and crustaceans. No estimates of the volume of seal faeces passed per day were available, though it is reasonable to assume that what is ingested and not assimilated in the gut must also pass. Assuming 6% of a median body weight for harbour seals of 110kg, that would equate to 6.6kg consumed per day and probably very nearly that defecated.

Both bacterial and viral pathogens affecting humans and livestock have been found in wild and captive seals. *Salmonella* and *Campylobacter* spp., some of which were antibiotic-resistant, were isolated from juvenile Northern elephant seals

(*Mirounga angustirostris*) with *Salmonella* found in 36.9% of animals stranded on the California coast (Stoddard et al 2005). *Salmonella* and *Campylobacter* are both enteric pathogens that can cause acute illness in humans and it is postulated that the elephant seals were picking up resistant bacteria from exposure to human sewage waste.

One of the *Salmonella* species isolated from the elephant seals, *Salmonella typhimurium*, is carried by a number of animal species and has been isolated from cattle, pigs, sheep, poultry, ducks, geese and game birds in England and Wales. Serovar DT104, also associated with a wide variety of animal species, can cause severe disease in humans and is multi-drug resistant (Poppe et al 1998).

Seals will forage widely for food and it is likely that seals will feed near the mussel farms at some point in time. The population is relatively small in relation to the size of the area concerned and is highly mobile therefore it is likely that any impact will be limited in time and area and unpredictable.

8.2 Cetaceans

A variety of cetacean species are routinely observed near Shetland. During 2001-2002, there were confirmed sightings of the following species (Shetland Sea Mammal Group 2003):

Table 8.1 Cetacean sightings, Shetland 2001-2002

Common name	Scientific name	No. sighted*
Minke whale	*Balaenoptera acutorostrata*	28
Humpback whale	*Megaptera novaeangliae*	1
Sperm whale	*Physeter macrocephalus*	3
Killer whale	*Orcinus orca*	183
Long finned pilot whale	*Globicephala melas*	14
White-beaked dolphin	*Lagenorhynchus albirostris*	399
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	136
Striped dolphin	*Stenella coeruleoalba*	1
Risso's dolphin	*Grampus griseus*	145
Common dolphin	*Delphinus delphis*	6
Harbour porpoise	*Phocoena phocoena*	>500

*Numbers sighted are based on rough estimates based on reports received from various observers and whale watch groups.

Little is known about the volume or bacterial composition of cetacean faeces. As mammals, it can be safely assumed that their guts will contain an unknown concentration of normal commensal bacteria, including *E. coli*.

Due to the shallow depth and distance from open sea, the Firth is unlikely to host whales or larger cetacean species. It is likely that dolphins will be found from time to time in the Firth and the impact of their presence is, as with pinnipeds, likely to be fleeting and unpredictable.

8.3 Birds

A number of seabird species breed in Shetland. These were the subject of a detailed census in 2000. Of the 25 seabird species identified as regularly breeding in Britain, 19 have substantial presence in Shetland (Mitchell et al 2004).

Table 8.2 Breeding seabirds, Shetland 2000

Common name	Species	Population*	Common name	Species	Population
Northern Fulmar	*Fulmarus glacialis*	188,544	Northern Gannet	*Morus bassanus*	26,249
European Storm Petrel	*Hydrobates pelagicus*	7,503*	Great Cormorant	*Phalacrocorax carbo*	192
European Shag	*Phalacrocorax aristotelis*	6,147	Arctic skua	*Stercorarius parasiticus*	1,120
Great Skua	*Stercorarius skua*	6,846*	Black-headed Gull	*Larus ridibundus*	586
Common Gull	*Larus canus*	2,424	Lesser Black-backed Gull	*Larus fuscus*	341
Herring Gull	*Larus argentatus*	4,027	Great Black-backed Gull	*Larus marinus*	2,875
Black-legged Kittiwake	*Rissa tridactyla*	16,732	Common Tern	*Sterna hirundo*	104
Arctic Tern	*Sterna paradisaea*	24,716	Common Guillemot	*Uria aalge*	172,681
Razorbill	*Alca torda*	9,492	Black Guillemot	*Cepphus grille*	15,739
Atlantic Puffin	*Fratercula arctica*	107,676			

*Population number based on Apparently Occupied Sites, Territories, Nests or Burrows. These may equate to more than one adult.

Of these, some are pelagic except during the breeding season and so would not impact the fisheries except during the summer months.

One of the most numerous year-round residents of the Shetlands is the Northern Fulmar. They are only present in colonies during the breeding season but are present in the area all year. According to the census, there are somewhere between 200 and 2,000 apparently occupied sites around the area of The Firth. This may equate to as many as 4,000 individuals, however this is a very crude estimate. These birds can nest on grassy cliffs, islands or under boulders and this habitat is found around the Firth.

Though the *E. coli* content of seabird droppings is not known, it is likely that rainfall runoff from around their colonies during the breeding season could impact shellfish areas located near the runoff.

Observations during the shoreline survey indicated no readily apparent colonies of nesting birds in the vicinity of the mussel farms in this area.

Waterfowl (ducks and geese) are present in Shetland at various times of the year. Eider ducks feed on the mussel lines and are present, sometimes in groups of 100 or more, throughout the year. Geese tend to pass through during migrations but

do not linger in very large numbers as they do further south. Waterfowl impact on the fisheries as The Firth likely to be mostly that of Eider ducks feeding on the mussel lines. Small numbers of Eider ducks were observed during the shoreline survey at The Firth, though larger numbers were seen feeding on a mussel farm in nearby Weisdale Voe. The locations and numbers of these birds are likely to vary and be relatively unpredictable in specific location and duration so their impact on the fishery will not be considered in determining the sampling plan.

8.4 Other

There is a significant population of European Otters (*Lutra lutra*) present in Shetland though their population is concentrated around Yell Sound with smaller populations scattered around the island.

Coastal otters, such as those found in Shetland, tend to be more active during the day, feeding on bottom-dwelling fish and crustaceans among the seaweed found on rocky inshore areas. An otter will occupy a home range extending along 4-5km of coastline, though these ranges may sometimes overlap (Scottish Natural Heritage website). Otters primarily forage within the 10m depth contour and feed on a variety of fish, crustaceans and shellfish (Paul Harvey, Shetland Sea Mammal Group, personal communication). Based on this, the Firth is unlikely to host more than a handful of otters.

Otters leave faeces (also known as spraint) along the shoreline or along streams. While otters may occur around the Firth area, it is not considered to be home to a substantial population and any impact to the fishery would be minimal.

Wildlife impact generally to the fisheries is likely to be minimal compared to the impact of diffuse pollution due to livestock. While some species can harbour bacteria and viruses that can cause illness in humans, their faeces are considered to pose a lower risk to human health than either human or livestock faecal contamination.

9. Meteorological data

The nearest weather station is located at Lerwick, approximately 16 km to the south east of the production area for which uninterrupted rainfall data is available for 2003-2006 inclusive. It is likely that the rainfall patterns at Lerwick are similar but not identical to those on The Firth and surrounding land due to their proximity, but it is not certain whether the local topography may result in differing wind patterns (Lerwick is on the east coast, The Firth is on the west coast). This section aims to describe the local rain and wind patterns and how they may affect the bacterial quality of shellfish within The Firth.

9.1 Rainfall

High rainfall and storm events are commonly associated with increased faecal contamination of coastal waters through surface water run-off from land where livestock or other animals are present, and through sewer and waste water treatment plant overflows (e.g. Mallin et al, 2001; Lee & Morgan, 2003).

Figures 9.1 to 9.4 and Tables 9.1 and 9.2 summarise the pattern of rainfall recorded at Lerwick. The box and whisker plots summarize the distribution of individual daily rainfall values (observations) by year (Figure 9.2) or by month (Figure 9.4). The grey box represents the middle 50% of the observations, with the median at the midline. The whiskers extend to the largest or smallest observations up to 1.5 times the box height above or below the box. Individual observations falling outside the box and whiskers are represented by the symbol *.

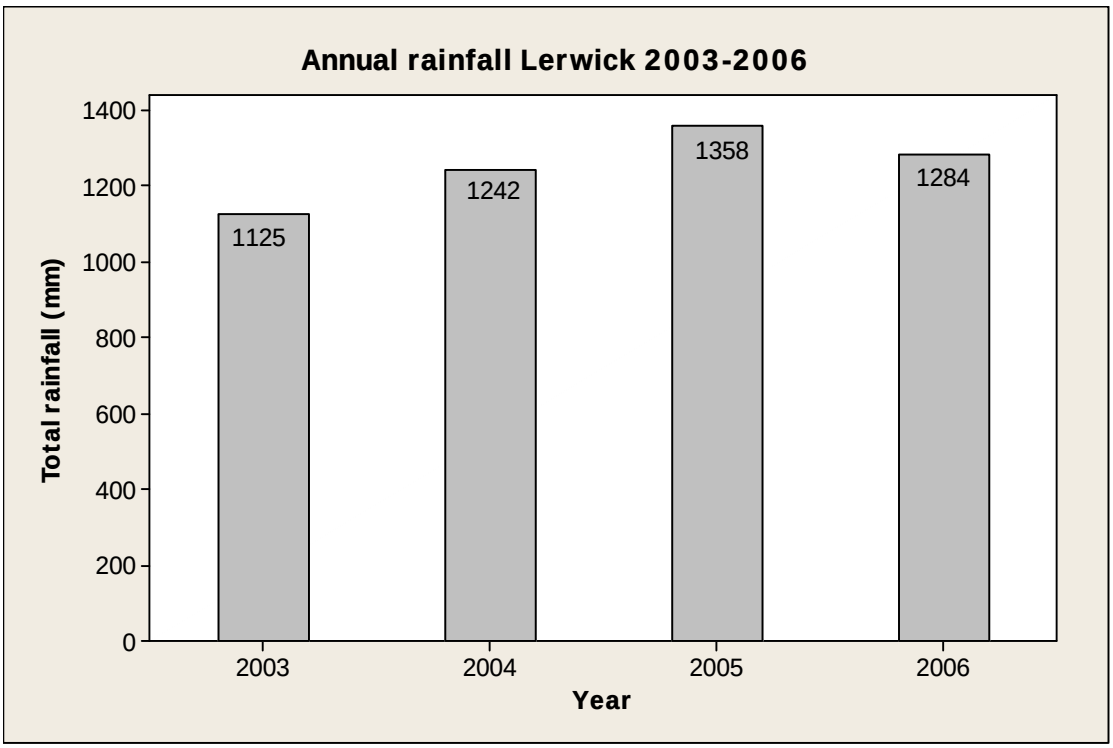


Figure 9.1 Bar chart of annual rainfall at Lerwick 2003-2006

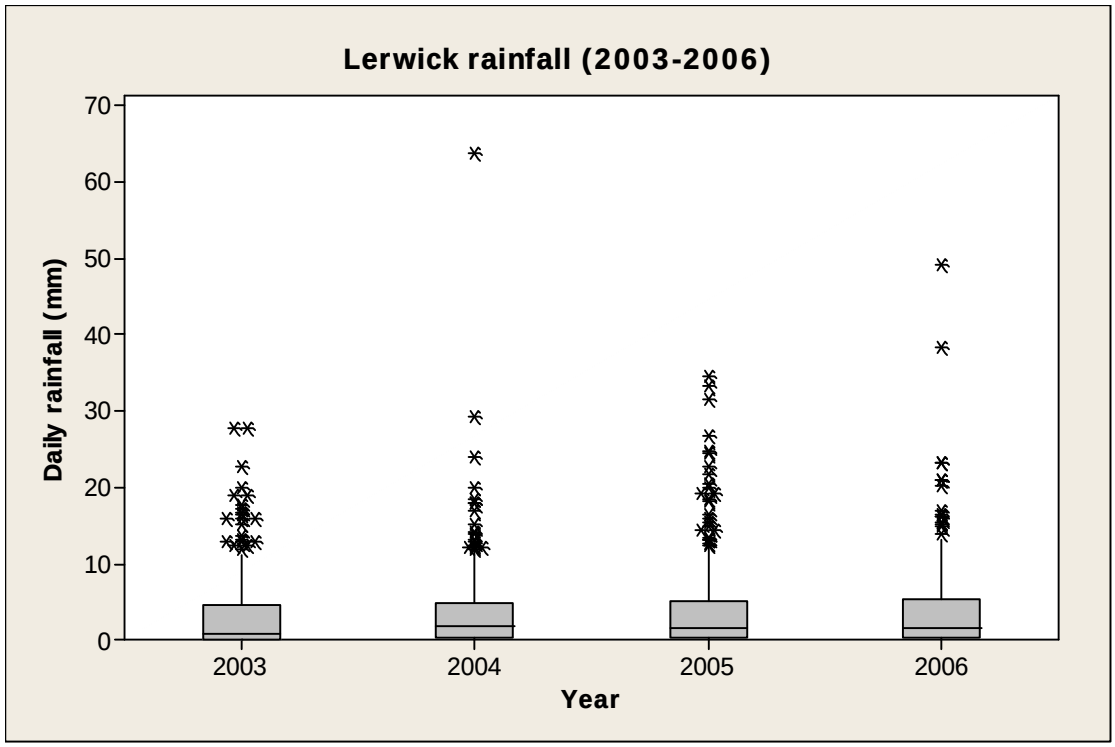


Figure 9.2 Boxplot of average daily rainfall by year at Lerwick

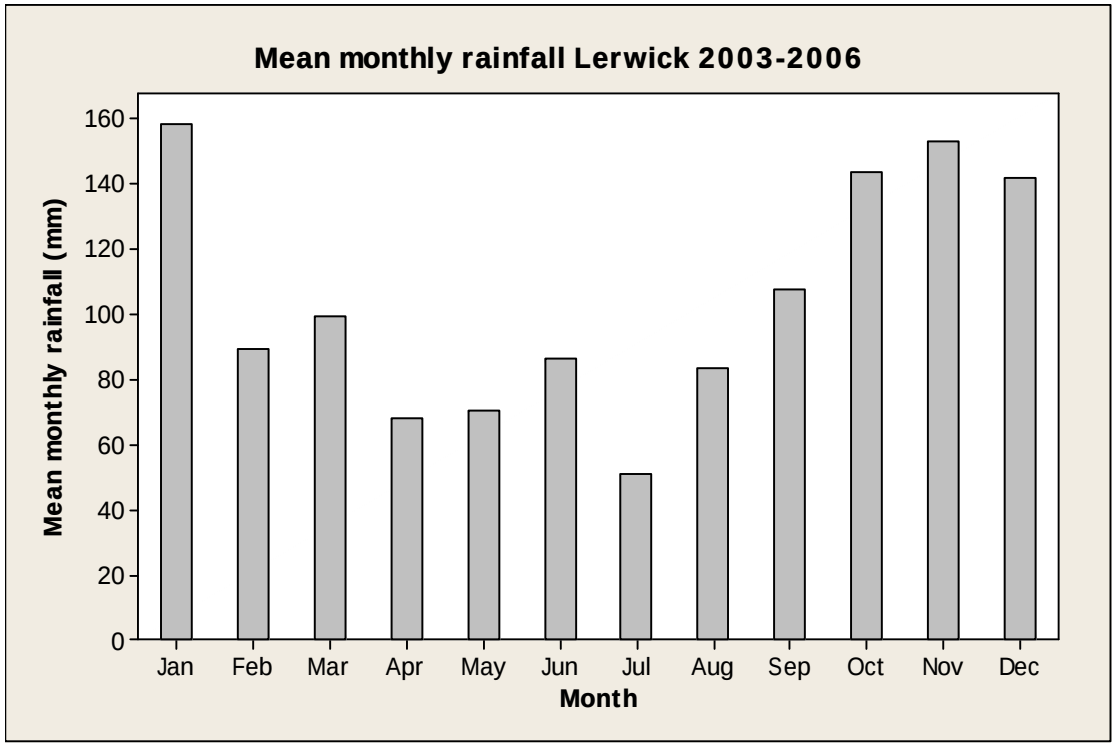


Figure 9.3 Bar chart of mean monthly rainfall at Lerwick 2003-2006

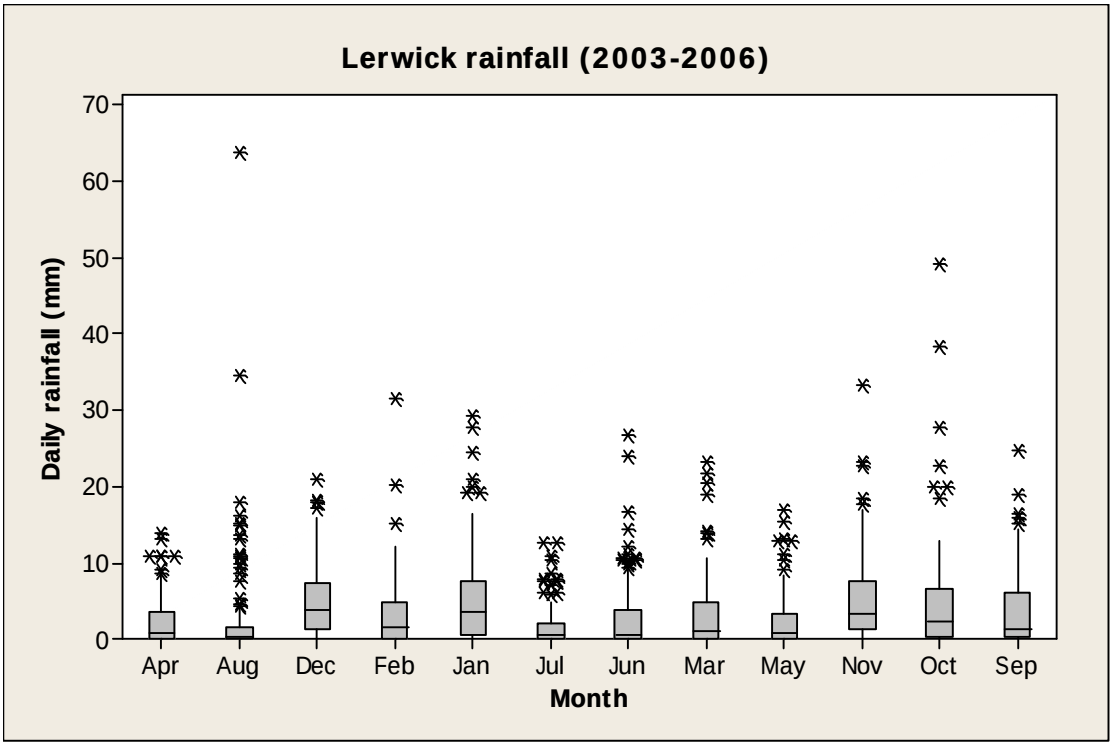


Figure 9.4 Boxplot of Lerwick daily rainfall by month 2003-2006

The wettest months were October, November, December and January. For the period considered here (2003-2006), only 19.9% of days experienced no rainfall, 44.6% of days experienced rainfall of 1mm or less.

A comparison of Lerwick rainfall data with Scotland average rainfall data for the period of 1970-2000 is presented in Table 9.3 (Data from Met office website © Crown copyright). This indicates that rainfall in Lerwick was lower than the average for the whole of Scotland for every month of the year, but there were fewer dry days in Lerwick during the autumn, winter and spring.

Table 9.1 Comparison of Lerwick mean monthly rainfall with Scottish average 1970-2000.

Month	Scotland rainfall (mm)	Lerwick rainfall (mm)	Scotland - days of rainfall >= 1mm	Lerwick - days of rainfall >= 1mm
Jan	170.5	135.4	18.6	21.3
Feb	123.4	107.8	14.8	17.8
Mar	138.5	122.3	17.3	19
Apr	86.2	74.2	13	14.4
May	79	53.6	12.2	10.1
Jun	85.1	58.6	12.7	11.3
Jul	92.1	58.5	13.3	11
Aug	107.4	78.3	14.1	12.5
Sep	139.7	115.3	15.9	17.4
Oct	162.6	131.9	17.7	19.4
Nov	165.9	152.4	17.9	21.5
Dec	169.6	150	18.2	22.2
Whole year	1520.1	1238.1	185.8	197.9

It can therefore be expected that levels of rainfall dependant faecal contamination entering the production area from these sources will be higher during the autumn and winter months. As there are few dry days, it is likely that a steady flow contaminated of runoff from pastures is to be expected throughout the wetter months. It is possible that there is a build-up of faecal matter on pastures during the drier summer months when stock levels are at their highest which results in more significant faecal runoff in the autumn at the onset of the wetter months.

9.2 Wind

Wind data collected at the Lerwick weather station is summarised by season and presented in figures 9.5.

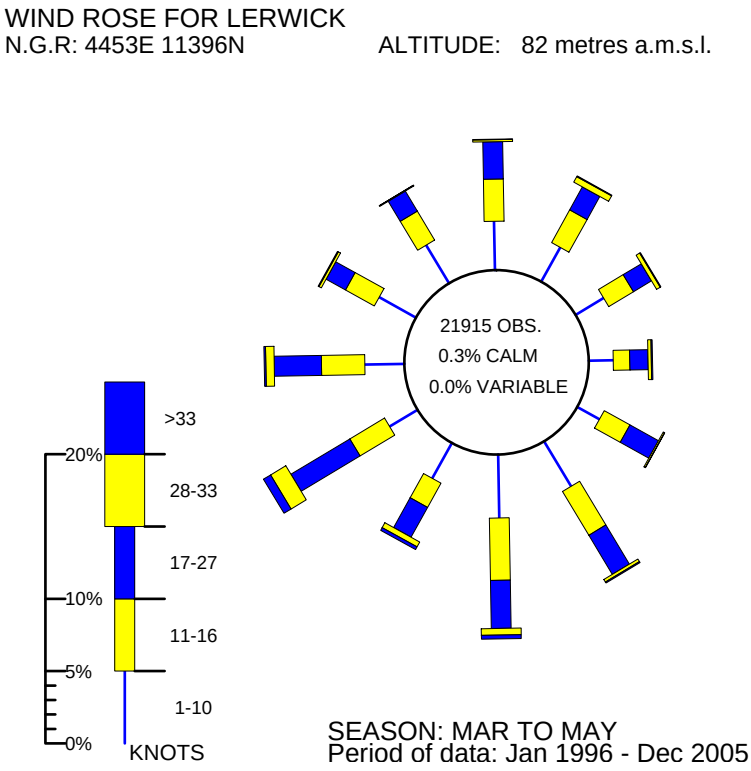


Figure 9.5 Wind rose for Lerwick March to May

WIND ROSE FOR LERWICK
N.G.R: 4453E 11396N ALTITUDE: 82 metres a.m.s.l.

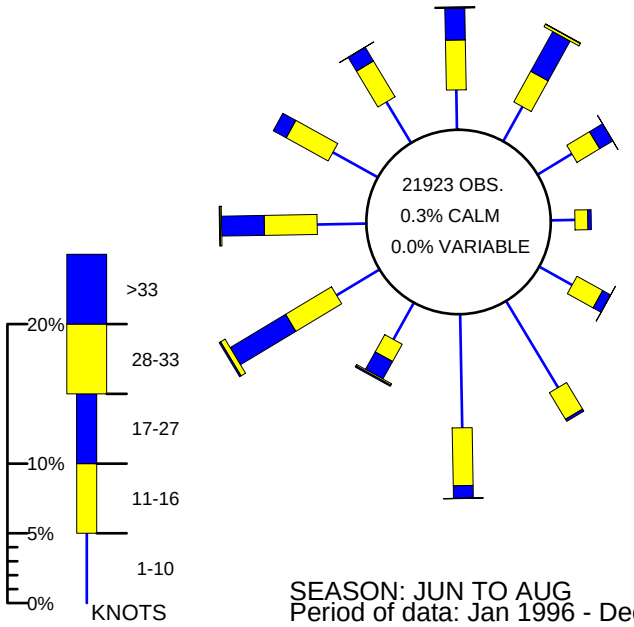


Figure 9.6 Wind rose for Lerwick June to August

WIND ROSE FOR LERWICK
N.G.R: 4453E 11396N ALTITUDE: 82 metres a.m.s.l.

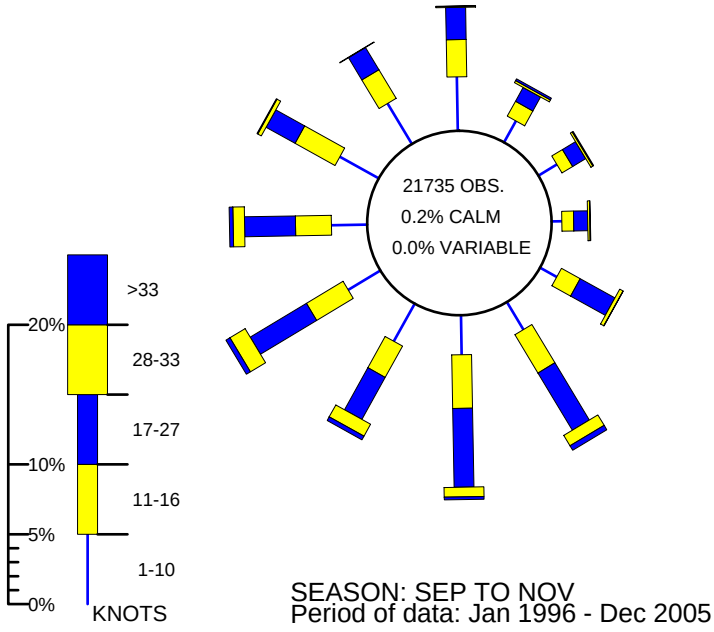


Figure 9.7 Wind rose for Lerwick September to November

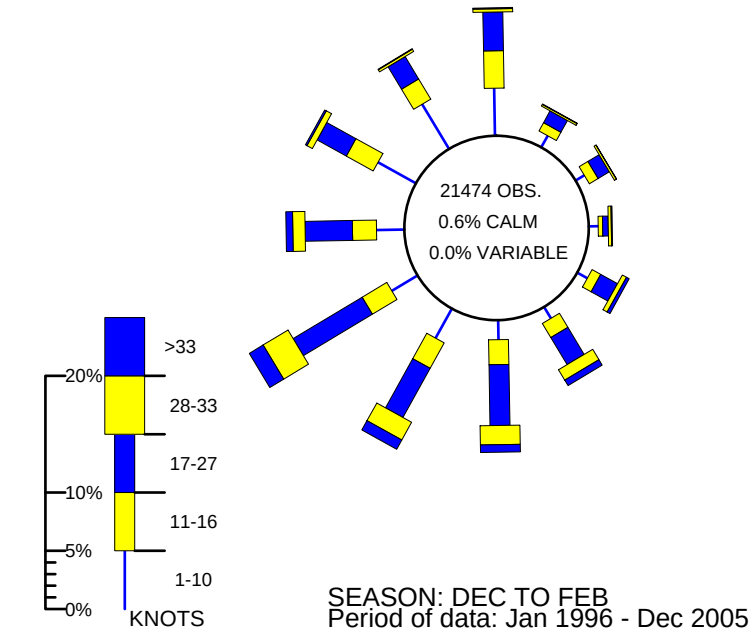


Figure 9.8 Wind rose for Lerwick December to February

Shetland is one of the more windy areas of Scotland with a much higher frequency of gales than the country as a whole. The wind roses show that the overall prevailing direction of the wind is from the south and west, and when it is blowing from this direction it is likely to be stronger than when blowing from other directions. Winds are generally lighter during the summer months and strongest in the winter. The Firth is connected to the open sea through Sandsound Voe, which faces SSE. The surrounding hills will have the effect of channelling the wind up or down Sandsound Voe.

A strong SSE wind combined with a spring tide may result in higher than usual tides which will carry accumulated faecal matter from livestock, above the normal high water mark, into the production area.

Wind effects are likely to cause significant changes in water circulation within the voe as tidally influenced movements of water are relatively weak (see section 13). 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 a surface water current of about 1 knot or 0.5 m/s. These surface water currents create return currents which may travel along the bottom or sides of the water body depending on bathymetry. Either way, strong winter winds will increase the circulation of water and hence dilution of contamination from point sources within the voe. A strong easterly wind would have the effect of pushing any contamination originating from the settlement of Tresta towards the production sites. A strong SSE wind may carry any contamination originating from the more distant settlement of Sandsound towards the production sites.

10. Current and historical classification status

The Firth (SI363) was first classified for production in 2007 on the basis of samples submitted from the Ness of Bixter site (SI36375108). The Tresta North site has not been classified and actually lies about 300m outside of The Firth current production area boundaries. A map of the current production area is presented in Figure 10.1. The current classification is presented in Table 10.1.

Table 10.1 Current classification of The Firth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007				B	B	B	A	A	A	A	A	A
2008	B	B	B									

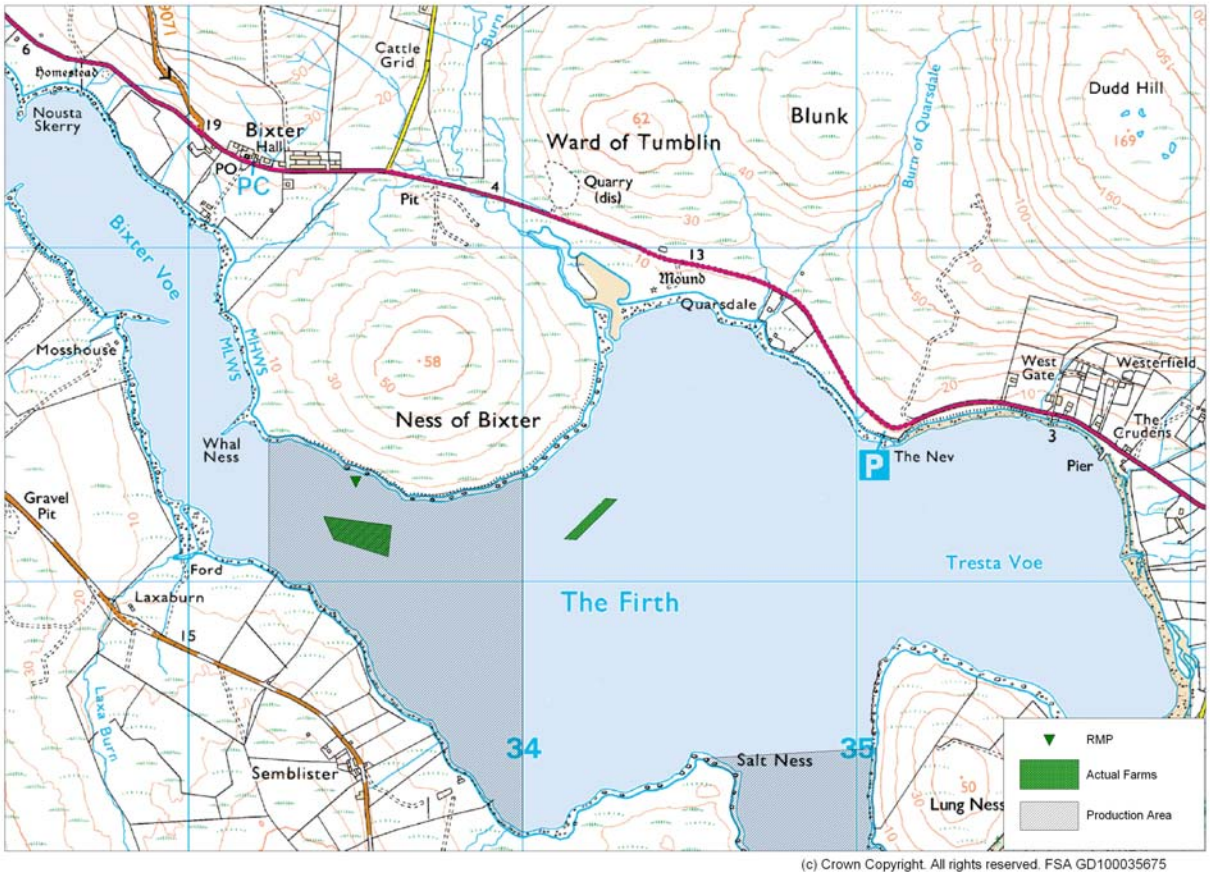


Figure 10.1 - Current production area

11. Historical *E. coli* data

11.1 Validation of historical data

All samples taken from The Firth (SI363) and East Firth up to the end of 2007 were extracted from the database and validated according to the criteria described in the standard operating procedure for validation of historical *E. coli* data. One sample was rejected due to a major geographical discrepancy. In the three instances where the result was reported as <20, it was adjusted to 10 for the purposes of statistical analysis. All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intervalvular fluid.

11.2 Summary of microbiological results

Common mussels were sampled from two locations from The Firth: Ness of Bixter, and from one location at East Firth: Site 1. Sampling and results are summarised in Table 11.1, and sampling locations are indicated in Figure 11.1

Table 11.1 - Summary of results from all sites within The Firth and East Firth

Sampling Summary				
Production area	The Firth	The Firth	The Firth	East Firth
Site	Ness of Bixter	Ness of Bixter	Ness of Bixter	Site 1 (Tresta North)
Species	Common mussels	Common mussels	Common mussels	Common mussels
SIN	SI297	SI297	SI297	SI 379
Location sampled	HU335513	HU336511	HU335513 & HU336511 combined	HU344514
Location of RMP				
Total no. of samples	11	4	15	2
No. 2005	0	0	0	0
No. 2006	6	0	6	0
No. 2007	5	4	9	2
Results Summary (*E.coli* mpn/100g)				
Minimum	<20	20	<20	<20
Maximum	500	250	500	70
Median	20	na	40	na
Geometric mean	33.9	na	41.2	na
90 percentile	70	na	178	na
95 percentile	285	na	325	na
No. exceeding 230/100g	1	1	2	na
No. exceeding 1000/100g	0	na	na	na
No. exceeding 4600/100g	0	na	na	na
No. exceeding 18000/100g	0	na	na	na

The majority of samples used in this analysis have come from HU335513 at Ness of Bixter, which lies further west than the other two sampling points. Where fewer than 10 samples have been submitted, statistics were not presented beyond minimum and maximum values as there is insufficient data on which to base them.

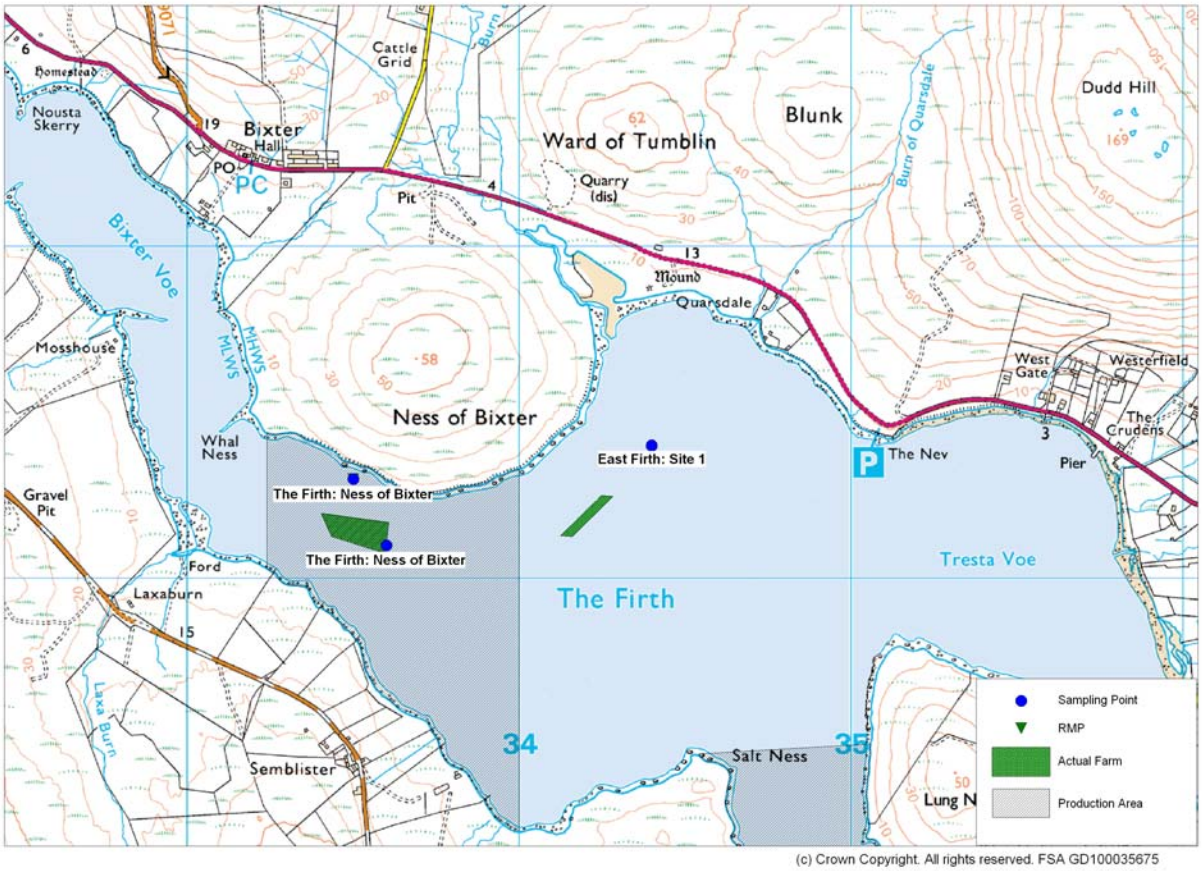


Figure 11.1 Sampling locations within the Firth and East Firth

11.3 Temporal pattern of results

Figure 11.2 presents a scatter plot of individual results against date for all samples taken from The Firth and East Firth. It is fitted with a loess smoother, a regression based smoother line calculated by the Minitab statistical software to help highlight any apparent underlying trends or cycles.

Figure 11.2, although based on a very limited dataset, indicates a seasonal pattern of results with peaks in the autumn.

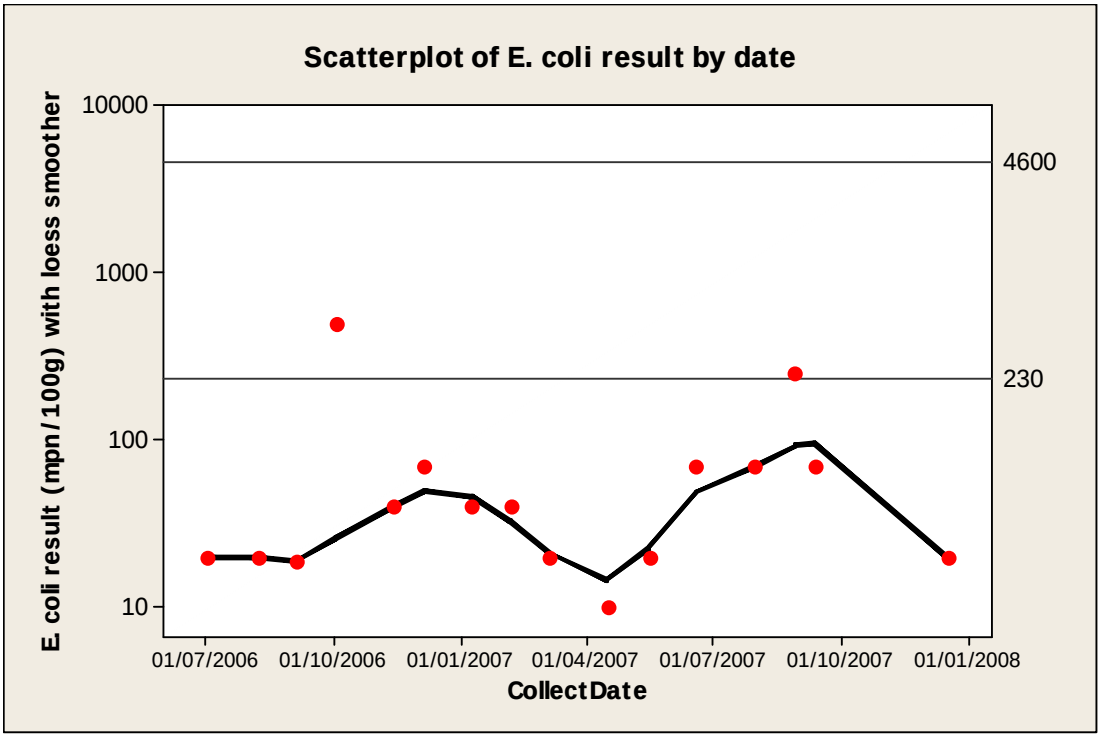


Figure 11.2 Scatterplot of results by date with loess smoother

11.4 Analysis of results against environmental factors

Environmental factors such as rainfall, tide state and size, winds, sunshine and temperatures can all influence the flux of faecal contamination into growing waters (e.g. Mallin et al, 2001; Lee & Morgan, 2003). The effects of these influences can be complex and difficult to interpret even with large datasets. In this case there is insufficient data available to undertake any analyses to investigate the relationship between environmental factors and sampling results.

A sanitary survey report was recently prepared for Sandsound Voe, which is approximately 1 km away from the Firth, and is part of the same water body. Results from Sandsound Voe gathered since July 2006 are very similar to those obtained for the same period from The Firth and East Firth (T-Test, p=0.417, Appendix 4), so might be expected to show similar responses to environmental factors.

Over 50 samples were considered in the analysis of historical *E. coli* data for the Sandsound Voe sanitary survey report. In Sandsound Voe, a weak positive correlation between rainfall recorded two and seven days prior to monitoring results, as well as a weak seasonal correlation with higher results obtained in autumn. No statistically significant correlation was found between wind direction and *E.coli* result for Sandsound Voe, though it is not certain that this would apply directly to conditions in The Firth.

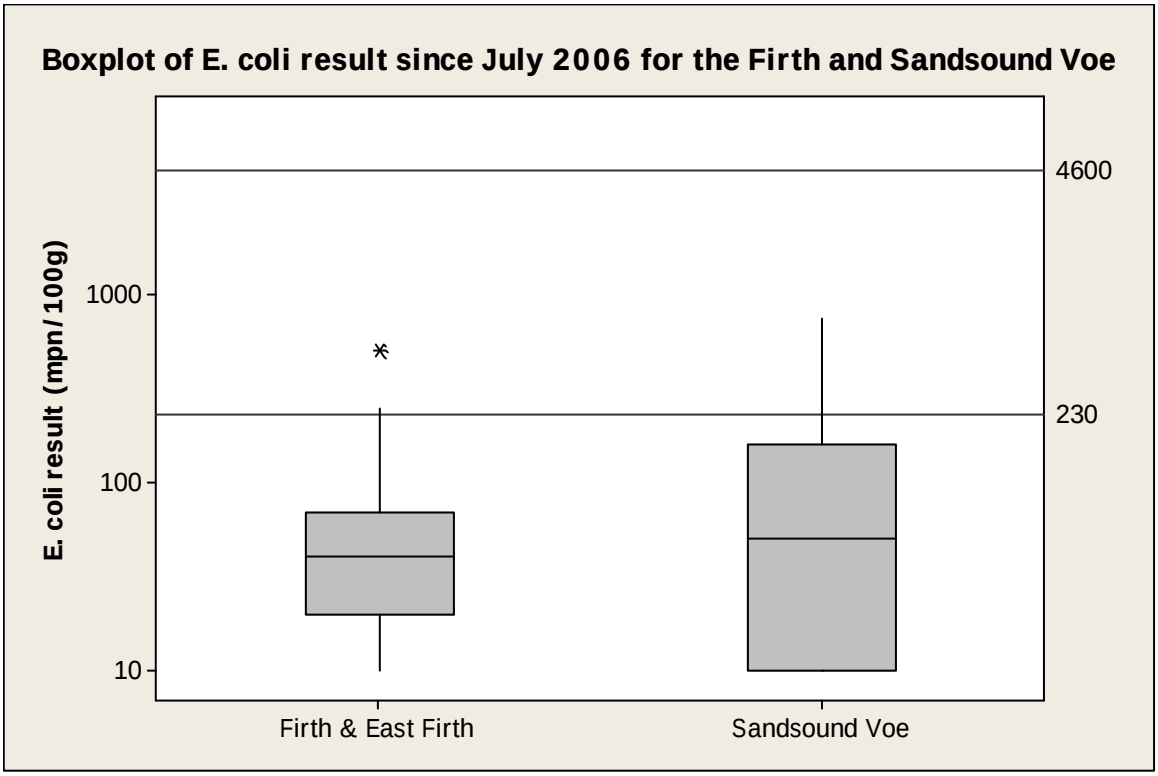


Figure 11.3 Boxplot of results for Firth & East Firth and Sandsound Voe since July 2006

Slightly further afield, in Weisdale Voe, a strong seasonal effect was found, with results in the autumn being significantly higher than in other seasons. There appeared to be very weak rainfall effects but these were not statistically significant. No influence of tide size was apparent. A statistically significant relationship between wind direction and sample result was found with higher results correlating with winds from the southwest.

It is likely that the microbiological quality of water within these two production areas is similar to that observed in the Firth, and responds to environmental conditions in a similar manner. It is therefore likely that the Firth will experience lower microbiological water quality in the autumn months, which is a fairly typical pattern for mussel production sites studied so far around the Shetland Islands. The early autumn is the period when livestock densities are highest, and the onset of the wetter and windier autumn/winter period so it is to be expected that contamination from livestock, the main source of contamination for this area, is at its highest. Effects of recent rainfall, wind direction and tide size tend to differ more between Shetland mussel production areas, and as a consequence are harder to predict for a new area.

11.5 Stability of results and sampling frequency

When a production area has held the same (non-seasonal) classification for 3 years, and the geometric mean of the results falls within a certain range, it is recommended that the sampling frequency can be decreased from monthly to bimonthly. This is not appropriate for the Firth or East Firth, as the area has only been classified since April 2007, and it holds a seasonal classification.

12. Designated Shellfish Growing Waters Data

The Firth has not been designated as a Shellfish Growing Waters area by the Scottish Government. As such, there is no historical monitoring data for The Firth associated with this program.

13. Bathymetry and Hydrodynamics

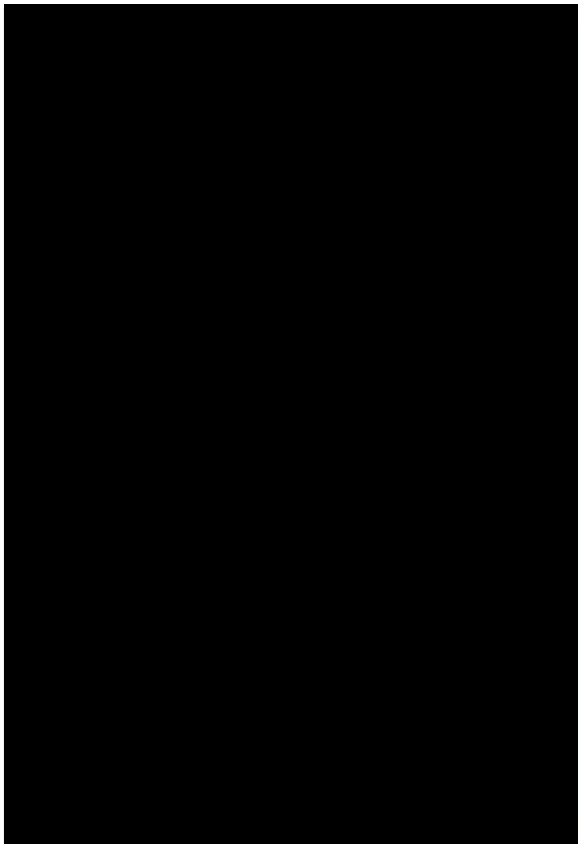


Figure 13.1 Bathymetry of the Firth

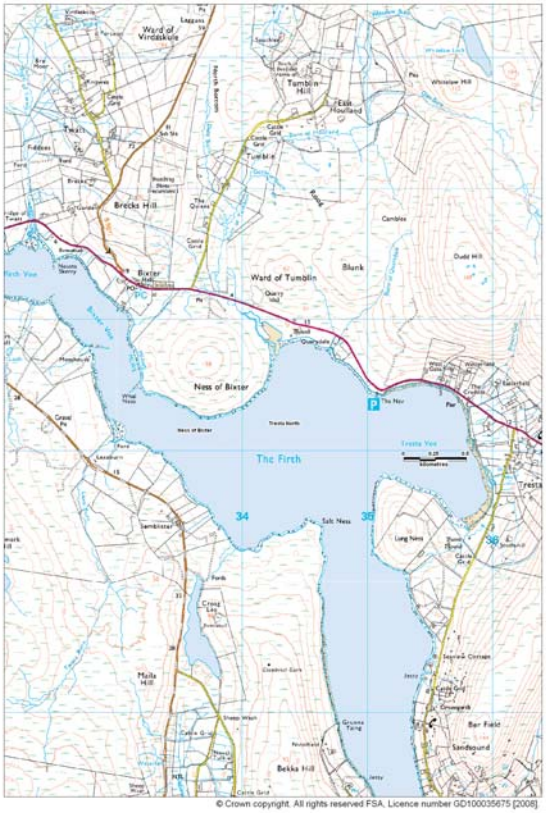


Figure 13.2 The Firth

The Firth is a relatively sheltered water body bounded by Effirth and Bixter Voes to the west, Tresta Voe to the east and Sandsound Voe to the south. Sandsound Voe is then open to the sea at its southern end. Flushing time is reported as being 8 days for the combined series of voes.

The water body is a shallow, sloping basin constricted physically between Bixter Voe and The Firth and between The Firth and Sandsound Voe. Maximum depths are less than 20 m for most of the water body and areas of drying are present In Effirth, Bixter and Tresta Voes.

13.1 Tidal Curve and Description

The two tidal curves below are for the port of Scalloway, the nearest secondary port– they have been output from UKHO TotalTide. The first is for seven days beginning 00.00 GMT on 11/05/07, the date of the first part of the shoreline survey. The second is for seven days beginning 00.00 GMT on 18/05/07. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle.

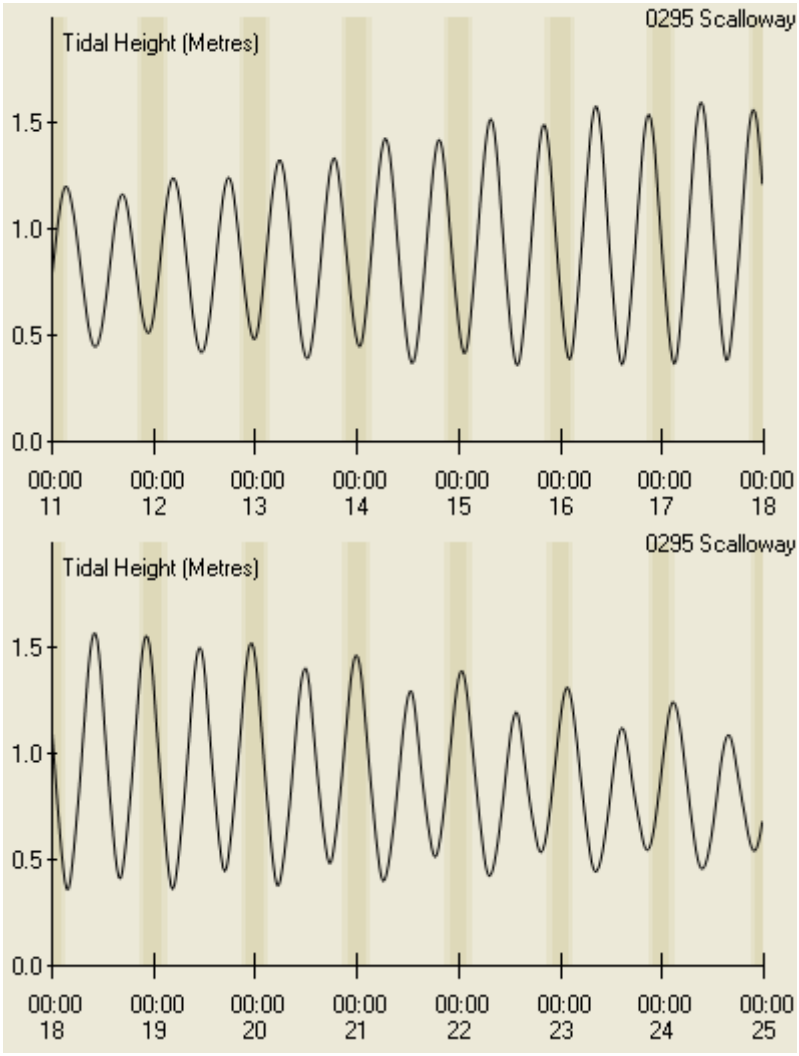


Figure 13.3 Tidal curves for Scalloway

The following is the UKHO summary description for Scalloway:

The tide type is Semi-Diurnal.

HAT 1.9 m
MHWS 1.6 m
MHWN 1.3 m
MLWN 0.6 m
MLWS 0.5 m

Predicted heights are in metres above chart datum. The tidal range at spring tide is approximately 1.1 m and at neap tide 0.7 m. Information on The Firth contained in the Scottish sea loch catalogue (Edwards & Sharples, 1986) is combined within that reported for Sandsound Voe and so is not suitably specific. Flushing time for the combined area is given as 8 days.

No tidal stream information is available for The Firth.

Conclusions regarding effect on impacting sources

The Firth is shallow and isolated from the open sea by land and by Sandsound Voe to the south. Tidal currents would be most pronounced near the narrow entrance to Sandsound Voe to the south and near the constriction at the entrance to Bixter Voe to the north west. Throughout the remainder of The Firth, tidal flows are expected to be minimal with wind driven currents having a greater impact on movement of pollutants around the area. Substantial drying areas located around the Firth indicate that water movement around these areas is slow, allowing sediment to settle out of the water and form banks.

The relatively long flushing time of 8 days ranks The Firth and Sandsound Voe 16th among Scottish sea lochs in terms of flushing time. Contaminants present in the voe would tend to linger allowing greater opportunity for wind driven mixing and uptake by shellfish.

Wind driven water movement could lead to resuspension of sediment (and any associated bacteria) in shallower areas. The Tresta mussel site lies near the 10 metre curve to the east of Ness of Bixter while the Ness of Bixter site lies in shallower water just before the shoaling area at the entrance to Bixter Voe to the north west of the firth.

The Ness of Bixter site may receive greater water flow around the farm as it lies nearer a constriction in the voe that would funnel tidal waters creating stronger currents in the vicinity of the farm particularly on the outgoing tide.

14. River Flow

No gauged rivers flow into the Firth.

The following streams and burns were identified, measured and sampled during site visits on 11 May 2007 and 5 December 2007. Flows for May observation were measured by timing the transit of a floating object across a measured distance (Pooh stick method) and in two cases were estimated visually. A flow meter was used for the December measurements. All measurements and loadings pertain to the day of survey only and discharges and bacterial content may not be representative of what occurs throughout the year.

Table 14.1 River flows for The Firth

No.	NGR	Description	Width (m)	Depth (m)	Meas. Flow (m/s)	Flow m3/day	*E. coli* (cfu/ 100ml)	Loading (*E.coli* /day)
1	HU 35803 50375	Stream	1.44	0.29	0.1*	3600	3500	1.3×10^{11}
2	HU 35907 50946	Stream	1	0.03	0.05*	130	110	1.4×10^{8}
3	HU 35828 51066	Burn of Tresta	3	0.25	0.7	45360	500	2.3×10^{11}
4	HU 35798 51291	Stouri Gill	0.6	0.04	0.1*	200	21000	4.4×10^{10}
5	HU 32343 52607	Burn of Twatt	4	0.05	0.6	10370	320	3.3×10^{10}
6†	HU 32771 50921	Laxa Burn	2.24	0.17	0.4	12890	58	7.5×10^{9}
7†	HU 33893 52143	Burn of Tumblin	1.9	0.27	0.6	24622	150	3.7×10^{10}
8†	HU 34740 51878	Stream	0.76	0.08	0.9	4770	10	4.8×10^{8}
9†	HU 34791 51854	Burn of Quarsdale	0.9	0.29	0.3	6130	20	1.2×10^{9}

* Flow estimated
† Measured December 2007

A significant number of freshwater streams and burns flow into the Firth. The shallow depths present in the area mean less opportunity for dilution of any contaminants present.

Laxa Burn discharges into The Firth less than 0.5 km to the east of the Ness of Bixter site. When measured and sampled in December, this burn showed a moderate loading of 7.5×10^{9} *E.coli* per day. Currents flowing through the construction at Whal Ness separating Bixter Voe from the Firth would tend to drive any contamination entering the voe from this burn toward the Ness of Bixter mussel lines on an outgoing tide.

The Tresta North site lies just under 0.5 km south of the Burn of Tumblin and slightly further away from the Burn of Quarsdale and an adjacent unnamed stream. Of these, the Burn of Tumblin provided the highest daily input of *E. coli* (3.7×10^{10} *E. coli*/day) based on measurements taken during the shoreline survey. The Burn of Quarsdale and the unnamed stream both provided lower loadings, at 1.2×10^{9} and 4.8×10^{8} *E. coli*/day respectively. Together, these could potentially impact the mussel farm at Tresta North and due to bathymetry in the area are less likely to affect the Ness of Bixter site. A further three streams were measured further east

within Tresta Voe. One of these, the Burn of Tresta, showed the highest loading of all the streams measured in the area.

The locations of the streams in relation to the fishery are shown in Figure 14.1. Streams are labelled with the number assigned in Table 14.1. Loadings are displayed in digital scientific format on the map, where 1E+10 is equal to 1 x 10^{10}.

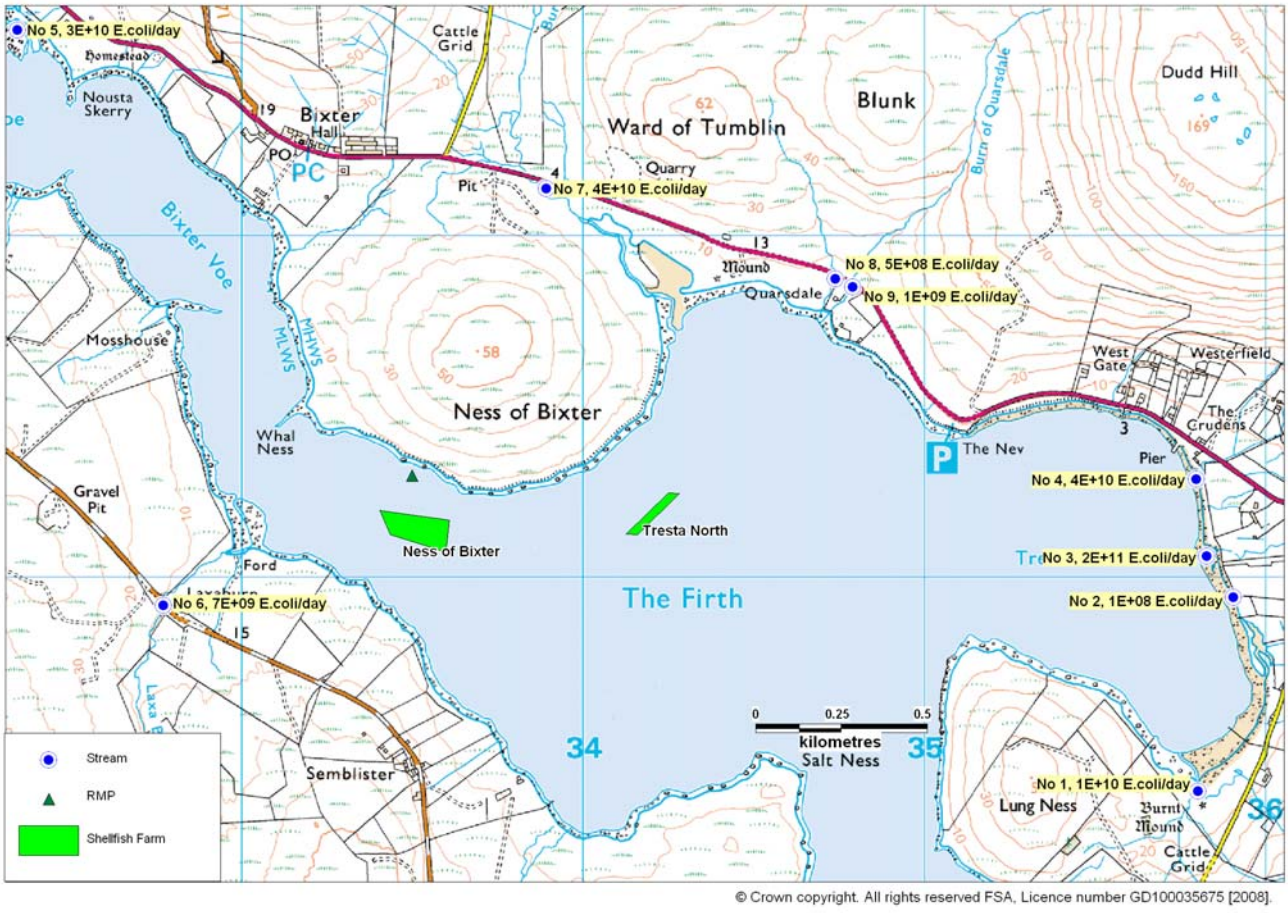


Figure 14.1 Bacterial loadings for The Firth

15. Shoreline Survey Overview

The shoreline survey at the Firth was triggered by the application for a new site at Tresta North. A production area covering the adjacent Ness of Bixter site was established in 2006 and was included in this survey.

The shoreline survey was conducted on 11-13 May, with sampling at Ness of Bixter taking place on 16 May. The site was visited a second time on 6 December 2007 to collect additional water samples and flow measurements from four of the streams that discharge into The Firth.

There were two settlements of note within the area, Tresta and Bixter, each with a community septic tank. These were observed during the shoreline survey and both discharged below water so sea water samples were collected adjacent to the outfalls. There were a few scattered homes that would have been on private septic systems. One small discharge pipe was observed with septic debris around it (blue toilet paper), though the discharge volume was too small measure or sample at the time. A sea water sample was collected from near the discharge and it contained 24 cfu *E.coli*/100 ml.

A number of seals were observed lying on the shoreline along the sand spits at Whal Ness and Mosshouse in Bixter Voe. At least 12 seals were counted, though there may have been more but they took to the water before we were close enough to see individuals clearly with binoculars.

Land use around The Firth was predominantly sheep grazing with no arable agriculture observed. Sheep were observed on the shoreline and sheep droppings were observed in the strand line debris. More than 200 sheep were observed on the day, though many more would have been obscured by the terrain and as lambing was underway the population was increasing daily.

A few birds were observed, though these were scattered and not present in significant numbers.

Seawater samples collected from on the fishery showed low levels of contamination with <1 cfu *E.coli*/100 ml recorded from all samples. Seawater samples collected from the shore were more contaminated with the highest *E. coli* concentrations observed along the shore of Tresta Voe. Samples collected from the shore of Bixter Voe were far less contaminated with a maximum result 100 cfu *E. coli*/100 ml.

Shellfish samples were collected from two points on the mussel farm at Tresta North. There were only two longlines on the site, both of which were nearly devoid of mussels. Mussels were collected from the bottoms of the floats, consequently no conclusions could be drawn about the effects of depth on bacterial content of the shellfish. Only one mussel sample was collected at the Ness of Bixter site by the official control sampling officer on 10 May. Bacterial concentrations for the three mussel samples collected were low, with two results at 40 MPN *E.coli*/100 g and one at <20 MPN *E.coli*/100 g.

Key findings from the shoreline survey are mapped in figure 15.1

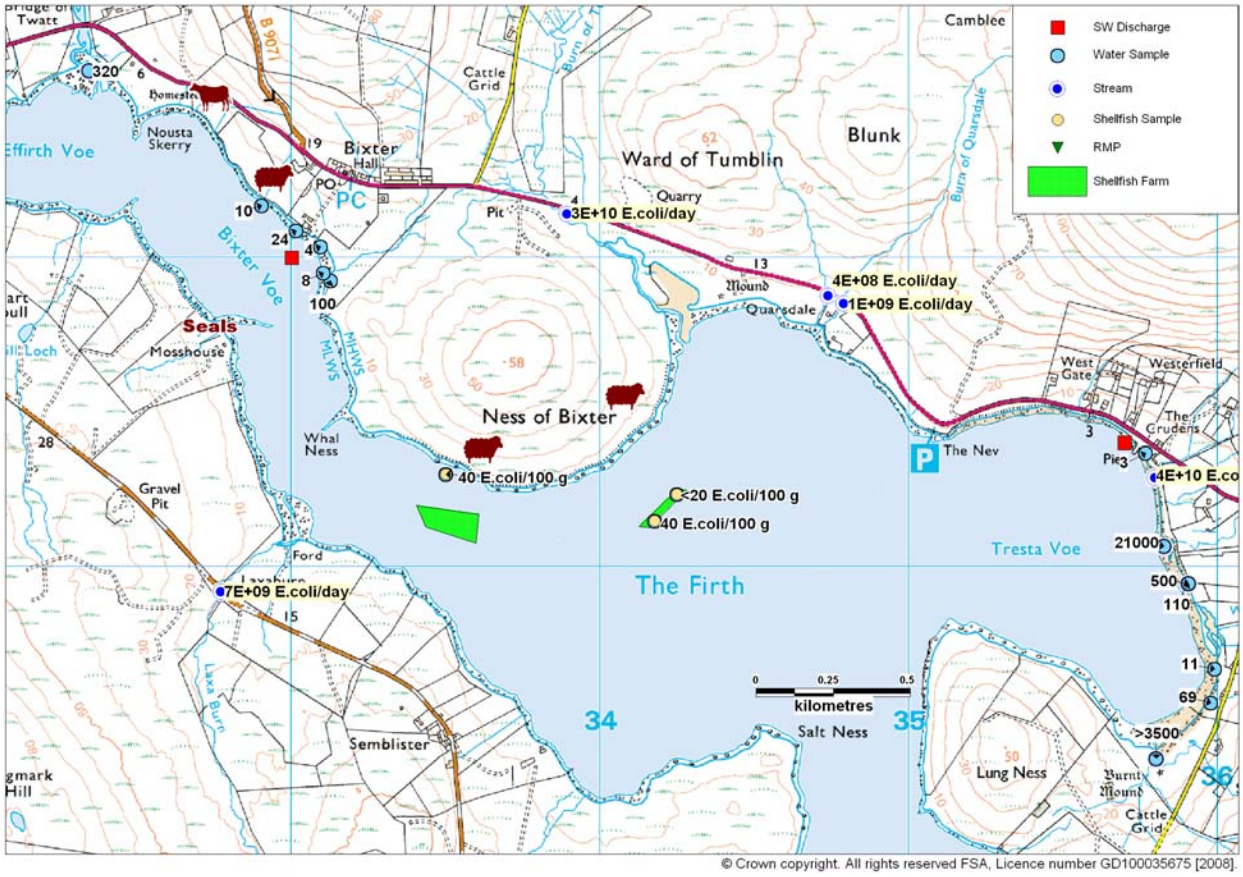


Figure 15.1 Summary of significant shoreline survey observations

16. Overall Assessment

Human Sewage Impacts
The Firth receives moderate impact from human sewage by Shetland standards. It has two settlements with community septic tanks, as well as private discharges from isolated homes and crofts around the shoreline.

The population of the area surrounding the combined areas of Effirth Voe, Bixter Voe, The Firth and Tresta Voe was 467 at the last census, while the two community discharges have design populations of 20 for Bixter and 10 for Tresta. The total population for the census area encompassing Bixter alone exceeds this total capacity with a population of 55. Therefore, it can be presumed that the majority of the habitations in the area are served by private septic systems. The age, type and state of repair of these systems are not known.

There is no accurate record of the number of private septic tanks in Shetland generally and around The Firth specifically because there has historically been no requirement to register them with either SEPA or the local council. Current regulations, however, require registration for new construction or upon sale of an existing property so over time this information will eventually be captured.

Any septic systems discharging to land via soakaways would be less effective on the eastern side of The Firth where soils are poorly draining than in more freely draining soils found around the settlements of Bixter and Semblister, which lie nearest the shellfish farms.

Seawater samples taken from adjacent the two community discharges showed higher levels of contamination were present near Tresta. It is anticipated that the most significant human sewage impact occurs in the easternmost regions of The Firth and Tresta Voe and that due to prevailing wind direction and lack of significant tidal flushing this would tend to stay entrained in Tresta Voe. The impact on the fishery would be greatest when winds were blowing from the east or northeast, though the exact movement of contaminants is difficult to predict.

Agricultural Impacts
Livestock and farming activities are an important factor in the use of land around The Firth. Much of the area is used for grazing and a number of crofts line the far eastern shore as well as the area around Semblister on the southern shore. Much of the remaining area is used as rough grazing land.

Landcover here is mixed with areas of bog and heath intermixed with some improved grassland and acid grassland. Improved grassland can be found to the south of the fishery on the crofts at Semblister as well as lining Bixter and Effirth Voes, along the Burn of Quarsdale and around the settlement of Tresta. These areas would supply a greater contribution of faecal bacteria due to runoff after heavy rains, particularly the areas around Tresta where soil type contributes to higher runoff.

Agricultural practices can have a dramatic impact locally on water quality. Sheep are grazed throughout the area and can be observed accessing the shoreline and sheep droppings were observed in strandline debris. However, changes to the way agricultural subsidies are applied and paid are anticipated to lead to a decline in sheep population in Shetland and hence in the amount of faecal waste deposited and potentially entering the voes.

Wildlife Impacts

Wildlife impact, as discussed in section 8, is unpredictable. While seals were observed on the shoreline in Bixter and Effirth Voes, their numbers were limited. Seals could be expected to forage anywhere within the voes and The Firth though their presence near the fishery is expected to be of limited duration and temporally unpredictable. The mussel farms are likely to receive faecal inputs from birds such as terns, gulls and cormorants that rest of the floats and lines. While these impacts may be significant very locally (directly under the birds) the impact to the wider fishery is unpredictable.

Seasonal Variation

As there was little monitoring history at the existing fishery in The Firth, care must be exercised in drawing conclusions regarding seasonal variation based on historical monitoring results. Analysis in Section 11 showed that there may be a seasonal component with higher results returned in the autumn. Results from the Sandsound Voe production area to the south indicate a weak seasonal effect in the concentrations of *E. coli* found in mussels collected from the ropes there, with somewhat higher results observed in autumn.

The area does not appear to have a significant tourist population. According to the harvester, a number of habitations in the area are only occupied during the summer but it was not possible to confirm this specifically.

There is a seasonal increase in sheep numbers present around The Firth, with peak populations occurring in the summer and early autumn. The onset of higher rainfall in the autumn months (section 9) would be expected to result in a flush of faecal bacteria being washed off the hillsides and especially from improved grassland areas.

As there is commercial pressure to harvest throughout the year, a year-round fishery has been presumed for the purposes of establishing a sampling plan.

Rivers and Streams

A number of streams and smaller watercourses feed into The Firth and its associated voes. Nine of the most significant of these were sampled and measured in order to determine bacterial loadings. The highest loadings were found in streams located around the area of Tresta. Streams discharging within 0.5 km of the fishery carried lower loadings but these would still represent a significant source of faecal contamination to the area waters.

Meteorology and Movement of Contaminants

Rainfall patterns at Lerwick (nearest rainfall station) showed a marked increase in average rainfall beginning in September. An increase in rainfall following a period

of drier weather would tend to wash a flush of bacteria from the surrounding land into the voe.

Analysis for the nearest production area with sufficient monitoring history (Sandsound Voe) showed weak positive correlation between rainfall recorded two and seven days prior to monitoring results, as well as a weak seasonal correlation with higher results obtained in autumn.

No statistically significant correlation was found between wind direction and *E.coli* result for Sandsound Voe, though it is not certain that this would apply directly to conditions in The Firth.

It is anticipated that for The Firth, highest *E.coli* concentrations will be found during the early autumn and at locations closest to specific sources of faecal contamination.

Implications for the Tresta North and Ness of Bixter are that contamination levels may be expected to be broadly similar at both. Contamination moving out of Effirth and Bixter Voes through the constriction to the west of Ness of Bixter would be expected to impact the Ness of Bixter site on outgoing tides, potentially resulting in higher contamination levels at the western end of the lines. Contamination here is likely to be well mixed and may be higher at mid column than at the surface due to reduced penetration of UV radiation below the top metre of water.

At Tresta North, higher contamination levels might be expected at the eastern end of the lines as these lie closer to discharges from Tumblin and Quarsdale burns. Here contamination levels might be expected to be higher at or near the surface due to the proximity of the fresh water sources. There is less opportunity for wind driven mixing of the microbially contaminated fresh water prior to reaching the shellfish farm. However, given the lack of sampling data from this farm it is not possibly to assess with any certainty.

Analysis of bathymetry and hydrodynamics of the area indicate that tidal currents are minimal except at natural constrictions between the voes. Mixing and movement of contaminants are likely to be wind driven and slow.

Analysis of Results

Sampling conducted during the shoreline survey indicated low levels of contamination present at the fisheries. Seawater samples taken from the fisheries all returned results of <1 cfu *E.coli*/100 ml, a result consistent with A classification waters. However, it must be noted that these samples were all taken on the same days and this may not reflect the peak level of contamination in the area. As there was insufficient stock for sampling at the Tresta North site, mussels were collected from the bottoms of the floats. These contained <20 and 40 MPN *E.coli*/100 g flesh and intervalvular fluid. The one sample collected from the existing site at Ness of Bixter also contained 40 MPN *E.coli*/100 g.

At the time of survey, there did not appear to be a significant difference between contamination levels observed at the two sites. However, the lack of stock present on the Tresta North site means that harvest in this area is unlikely to occur for at

least 2 years and results from any bacteriological survey conducted at this time would not necessarily relate to conditions on site closer to the time of harvest.

Water samples collected during the shoreline survey indicated highest levels of contamination were present along the eastern shoreline at Tresta. Samples taken from freshwater sources showed levels of contamination of up to 21000 cfu *E.coli*/100 ml though the highest concentration observed in any of the seawater samples was 50 cfu *E.coli*/100 ml (taken at the head of Effirth Voe). A seawater sample taken from adjacent to the Bixter septic tank outfall contained 24 cfu *E.coli*/100 ml. As contaminants are not expected to move significantly within the voe, it is likely that the highest concentrations of contaminants will be found only in the vicinity of the shoreline near sources.

17. Recommendations

The Firth SI 363

The stated RMP for the Firth does not appear to lie on the fishery due to the grid reference being designated only to 100 m accuracy. It is recommended that this be designated to a greater level of accuracy. A grid reference of HU 3345 5115 is proposed. This lies on the western end of the fishery in order to reflect any contamination coming from the stream located at Effirth Voe and the septic tank at Bixter.

The current production area boundaries for The Firth are described as the area bounded by lines drawn between HU 3324 5103 and HU 3324 5144 and between HU 3400 5133 and HU 3400 5024 extending to MHWS. It is recommended that these be retained as stated.

A sampling depth of 3-5 metres is recommended for this site as contaminants are more likely to be mixed in this area and samples taken at the surface may not reflect peak levels of contamination. As this production area does not meet the criteria for reduced sampling based on a stability assessment and fortnightly sampling does not appear to be warranted, monthly monitoring is recommended.

East Firth SI 379

It is recommended that the production area be established as the area bounded by lines drawn between HU 3400 5133 and HU 3400 5024 and between HU 3418 5148 and HU 3512 5142 and HU 3454 5047 extending to MHWS. The bay at the mouth of the Burn of Quarsdale and all of Tresta Voe have been excluded from this area due to the higher levels of contamination observed in these areas.

As there is currently insufficient stock to sample on site, it is recommended that bagged shellfish be placed at HU 3425 5124 at depths of one meter and 5 meters. The recommended RMP is located at the end of the fishery nearest the Burns of Tumblin and Quarsdale, both of which contribute faecal bacteria to the waters near the fishery. This will allow comparison of contamination levels at the two depths in order to determine which to use for on-going monitoring.

This area does not meet the criteria for reduced sampling based on a stability assessment and fortnightly sampling does not appear to be warranted. It is recommended that sampling be conducted monthly (at both depths) and on the same day as sampling at the RMP for The Firth.

Potential for Single Production Area

Analysis of sources and movement of contaminants suggests that the two sites may be roughly equivalent in levels of contamination and therefore the two could be considered for combination into a single production area upon completion of one year's sampling to be conducted when mussels have been confirmed growing on the site.

Monitoring results for the two production areas will be reviewed after 1 year. If the fishery at the East Firth proves viable and if no significant differences are observed

between the results for the two production areas, they may be recommended for consolidation into a single production area with a single RMP.

A map showing relative locations of the production areas, farms and sampling points is provided in Figure 17.1 overleaf.

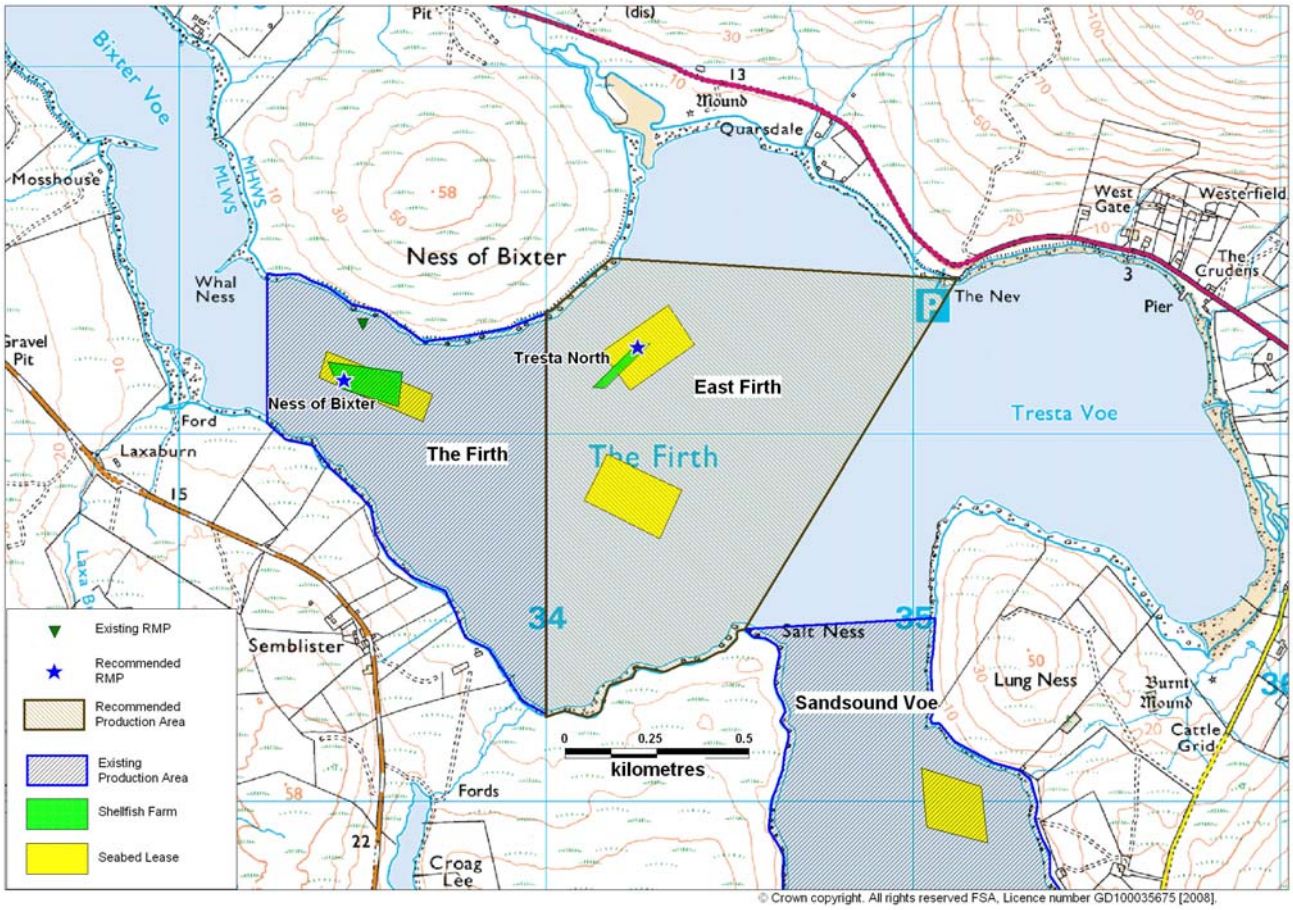


Figure 17.1 Recommendations for The Firth

18. References

Alderisio, K.A. and N. DeLuca (1999). Seasonal enumeration of fecal coliform bacteria from the feces of Ring-billed gulls (*Larus delawarensis*) and Canada geese (*Branta canadensis*). *Applied and Environmental Microbiology*, 65:5628-5630.

Brown, E. & C. Duck. 1996. The status of seals around Shetland. *Shetland Sea Mammal Report 1996*, pp 7-15.

Brown J. (1991). The final voyage of the Rapaiti. A measure of surface drift velocity in relation to the surface wind. *Marine Pollution Bulletin*, 22, 37-40.

Burkhardt, W., Calci, K.R., Watkins, W.D., Rippey, S.R., Chirtel, S.J. (2000). Inactivation of indicator microorganisms in estuarine waters. *Water Research*, Volume 34(8), 2207-2214.

Cliver, Dean. Faculty, Food Safety Unit, University of California Davis, Posting dated 18 Sep 2001 at http://www.madsci.org/posts/archives/sep2001/1000867411.Zo.r.html Accessed 14/01/08.

Edwards, A. and F. Sharples. (1986) Scottish sea lochs: a catalogue. Scottish Marine Biological Association, Oban. 250pp.

Harrop, H. (2003). The grey seals Halichoerus grypus of Lerwick Harbour – friends or foes? A personal view. *Shetland Sea Mammal Report*, 2001 & 2002. pp 29-30.

Kay, D, Crowther, J., Stapleton, C.M., Wyer, M.D., Fewtrell, L., Anthony, S.G., Bradford, M., Edwards, A., Francis, C.A., Hopkins, M. Kay, C., McDonald, A.T., Watkins, J., Wilkinson, J. (2008). Faecal indicator organism concentrations in sewage and treated effluents. *Water Research* 42, 442-454.

Kay, D, Crowther, J., Stapleton, C.M., Wyer, M.D., Fewtrell, L., Anthony, S.G., Bradford, M., Edwards, A., Francis, C.A., Hopkins, M. Kay, C., McDonald, A.T., Watkins, J., Wilkinson, J. (2008). Faecal indicator organism concentrations and catchment export coefficients in the UK. *Water Research* 42, 2649-2661.

Lee, R.J., Morgan, O.C. (2003). Environmental factors influencing the microbial contamination of commercially harvested shellfish. *Water Science and Technology* 47, 65-70.

Lisle, J.T., Smith, J.J., Edwards, D.D., and McFeters, G.A. (2004). Occurrence of microbial indicators and clostridium perfringens in wastewater, water column samples, sediments, drinking water, and Weddell Seal feces collected at McMurdo Station, Antarctica. *Applied Environmental Microbiology*, 70:7269-7276.

Macaulay Institute. http://www.macaulay.ac.uk/explorescotland. Accessed September 2007.

Mallin, M.A., Ensign, S.H., McIver, M.R., Shank, G.C., Fowler, P.K. (2001). Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia* 460, 185-193.

Mitchell, P. Ian, S. F. Newton, N. Ratcliffe & T. E. Dunn. 2004. Seabird Populations of Britain and Ireland, Results of the Seabird 2000 Census (1998-2002). T&AD Poyser, London.

Poppe, C., Smart, N., Khakhria, R., Johnson, W., Spika, J., and Prescott, J. (1998). Salmonella typhimurium DT104: A virulent drug-resistant pathogen. *Canadian Veterinary Journal*, 39:559-565.

Scottish Natural Heritage. http://www.snh.org.uk/publications/on-line/wildlife/otters/biology.asp. Accessed October 2007.

Sea Mammal Research Unit. 2002. Surveys of harbour (common) seals in Shetland and Orkney, August 2001, Scottish Natural Heritage Commissioned Report F01AA417.

Shetland Sea Mammal Group (2003) Shetland Sea Mammal Report 2001 & 2002.

Stoddard, R. A., Gulland, F.M.D., Atwill, E.R., Lawrence, J., Jang, S. and Conrad, P.A. (2005). Salmonella and Campylobacter spp. in Northern elephant seals, California. *Emerging Infectious Diseases* www.cdc.gov/eid 12:1967-1969.

.

19. List of Tables and Figures

Appendices

1. Shoreline Survey Report
2. Sampling Plan
3. Tables of Typical Faecal Bacteria Concentrations
4. Statistical Data
5. Hydrographic Methods

Shoreline Survey Report

The Firth, East Firth
SI 363 and SI 379

Scottish Sanitary Survey Project

Cefas

Shoreline Survey Report

Prod. Area:	The Firth, East Firth
Site name(s):	Ness of Bixter (SI 363 751 08), Tresta North (SI 379 769 08)
Species:	Common mussels
Harvesters:	S. Hawkins; Demlane
Local Authority:	Shetland Islands Council
Date Surveyed:	11-13 May, 16 May (Ness of Bixter samples only)
Surveyed by:	Michelle Price-Hayward and Alastair Cook
Existing RMP:	Firth, Ness of Bixter HU335513
Area Surveyed:	See map in Figure 1

Weather observations:

11 May: Dry, partly cloudy. Wind NNW, force 3
12 May: Rain. Wind E, force 2-3.
13 May: Scattered showers, partly cloudy. Wind light E, shifting to NW and freshening in afternoon.
16 May: Sunny, warm. Wind force 1-2.

Site observations

Fishery

The Tresta North site had two long lines on it. Both lines were virtually empty of mussels. Samples were taken from the bottoms of the floats. It is not likely that there will be sufficient stock to harvest from this site in the near future. The harvester's representative indicated that the lines had been in for over a year and that they had anticipated harvesting them in a year's time. The Ness of Bixter site was visited on 16 May by Sean Williamson along with the harvester Steven Hawkins due to equipment problems and scheduling conflicts. Location of the fishery is mapped in Figure 1.

Sewage/Faecal Sources

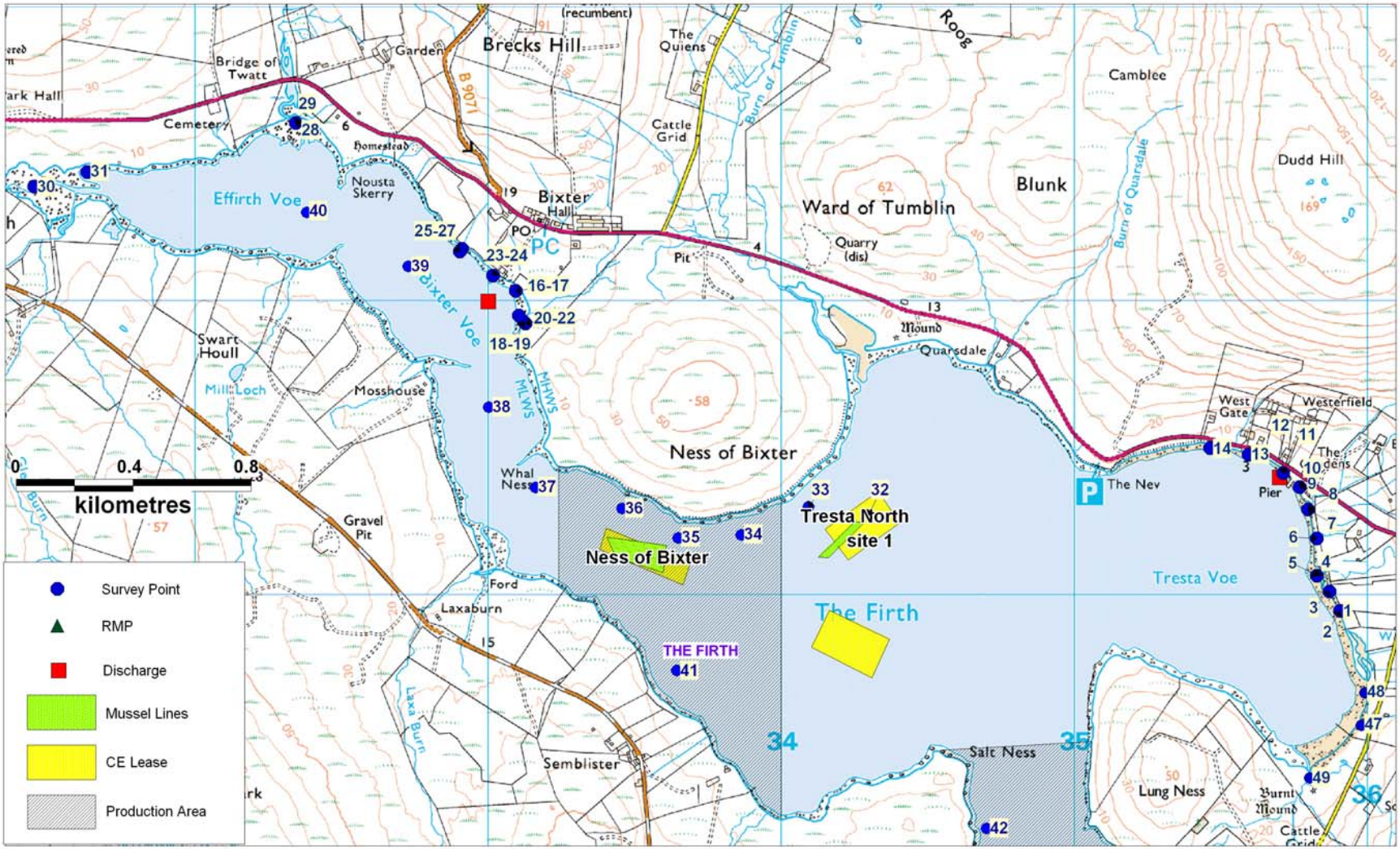
The Firth and East Firth are connected with the north end of Sandsound. There are numerous small freshwater seeps and minor streams draining surrounding grazing land into the Firth.

Scottish Water have noted two public septic tanks in the vicinity: one at Tresta and the other further to the west in Bixter. These have consented design populations of 10 and 20 respectively. Locations of both were confirmed. Outfalls are below low water so sea water samples were taken from near the outfalls.

Seasonal Population

While there is some tourism and seasonal increase in population on Shetland generally, little of it is expected to affect this area. No seasonal campgrounds were observed in the area and there is little in the way of tourist accommodation. Some of the homes are only let seasonally according to the harvester.

Figure 1. Map of Survey Area



Boats/Shipping
Little in the way of boating or shipping occurs within the production areas. The primary boating use is by work boats servicing the mussel and salmon farms.

Land Use
The two settlements, Bixter and Tresta, are relatively small. There are in addition a number of private homes scattered along the shoreline.

There is no arable agriculture surrounding the Firth. Much of the land is used for grazing sheep. Sheep were in evidence on the shoreline and sheep droppings were observed in strandline debris. Numbers were difficult to pin down as the area is hilly and many were obscured from view.

A minimum of 250 sheep were observed during the survey. From a single point on the shore, 134 sheep were in view. Numbers were fairly consistent across the area with each field containing between 30-40 sheep. As lambing was underway, it is expected that this number would be an underestimate.

A total of 12 cattle and 8 chickens were observed and recorded.

Wildlife/Birds
Few birds were observed, and those seen were Eider ducks. Very small numbers of gulls and cormorants were observed but not specifically recorded.

The west end of the firth is restricted by two long shoals. The area is home to a seal colony and on the day surveyed, at least 12 seals were observed in the area.

Specific observations taken on site are mapped in Figure 1 and listed in Table 1. Recorded observations apply to the date of survey only. Animal numbers were recorded on the day from the observer's point of view. This does not necessarily equate to total numbers present as natural features may obscure individuals and small groups of animals from view.

Dimensions and flows of watercourses are estimated at the most convenient point of access and not necessarily at the point at which the watercourses enter the voe or loch.

General observations
Discussion with the local agricultural office indicated that sheep populations had declined over the past decade with continued decline expected due to changes to agricultural subsidies being implemented this year.

The sheep population on Shetland roughly doubles during May-June as lambs are born. Ewes are kept in close to habitations for lambing, possibly increasing impact to coastal areas as many homes are located along the edges of the voes. The vast majority of lambs born in spring are then shipped to the mainland in September-October for finishing.

During winter when grazing is scarce, sheep will feed on seaweed at the shoreline. Sheep fed preferentially on seaweed produce a distinctly flavoured meat that is sold as a specialty product. Sheep can access the shoreline at all times of the year.

Agriculture is practiced within the crofting system on Shetland and many of the fenced areas observed along the voes represent individual crofts. Little in the way of arable agriculture is possible in due to soil infertility and climate so most of the crofts graze sheep or, more rarely, cattle.

Discussion with the local agricultural office indicated that sheep populations had declined over the past decade with continued decline expected due to changes to agricultural subsidies being implemented this year.

Some of the homes in the area are widely distributed and do not appear to be on any sort of mains septic system but rather have individual septic tanks. There has historically been no requirement in Scotland to register these individual systems and so little record is available regarding their age, type, size or location. The Shetland Island Council currently provides a septic tank clean out service, for which it has recently begun to charge a fee.

Recorded observations apply to the date of survey only. Animal numbers were recorded on the day from the observer's point of view. This does not necessarily equate to total numbers present as natural features may obscure individuals and small groups of animals from view.

Dimensions and flows of watercourses are estimated at the most convenient point of access and not necessarily at the point at which the watercourses enter the voe or loch.

Table 1. Survey Observations at The Firth

No.	Date	NGR	Photograph of Area	Description
1	11/05/2007	HU 35907 50946		Small stream 1mx4cmxvery slow flow percolating onto beach
2	11/05/2007	HU 35907 50946		Water sample Firth 1 Fresh 1120
3	11/05/2007	HU 35871 51013		2 pairs eider on firth observed from this point
4	11/05/2007	HU 35828 51066		Freshwater stream 3mx2.5cmx0.7m/s
5	11/05/2007	HU 35828 51066		Water sample Firth 2 fresh 1132
6	11/05/2007	HU 35828 51193		Very small drainage ditch
7	11/05/2007	HU 35798 51291		Small stream 60cmx4cm. Sheep on foreshore. House on shoreline. 8 chickens in garden
8	11/05/2007	HU 35798 51291		Water sample firth 3 fresh taken from stream 1140
9	11/05/2007	HU 35769 51368		small freshwater stream coming from pipe run under road. House across road
10	11/05/2007	HU 35769 51368		water sample firth 4 fresh 1150
11	11/05/2007	HU 35713 51415	Figure 6	4 insepection covers in layby, septic tank vent (strong odour) outflow pipe concreted out across beach discharges underwater 5m out, couldn't tell if it was flowing, may serve up to 24 houses
12	11/05/2007	HU 35713 51415	Figure 8	Water sample firth 5 salt taken at end of pipe 1205
13	11/05/2007	HU 35595 51478		small freshwater stream coming from pipe run under road.
14	11/05/2007	HU 35463 51500		small freshwater stream coming from pipe run under road.
15	11/05/2007	HU 31102 52067		Bixter septic tank discharging to 6" plastic pipe onto beach (flow est 5-10 l/min) Also old iron pipe next to it (broken so probably not in use).
16	11/05/2007	HU 33094 52035	Figure 10	End of Bixter septic tank pipe
17	11/05/2007	HU 33094 52035		water sample firth 6 (fresh/septic discharge) 1310
18	11/05/2007	HU 33120 51931	Figure 11	line of sheep droppings in tideline from this point to where water sample 6 was taken
19	11/05/2007	HU 33126 51925		small stream sampled – see 20
20	11/05/2007	HU 33126 51925		water sample firth 7 fresh 1315
21	11/05/2007	HU 33120 51931		small stream - sample taken from shore see 22
22	11/05/2007	HU 33104 51951		water sample firth 8 1330 taken from shore
23	11/05/2007	HU 33015 52088	Figure 13	4" plastic pipe dribbling onto beach. Pile of blue toilet paper around end. Flow<1l/min and insufficient to sample –see 24
24	11/05/2007	HU 33015 52088		water sample firth 9 salt taken from shore adjacent to where plastic toilet paper pipe discharges 1345
25	11/05/2007	HU 32910 52178		very small stream onto beach
26	11/05/2007	HU 32902 52169		water sample firth 10 salt taken 1345
27	11/05/2007	HU 32902 52169		134 sheep on surrounding hill observed from this point

No.	Date	NGR	Photograph of Area	Description
28	11/05/2007	HU 32343 52607	Figure 17	freshwater stream 4mx5cmx0.6m/s
29	11/05/2007	HU 32343 52607	Figure 14	water sample firth 11 fresh 1425
30	11/05/2007	HU 31450 52390		Water sample firth 12 (location estimated due to failed reading on gps)
31	11/05/2007	HU 31630 52440		Water sample firth 13 (location estimated due to failed reading on gps)
32	12/05/2007	HU 34298 51272		end of mussel ropes on green buoys. 4 cormorants on buoys. Nothing on adjacent shoreline apart from 5 sheep
33	12/05/2007	HU 34092 51301		10 eiders observed from here
34	12/05/2007	HU 33863 51205		nothing of significance noted at this point
35	12/05/2007	HU 33647 51194		another 5 sheep seen from here
36	12/05/2007	HU 33456 51295		other end of mussel ropes
37	12/05/2007	HU 33161 51366		nothing of significance noted at this point
38	12/05/2007	HU 33001 51640		adjacent house is empty. Seal on spit
39	12/05/2007	HU 32726 52118		11 seals on shore to the north. 70 more sheep. 12 cows.
40	12/05/2007	HU 32379 52303		nothing of significance noted at this point
41	13/05/2007	HU 34282 51247		Corner of Tresta North ropes (2 in total)
42	13/05/2007	HU 34153 51126		Corner of Tresta North ropes
43	13/05/2007	HU 34126 51129		Corner of Tresta North ropes
44	13/05/2007	HU 34250 51250		Corner of Tresta North ropes
45	13/05/2007	HU 34249 51234		Tresta North Water sample 1 (34.6ppt, 9.1C). Tresta North mussel sample 1 taken from underside of floats 0.1m depth (no mussels on ropes at all)
46	13/05/2007	HU 34177 51147		Tresta North Water sample 2 (34.6ppt, 9.1C). Tresta North mussel sample 2 taken from underside of floats 0.1m depth (no mussels on ropes at all). Seal sighted
47	09/05/2007	HU 35979 50557		Water sample Sandsound 9 (fresh)
48	09/05/2007	HU 35992 50668		small stream 110cm wide 2 cm deep, no flow taken Water sample Sandsound 10 (fresh)
49	10/05/2007	HU 35510 49396		Water sample Sandsound 11 (fresh) (see stream in no. 26)

Sampling
Water and mussel samples were collected at sites marked on the map. Samples were transferred to coolboxes and then transported to Shetland Seafood Quality Control for analysis of *E. coli* content.

Water samples were tested for salinity in the field using a hand-held refractometer, giving results in parts per thousand (ppt) salt.

Seawater samples were also tested for salinity by the laboratory using a salinity meter under more controlled conditions. These results were anomalous and investigation by the laboratory revealed operator errors in measurement. Therefore, laboratory salinity results are not reported here.

E. coli results follow in Tables 2 and 3 and are mapped in Figures 2 and 3.

Table 2: Water Sample Results

No.	**Sample**	**Type**	**E. coli (cfu/100ml)**
1	Tresta 1	Water	<1
2	Tresta 2	Water	<1
3	Firth 1	Water	110
4	Firth 2	Water	500
5	Firth 3	Water	2.10E+04
6	Firth 4	Water	3
7	Firth 6	Water	4
8	Firth 7	Water	100
9	Firth 8	Water	8
10	Firth 9	Water	24
11	Firth 10	Water	10
12	Firth 11	Water	320
13	Firth 12	Water	50
14	Firth 13	Water	460
15	Ness of Bixter 1	Water	<1
16	Ness of Bixter 2	Water	<1

Table 3: Shellfish Sample Results

No.	Sample	Type	E. coli (cfu/100g)	Depth
1	Ness of Bixter	Mussel	40	
2	Tresta 1	Mussel	<20	0
3	Tresta 2	Mussel	40	0

Figure 2. Firth Water Results

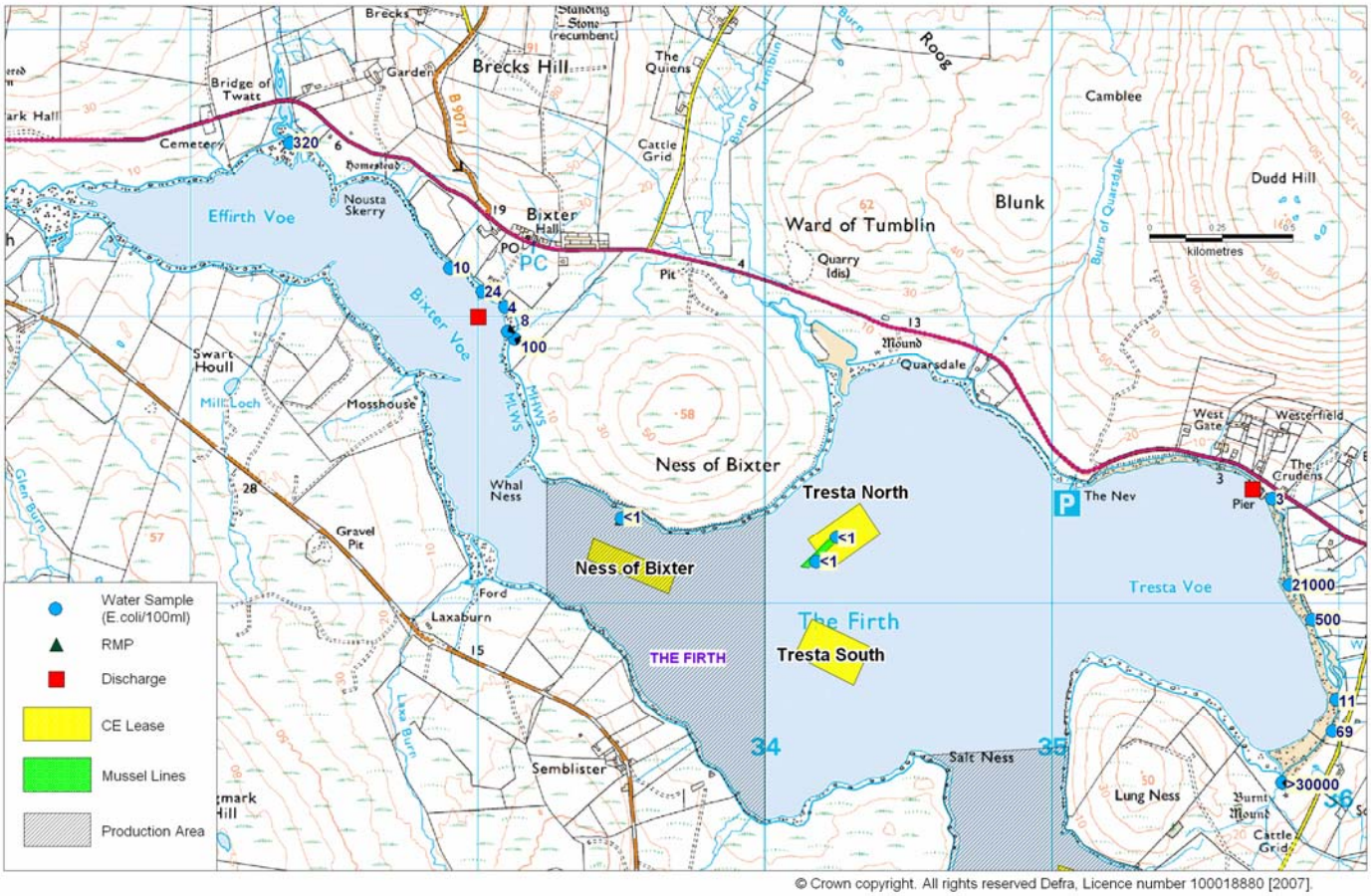


Figure 3. Firth Shellfish Results

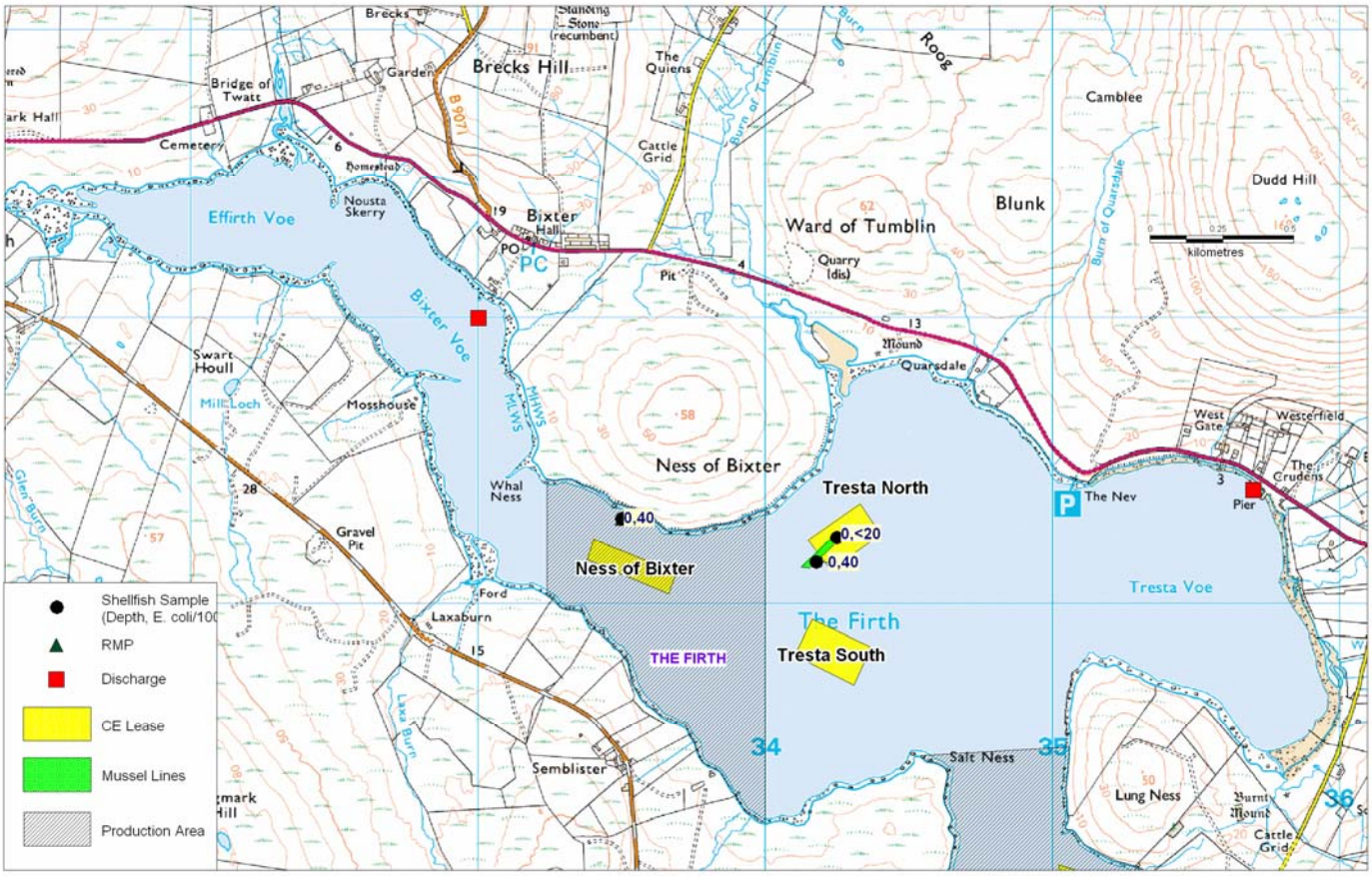


Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

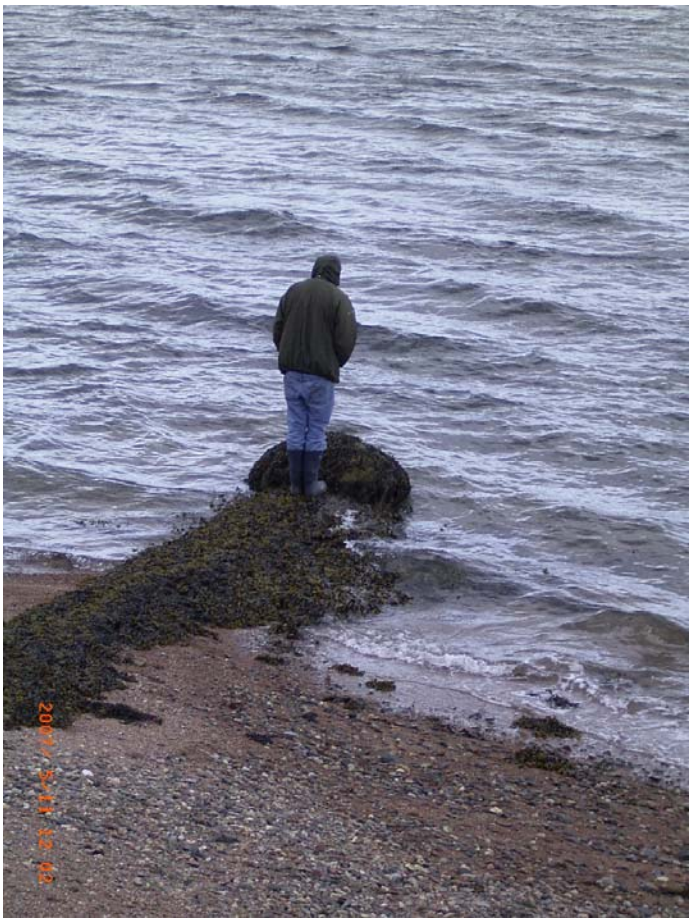


Figure 9.

Figure 10.

Figure 11.

Figure 12.

Figure 13.

Figure 15.

Figure 16.

Figure 17.

Sampling Plan for The Firth

PRODUCTION AREA	SITE NAME	SIN	SPECIES	TYPE OF FISHERY	NGR OF RMP	EAST	NORTH	TOLERANCE (M)	DEPTH (M)	METHOD OF SAMPLING	FREQ OF SAMPLING	LOCAL AUTHORITY	AUTHORISED SAMPLER(S)	LOCAL AUTHORITY LIAISON OFFICER	OTHER INFO
East Firth	Tresta North	SI 379 769 08	Common mussels	Long line	HU 3425 5124	43425	115124	20	1 and 5	Hand	Monthly	Shetland Islands Council	Sean Williamson George Williamson Kathryn Winter Marion Slater	Dawn Manson	
The Firth	Ness of Bixter	SI 363 751 08	Common mussels	Long line	HU 3345 5115	43345	115115	20	3-5	Hand	Monthly	Shetland Islands Council	Sean Williamson George Williamson Kathryn Winter Marion Slater	Dawn Manson	

Tables of Typical Faecal Bacteria Concentrations

Summary of faecal coliform concentrations (cfu 100ml-1) for different treatment levels and individual types of sewage-related effluents under different flow conditions: geometric means (GMs), 95% confidence intervals (Cis), and results of t-tests comparing base- and high-flow GMs for each group and type.

Indicator organism	Base-flow conditions				High-flow conditions			
Treatment levels and specific types: Faecal coliforms	n^c	Geometric mean	Lower 95% CI	Upper 95% CI	n^c	Geometric mean	Lower 95% CI	Upper 95% CI
Untreated	252	$1.7 \times 10^{7*}$ (+)	1.4×10^{7}	2.0×10^{7}	282	$2.8 \times 10^{6*}$ (-)	2.3×10^{6}	3.2×10^{6}
Crude sewage discharges	252	$1.7 \times 10^{7*}$ (+)	1.4×10^{7}	2.0×10^{7}	79	$3.5 \times 10^{6*}$ (-)	2.6×10^{6}	4.7×10^{6}
Storm sewage overflows					203	2.5×10^{6}	2.0×10^{6}	2.9×10^{6}
Primary	127	$1.0 \times 10^{7*}$ (+)	8.4×10^{6}	1.3×10^{7}	14	4.6×10^{6} (-)	2.1×10^{6}	1.0×10^{7}
Primary settled sewage	60	1.8×10^{7}	1.4×10^{7}	2.1×10^{7}	8	5.7×10^{6}		
Stored settled sewage	25	5.6×10^{6}	3.2×10^{6}	9.7×10^{6}	1	8.0×10^{5}		
Settled septic tank	42	7.2×10^{6}	4.4×10^{6}	1.1×10^{7}	5	4.8×10^{6}		
Secondary	864	$3.3 \times 10^{5*}$ (-)	2.9×10^{5}	3.7×10^{5}	184	$5.0 \times 10^{5*}$ (+)	3.7×10^{5}	6.8×10^{5}
Trickling filter	477	4.3×10^{5}	3.6×10^{5}	5.0×10^{5}	76	5.5×10^{5}	3.8×10^{5}	8.0×10^{5}
Activated sludge	261	$2.8 \times 10^{5*}$ (-)	2.2×10^{5}	3.5×10^{5}	93	$5.1 \times 10^{5*}$ (+)	3.1×10^{5}	8.5×10^{5}
Oxidation ditch	35	2.0×10^{5}	1.1×10^{5}	3.7×10^{5}	5	5.6×10^{5}		
Trickling/sand filter	11	2.1×10^{5}	9.0×10^{4}	6.0×10^{5}	8	1.3×10^{5}		
Rotating biological contactor	80	1.6×10^{5}	1.1×10^{5}	2.3×10^{5}	2	6.7×10^{5}		
Tertiary	179	1.3×10^{3}	7.5×10^{2}	2.2×10^{3}	8	9.1×10^{2}		
Reedbed/grass plot	71	1.3×10^{4}	5.4×10^{3}	3.4×10^{4}	2	1.5×10^{4}		
Ultraviolet disinfection	108	2.8×10^{2}	1.7×10^{2}	4.4×10^{2}	6	3.6×10^{2}		

Source: Kay, D. et al (2008) Faecal indicator organism concentrations in sewage and treated effluents. *Water Research* 42, 442-454.

Comparison of faecal indicator concentrations (average numbers/g wet weight) excreted in the faeces of warm-blooded animals

Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^{8}
Cow	230,000	23,600	5.4×10^{9}
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^{8}
Pig	3,300,000	2,700	8.9×10^{8}
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^{8}
Human	13,000,000	150	1.9×10^{9}

Source: Adapted from Geldreich 1978 by Ashbolt et al in World Health Organisation (WHO) Guidelines, Standards and Health. 2001. Ed. by Fewtrell and Bartram. IWA Publishing, London.

Statistical Data

All analyses were undertaken using log transformed results as this gives a more normal distribution.

Distribution on log scale (with Kolmogorov-Smirnov normality test results)

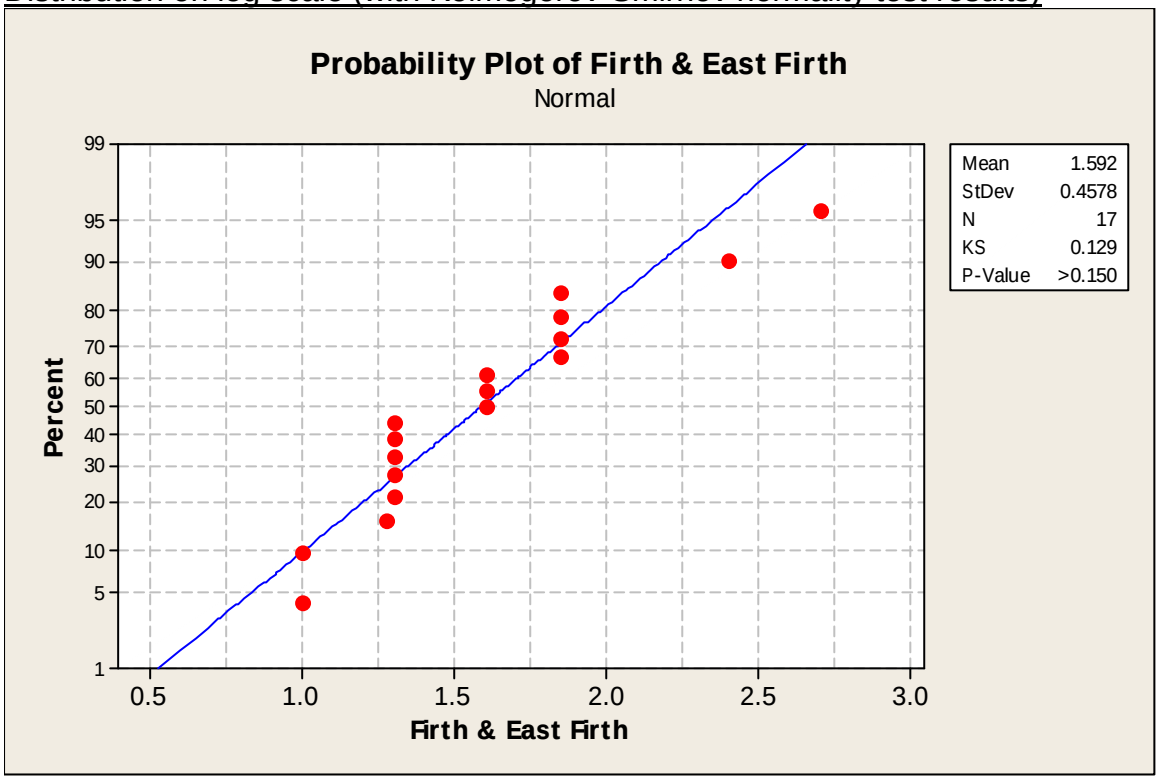


Figure 1. T-Test comparison of results from The Firth and East Firth with Sandsound Voe, post July 2006

```
Two-sample T for Firth & East Firth vs Sandsound Voe

                     N   Mean  StDev  SE Mean
Firth & East Firth  17  1.592  0.458     0.11
Sandsound Voe       15  1.749  0.598     0.15


Difference = mu (Firth & East Firth) - mu (Sandsound Voe)
Estimate for difference:  -0.157
95% CI for difference:  (-0.548, 0.234)
T-Test of difference = 0 (vs not =): T-Value = -0.83  P-Value = 0.417  DF =
26
```

Hydrographic Methods

The new EU regulations require an appreciation of the hydrography and currents within a region classified for shellfish production with the aim to "determine the characteristics of the circulation of pollution, appreciating current patterns, bathymetry and the tidal cycle." This document outlines the methodology used by Cefas to fulfil the requirements of the sanitary survey procedure with regard to hydrographic evaluation of shellfish production areas. It is written as far as possible to be understandable by someone who is not an expert in oceanography or computer modelling. A glossary at the end of the document defines commonly used hydrographic terms e.g. tidal excursion, residual flow, spring-neap cycle etc.

The hydrography at most sites will be assessed on the basis of bathymetry and tidal flow software only and is not discussed in any detail in this document. Selected sites will be assessed in more detail using either: 1) a hydrodynamic model, or 2) an extended consideration of sources, available field studies and expert assessment. This document will focus on this more detailed hydrographic assessment and describes the common methodology applied to all sites.

<u>Background processes</u>
Currents in estuarine and coastal waters are generally driven by one of three mechanisms: 1) Tides, 2) Winds, 3) Density differences.

Tidal flows often dominate water movement over the short term (approximately 12 hours) and move material over the length of the *tidal excursion*. Tides move water back and forth over the tidal period often leading to only a small net movement over the 12 hours tidal cycle. This small net movement is partly associated with the *tidal residual* flow and over a period of days gives rise to persistent movement in a preferred direction. The direction will depend on a number of factors including the bathymetry and direction of propagation of the main tidal wave.

Wind and density driven current also lead to persistent movement of water and are particular important in regions of relatively low tidal velocities characteristic of many of the water bodies in Scottish waters. Whilst tidal flows generally move material in more or less the same direction at all depths, wind and density driven flows often move material in different directions at the surface and at the bed. Typical vertical profiles are depicted in figure 1. However, it should be understood that in a given water body, movement will often be the sum of all three processes.

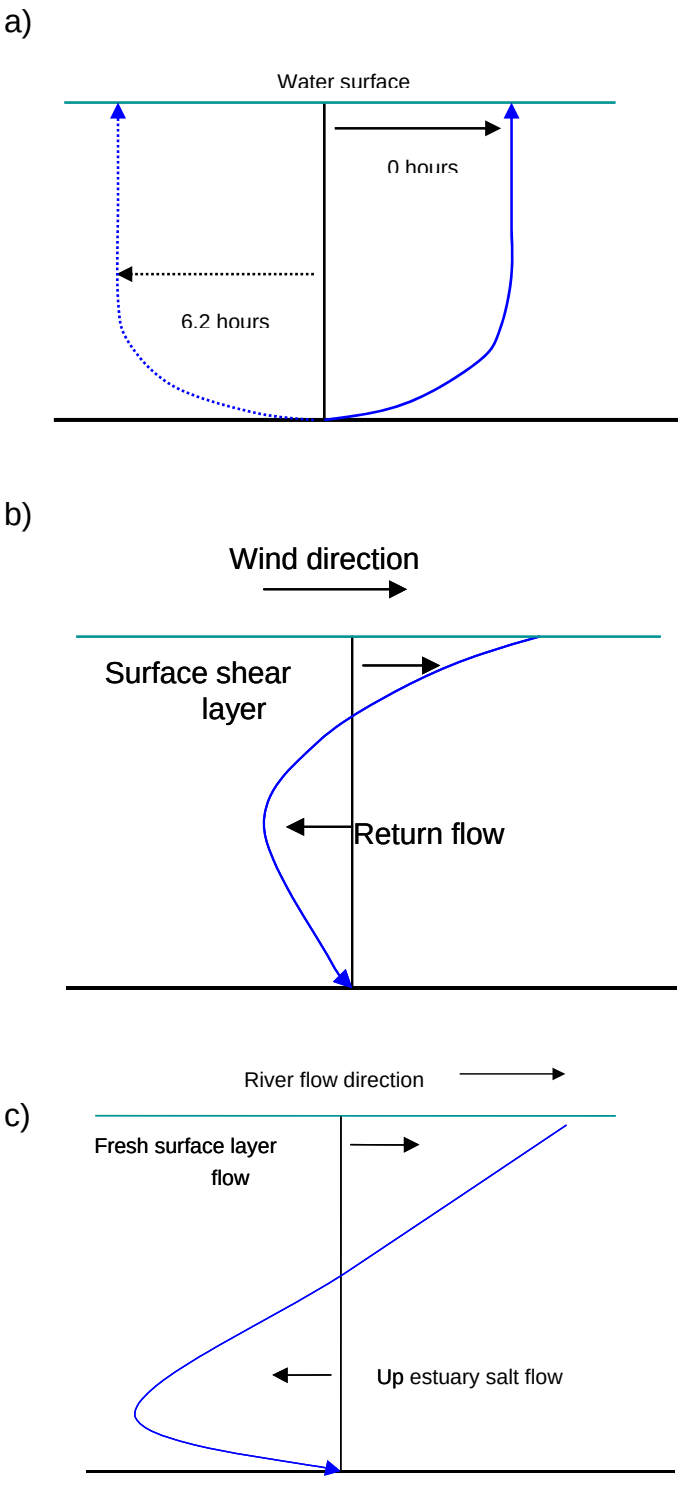


Figure 1. Typical vertical profiles for currents generated by different mechanisms. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction over a period of 6.2 hours. b) wind driven current profile, c) density driven current profile.

In sea lochs, currents associated with *windrows* can transport contaminated water near the shore to production areas further offshore. Windrows are often generated by winds directed along the main length of the loch. Figure 2 illustrates the water movements associated with this. As can be seen the water circulates in a series of cells that draw material across the loch at right angles to the wind direction. This is a particularly common situation for lochs with high land on either side as these tend to act as a steering mechanism to align winds along the water body.

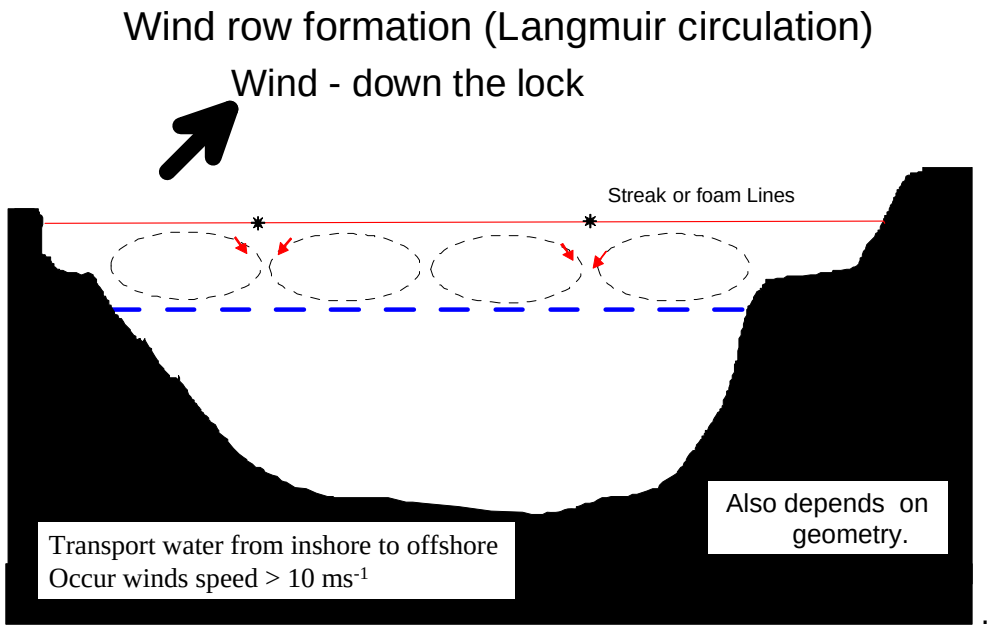


Figure 2: Schematic of wind driven 'wind row' currents. View is down the loch.The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.