Scottish Sanitary Survey Project

Sanitary Survey Report
Sandsound Voe
SI 242
December 2007

Report Distribution – Sandsound Voe

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

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Appendices

Acknowledgements

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

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Sean Williamson, NAFC
Robert Anderson
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The Shetland Sea Mammal Group
Scottish Water
Dr. Alan Lilly, Macaulay Land Research Institute

1. General description

Sandsound Voe is located on the western side of the main island of Shetland, as illustrated in Figure 1.1.

42m deep at its deepest sounding, Sandsound voe is a just under 1km and 4.5km long with a ‘neck’ in middle of voe that is about 0.2km wide. The southern end is completely open to sea.

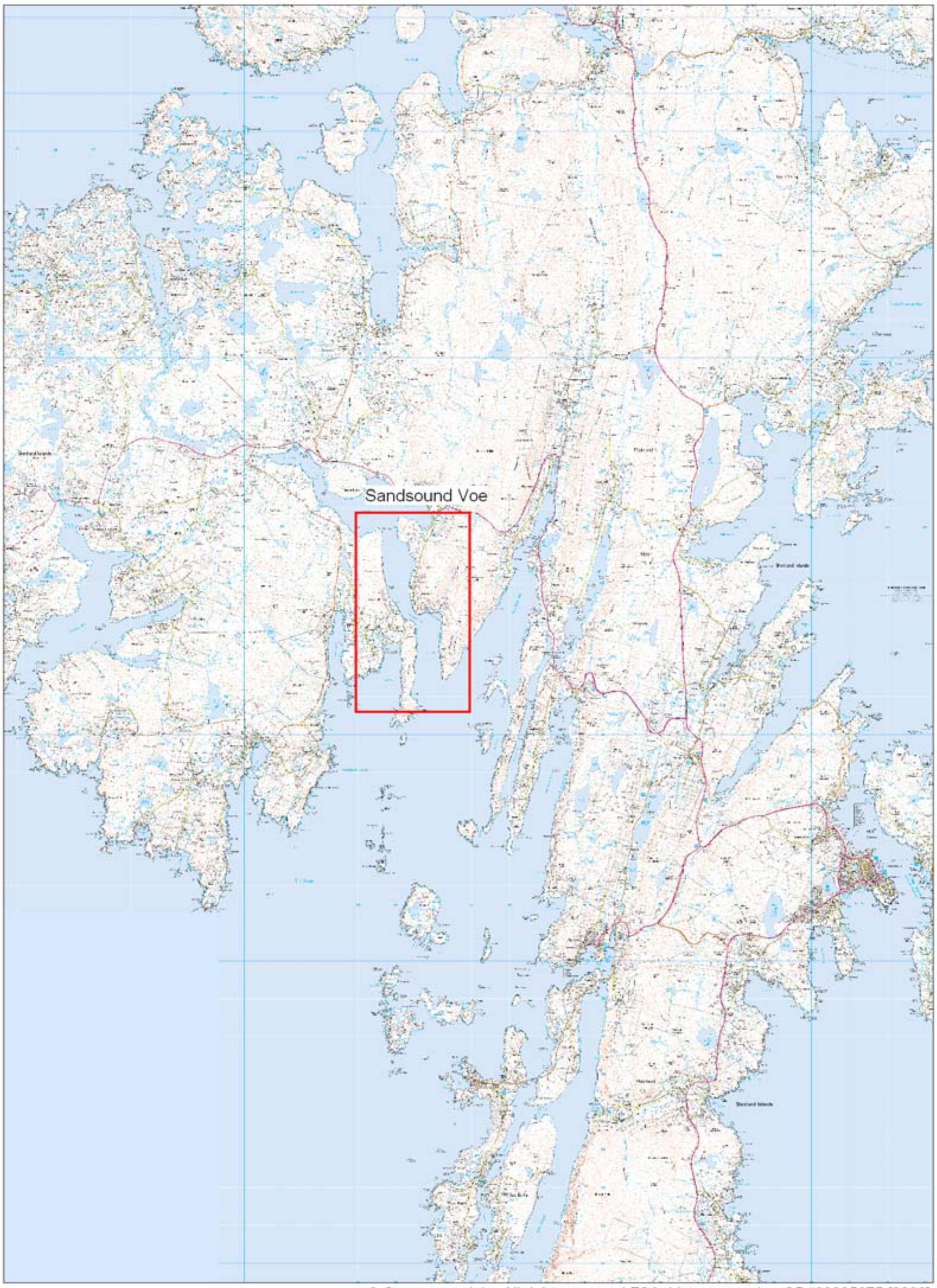


Figure 1.1 Location of Sandsound Voe

2. Fishery

Mussels are grown to 8m depths on 5 longlines. The boundary of the area currently occupied by mussel lines was recorded using GPS to 10m accuracy. Both this area and the area of the crown estate lease are illustrated on the map in Figure 2.1.

Harvesting on site occurs year round when there is stock ready for market. Mussels grown in this area take two to two and a half years to reach marketable size.

The recorded RMP was not located within the crown estate lease or the actual fishery. Samples have been submitted from various locations within the mussel farm, depending upon availability of stock but results have been recorded against the grid reference established incorrectly for the RMP.

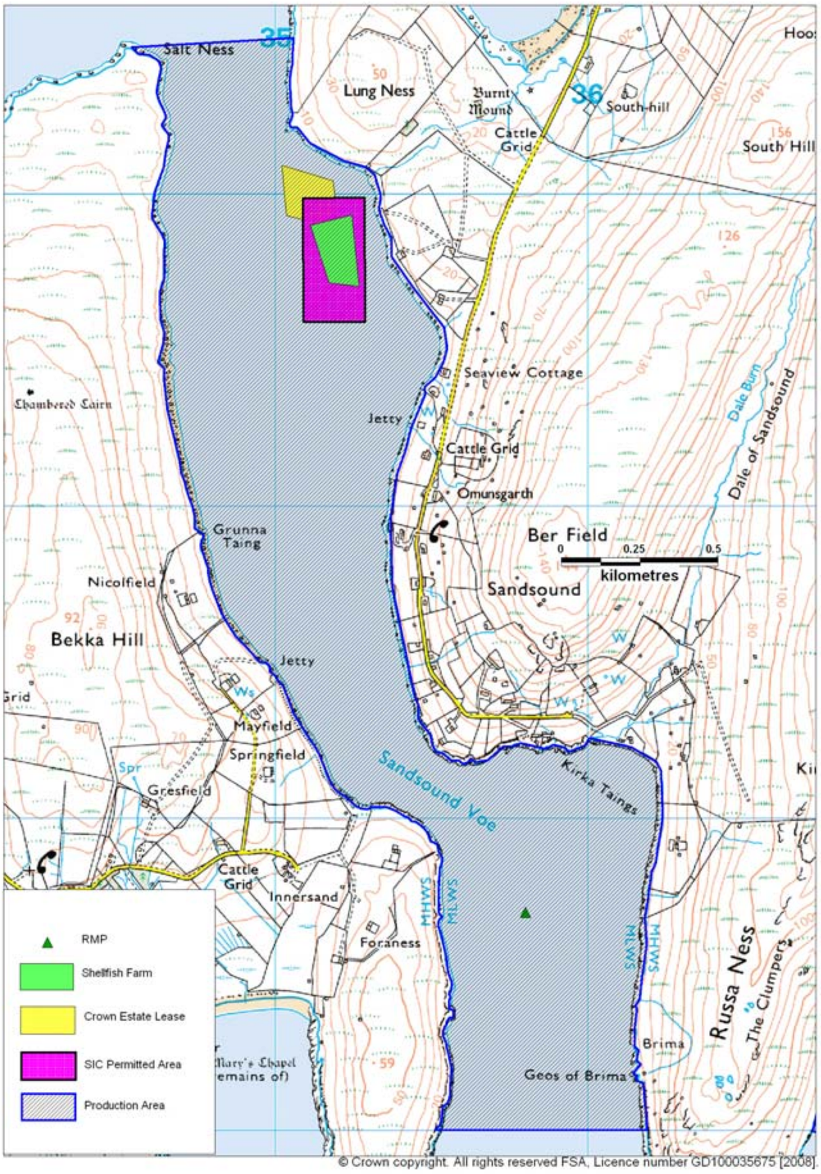


Figure 2.1 Location of Sandsound Voe mussel farm

3. Human population

Figure 3.1 below shows information obtained from the General Register Office for Scotland on the population within the census output in the vicinity of Sandsound Voe.

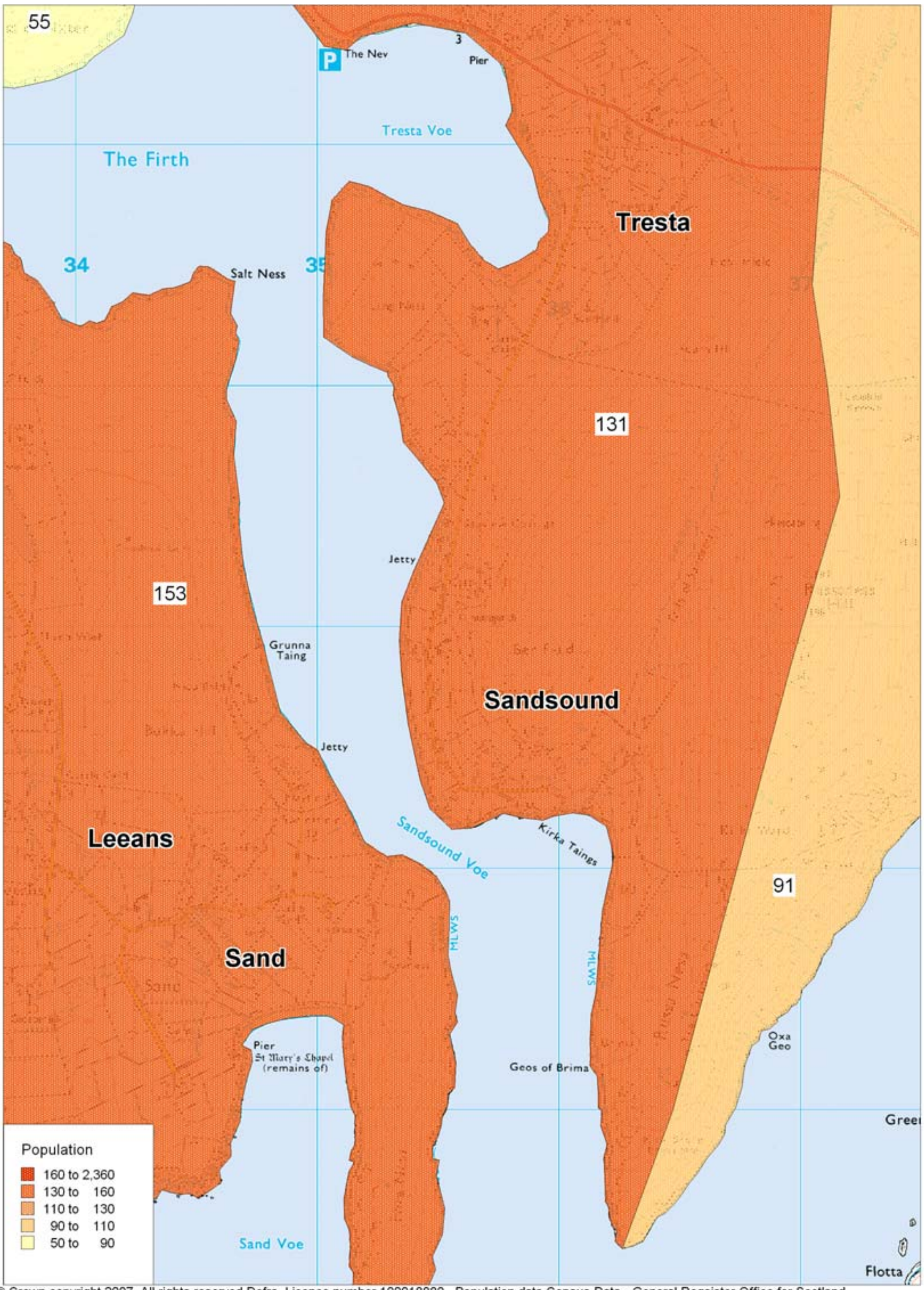


Figure 3.1 Population map for Sandsound Voe

The population for the three census output areas bordering immediately on Sandsound Voe are:

60RD000156	131
60RD000136	136
60RD000032	153

On the eastern side of the voe are the settlements of Tresta to the north and Sandsound to the south. On the western side of the voe the settlements are more dispersed and there are only two small villages the Sand and Leeans. Most of the population is concentrated towards the upper eastern shore and the central western shore of the voe and, given the absence of public sewerage systems, any associated faecal pollution from human sources will be concentrated in these areas.

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

There are two permitted discharges in the Firth, to the north of the Sandsound Voe production area. There are community septic tanks at Tresta (1.5km from northern edge of production area) and Bixter (approximately 2.4km away). Details can be found in Table 4.1 below.

Table 4.1 Discharges identified by Scottish Water

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

These are shown in the map overleaf at Figure 4.1.

No sanitary or microbiological data were available for these discharges.

A number of the homes around the voe have private septic tanks. It has not 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 Sandsound Voe. However, it was apparent upon survey that habitations around the voe were not connected to a public septic system and had private septic tanks. Further information on these can be found in Appendix, Shoreline Survey.

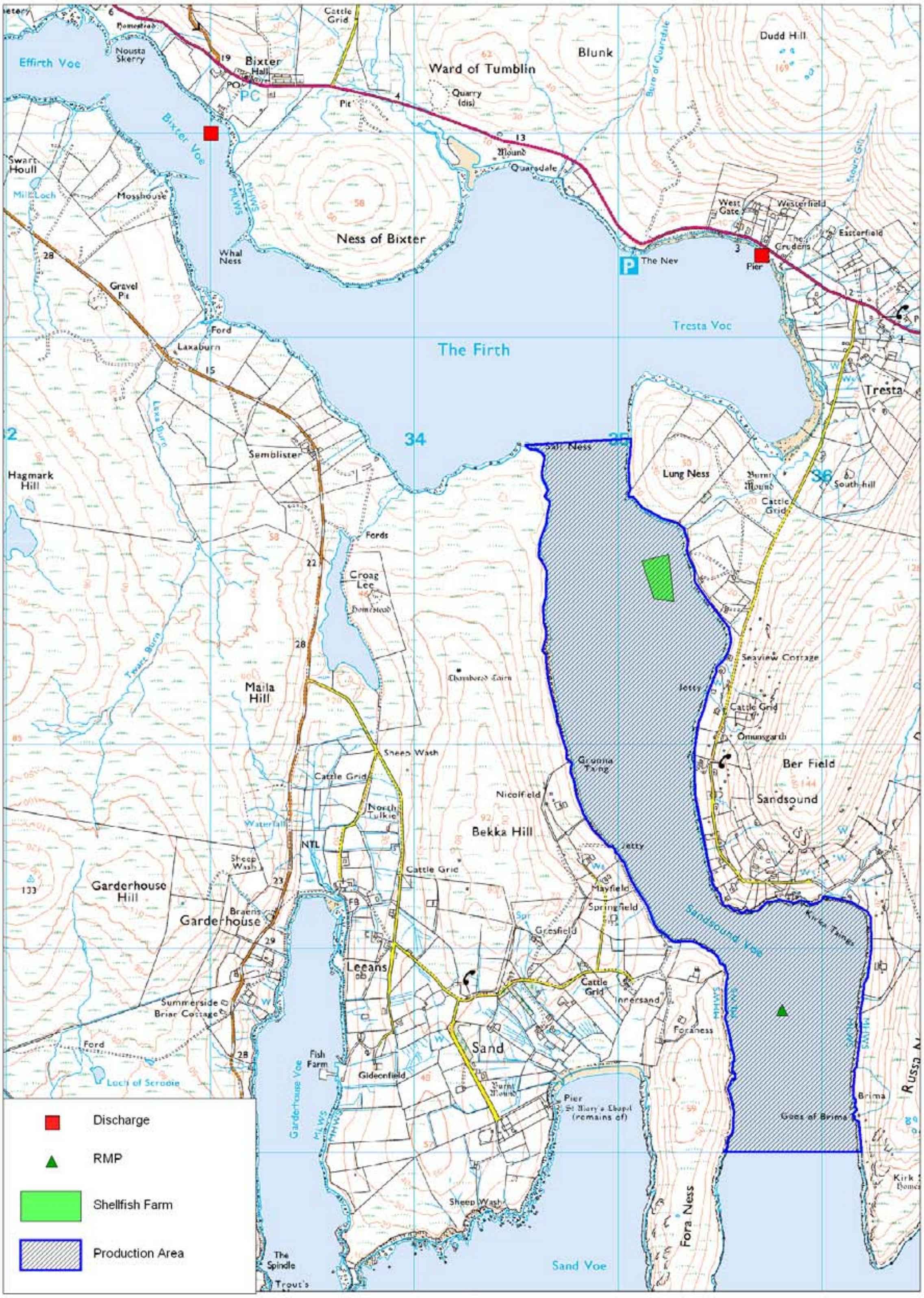


Figure 4.1 Map of Sandsound Voe sewage discharges

5. Geology and soils

Component soils and their associations were identified 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. Definitions of the soil types can be found in a 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 Shetland. 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 Shetland regions mapped have an average surface % runoff of 44.3%, so it is likely that in this case they would be poorly draining.

A map displaying these seven soil type groups and identifying whether they are characteristically freely or poorly draining can be found in Figure 5.1.

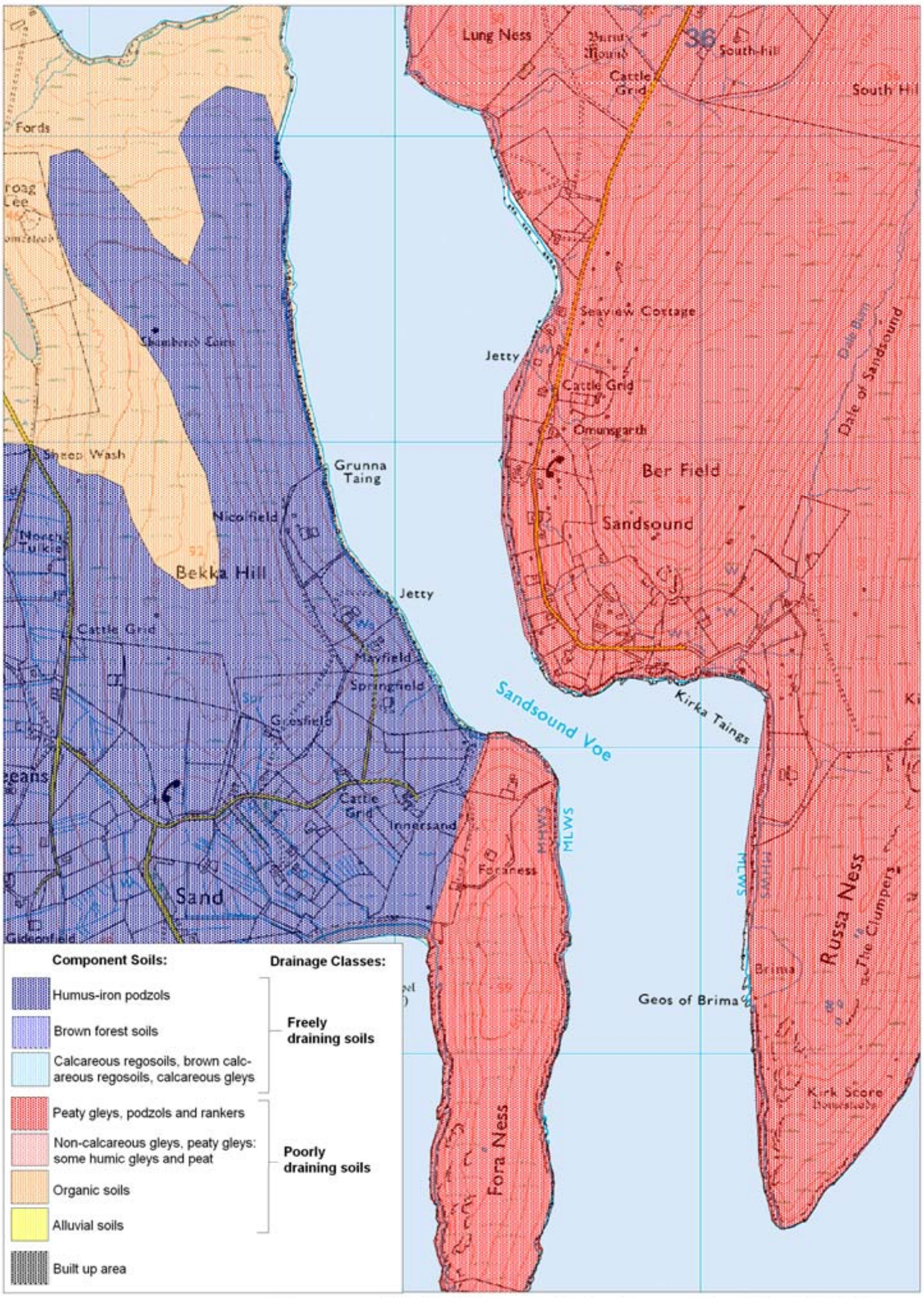


Figure 5.1 Component soils and drainage classes

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 Sandsound Voe and the western stretch of Fora Ness.

The second dominant soil type is composed of humus-iron podzols. This continues north along the Fora Ness coastline until the very tip of the voe, where is becomes the third component soil class of organic soils.

Poorly draining soils are found along the eastern coastline of Sandsound Voe, where surface runoff is likely to be high, as organic soils and peaty gleys, podzols and rankers are often waterlogged. More freely draining soils are found along the western coastline of Sandsound Voe, where surface runoff would be reduced as the permeability of the soil has increased.

In the case of Sandsound Voe, the potential for runoff contaminated with *E. coli* from animal waste is higher along the eastern side of the voe due to the steeper terrain and poorly drained soil types found there.

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:

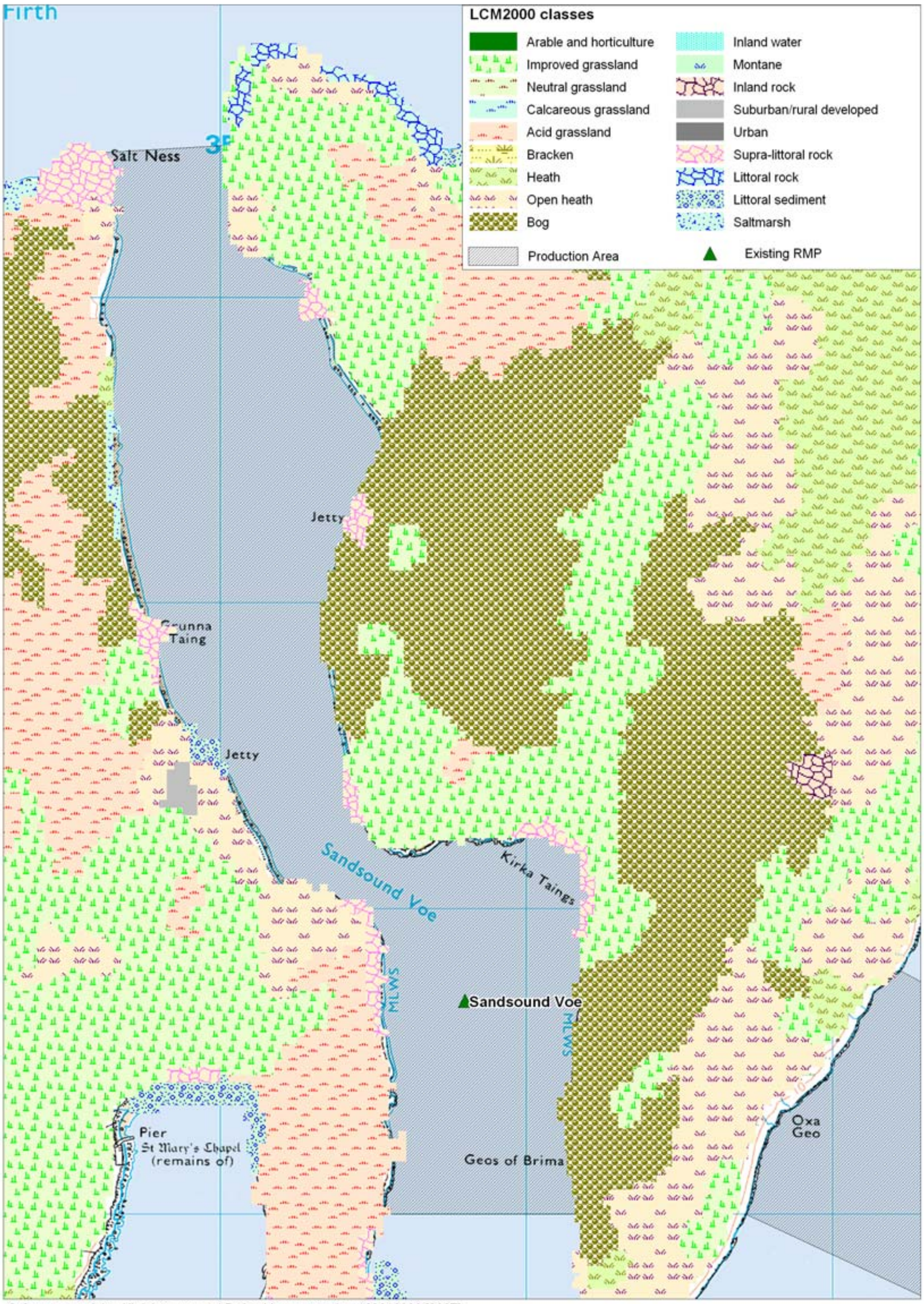


Figure 6.1 LCM2000 class data map for Sandsound Voe

Most of the land on the east side of the voe is shown as improved grassland and bog. There are a few areas of supra-littoral rock and open heath along this coastline. On the western side of the voe, the land cover is more fragmented with patches of acid grassland, bog, improved grassland and open heath. On the eastern and western coastline of Sandsound Voe there are areas of supra-littoral rock and littoral sediment.

The faecal coliform contribution would be expected to be highest from developed areas (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.

The impact of land cover on Sandsound Voe would be an increased potential load of *E. coli* coming from areas of improved grassland on the eastern side of the voe, particularly along the northeastern shore and along the south facing shore at the southern end of the voe.

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 declined on the grounds of confidentiality because the parishes in most cases contained only a small number of farms making it possible to determine specific data for individual farms. The only significant source of information was therefore the shoreline survey (see Appendix 2), which only relates to the time of the site visit between 12 and 16 May, 2007.

The shoreline survey identified that sheep were grazed widely around the voe and that there were no significant concentrations in one or more areas over others. The geographical spread of contamination at the shores of the voe is therefore considered to be even (although random with regard to specific time and place) and therefore needs to be 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 were 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 animals observed and noted during the shoreline survey is illustrated in Figure 7.1.

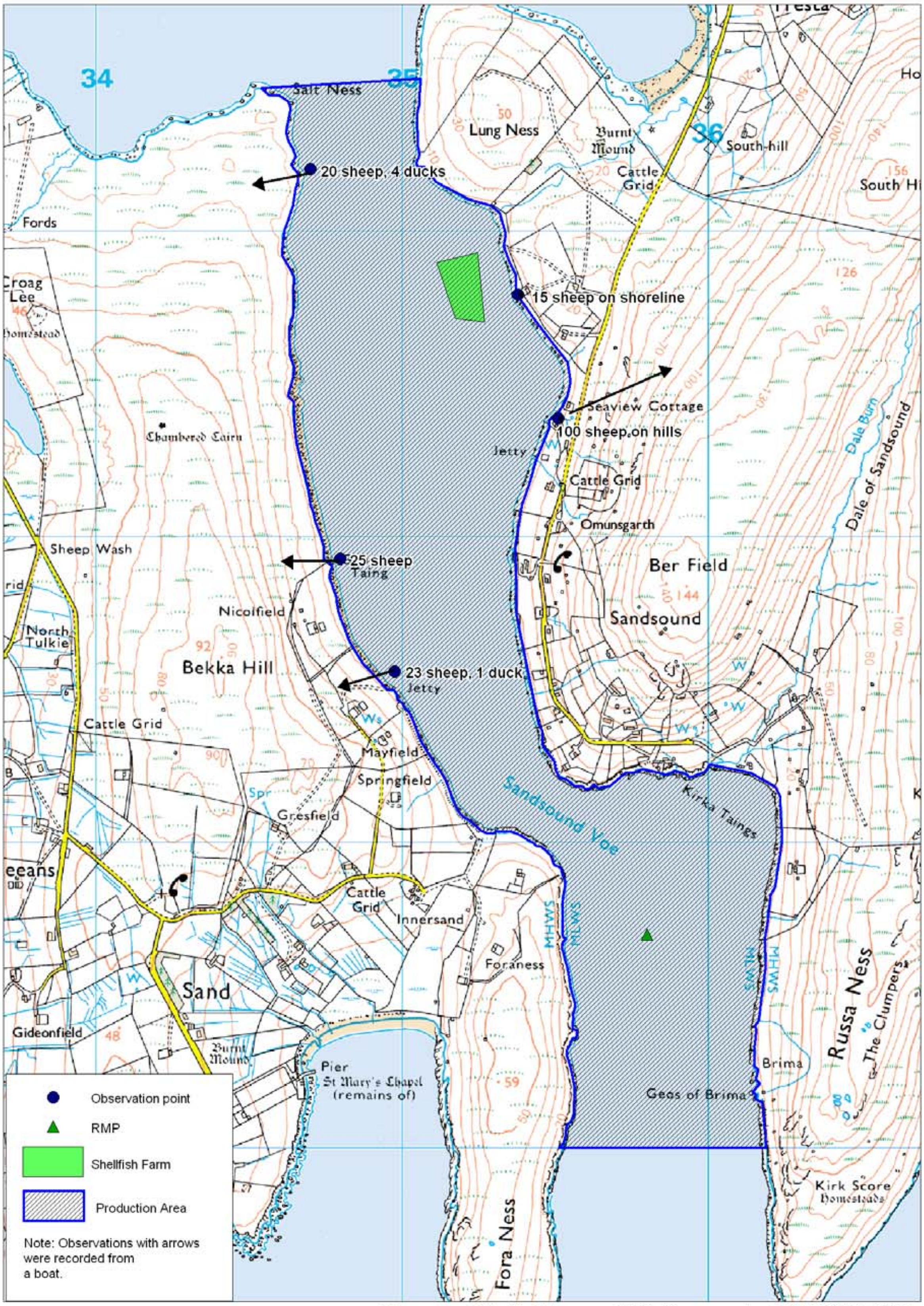


Figure 7.1 Livestock observations at Sandsound Voe

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 *Escherichia 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 is expected in late 2007.

During the August 2001 survey, 202 common seals were counted at haulout sites to the southwest of the mouth of Weisdale Voe. This represented a decline in numbers from the previous two surveys in 1997 and 1993.

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). Up to 70 grey seals reportedly feed at the Shetland Catch factory in Lerwick (Harrop 2003).

Seals have been observed lying between mussel floats in the Firth and Sandsound Voe (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. During the shoreline survey, seals were observed in the water and on shore in Effirth and Bixter Voes to the northwest of Sandsound Voe.

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 near Shetland by species.

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 *Escherichia coli*. It is highly likely that cetaceans will be found from time to time in the Voe and the impact of their presence is, as with pinnipeds, likely to be fleeting and unpredictable.

8.3 Seabirds

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 of Shetland

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 colonies around the area of Sandsound Voe numbering somewhere between 200 and 4,000 apparently occupied sites. This may equate to as many as 8,000 individuals, however this is a very crude estimate. These birds can nest on grassy cliffs, islands or under boulders.

While the *E. coli* content of their droppings is unknown, it is likely that rainfall runoff from around their colonies during the breeding season could impact shellfish areas located near the runoff.

8.4 Other

There is a significant population of European Otters (Lutra lutra) present in Shetland with parts of Yell Sound nominated as candidate Special Areas of Conservation (cSAC) for otters. Within Yell Sound, an otter survey was conducted in 2002 and an estimated 277 otters were recorded (Shetland Sea Mammal Group 2003). A smaller number of otters would be expected within Sandsound Voe.

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).

Otters leave faeces (also known as spraint) along the shoreline or along streams. While otters may occur around the Sandsound Voe area, the voe is not considered to host a substantial population.

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 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 Sandsound voe fishery is likely to be mostly that of Eider ducks feeding on the mussel lines. Approximately 10 Eider ducks and 10 gulls were observed in the voe during the shoreline survey, however as many as 100 could be found feeding on mussel lines in the area according to the harvester.

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 12 km to the south east of the production area. Uninterrupted rainfall data is available for 2003-2006 inclusive. It is likely that the rainfall patterns at Lerwick are broadly similar but not identical to those on Sandsound Voe and surrounding land due to their proximity, but may differ on any given day. It is possible the local topography may result in differing wind patterns (Lerwick is on the east coast, Sandsound Voe 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 Weisdale Voe.

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 Table 9.1 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 *.

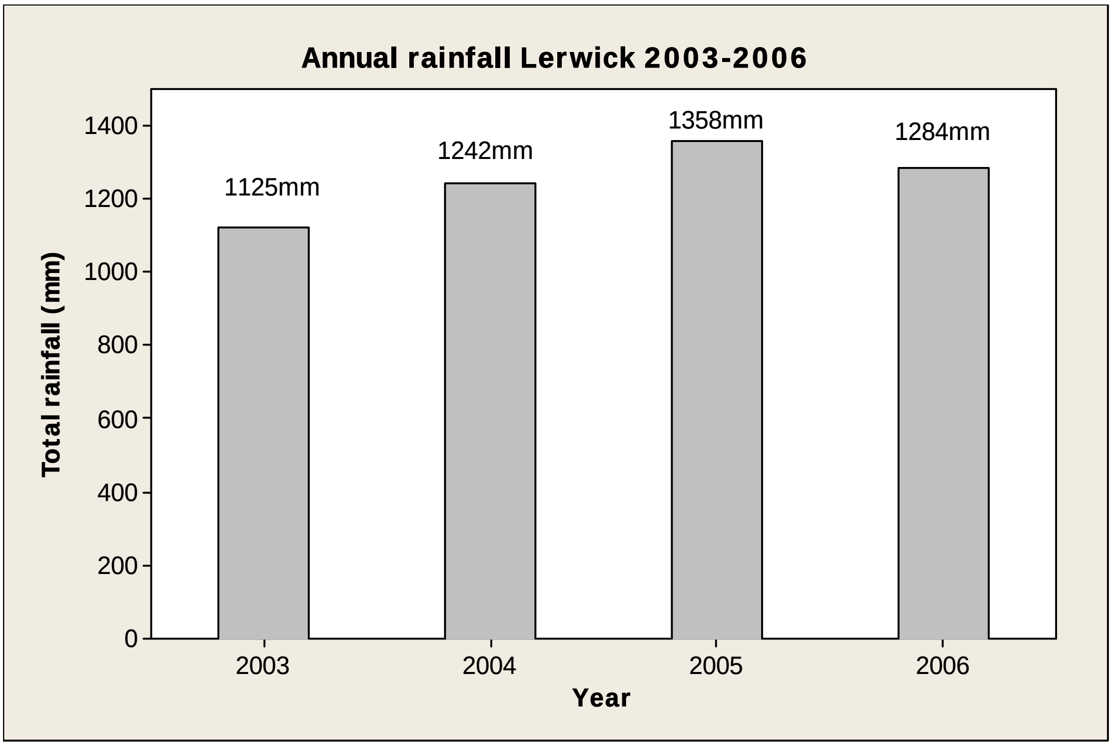


Figure 9.1 Annual rainfall at Lerwick 2003-2006

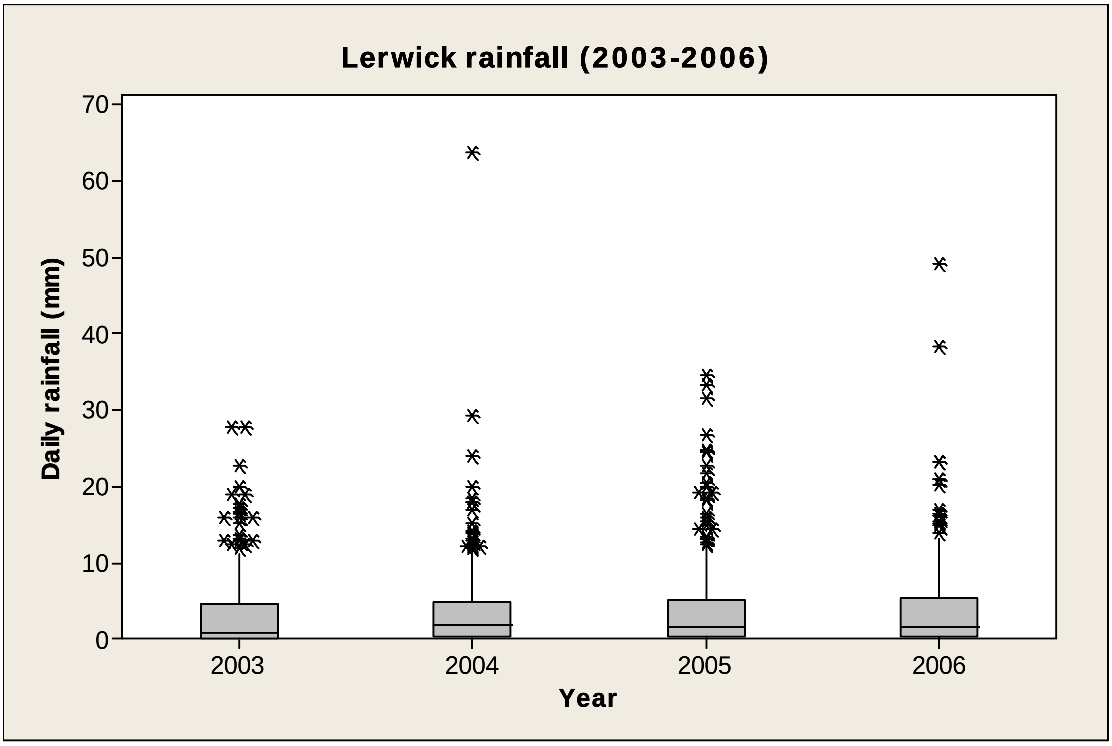


Figure 9.2 Boxplot of daily rainfall by year 2003-2006

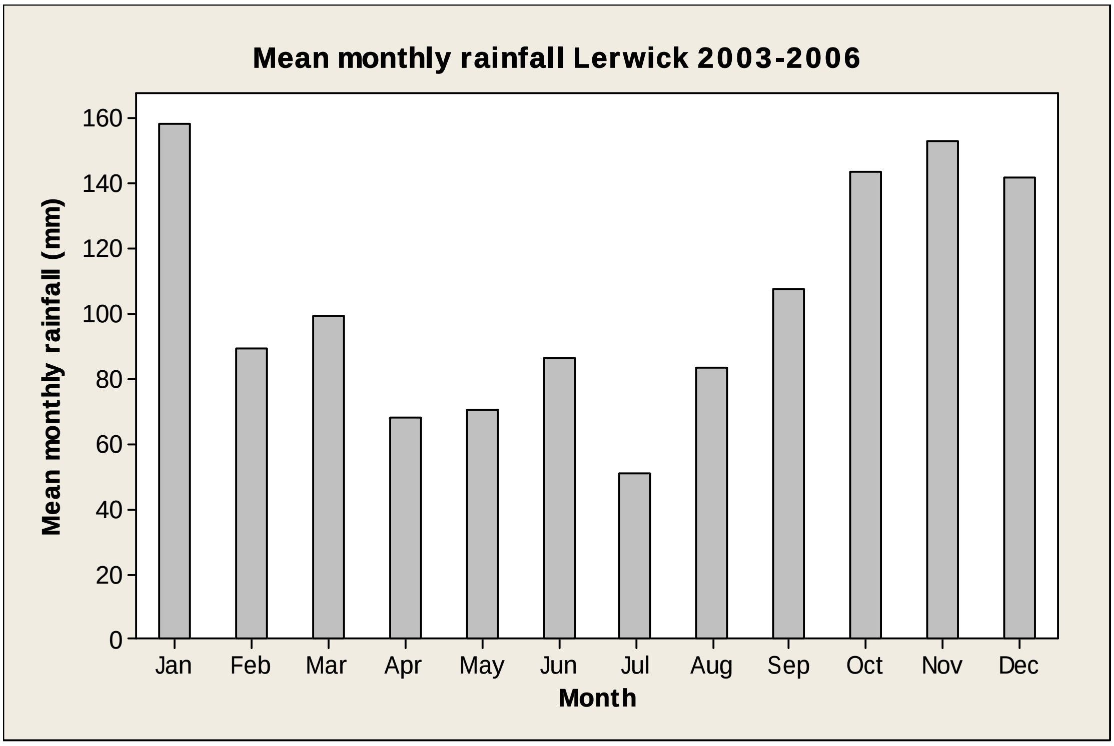


Figure 9.3 Mean monthly rainfall at Lerwick 2003-2006

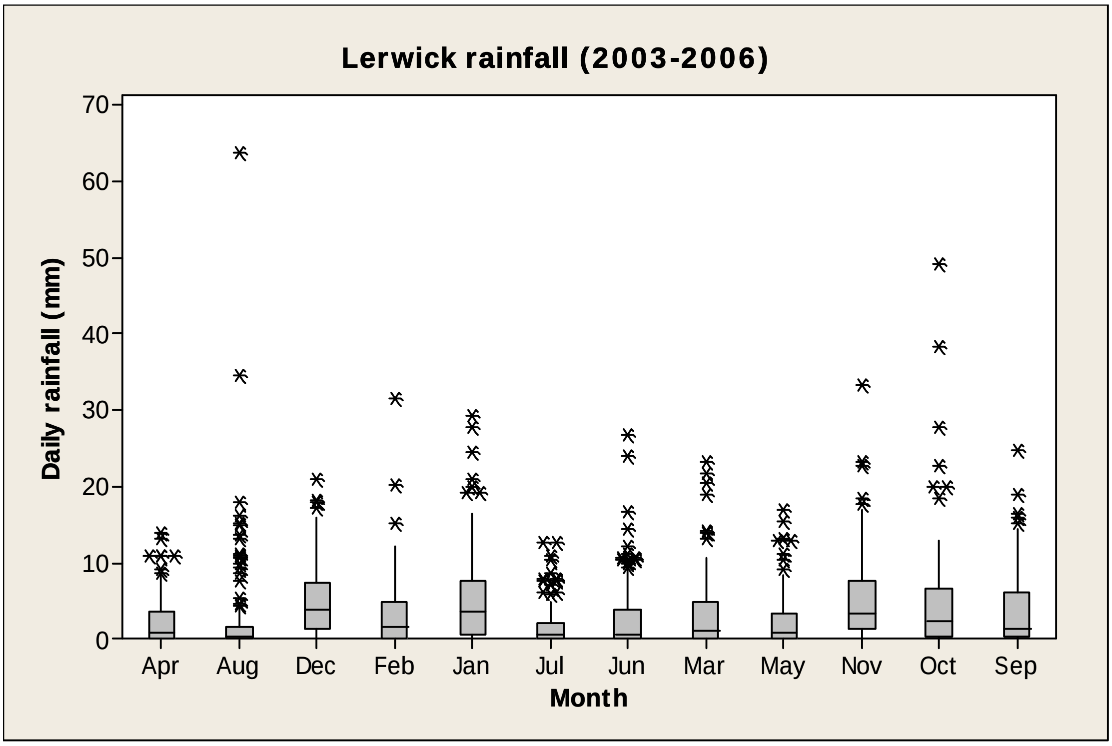


Figure 9.4 Boxplot of daily rainfall by month 2003-2006

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 dependent 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 some contaminated runoff from pastures is to be expected throughout the wetter months. It is possible that faecal matter can build up on pastures during the drier summer months when stock levels are at their highest, leading to more significant faecal contamination of runoff at the onset of the wetter weather in the autumn.

9.2 Wind

Wind data collected at the Lerwick weather station is summarised by season and presented in figures 9.5 to 9.8.

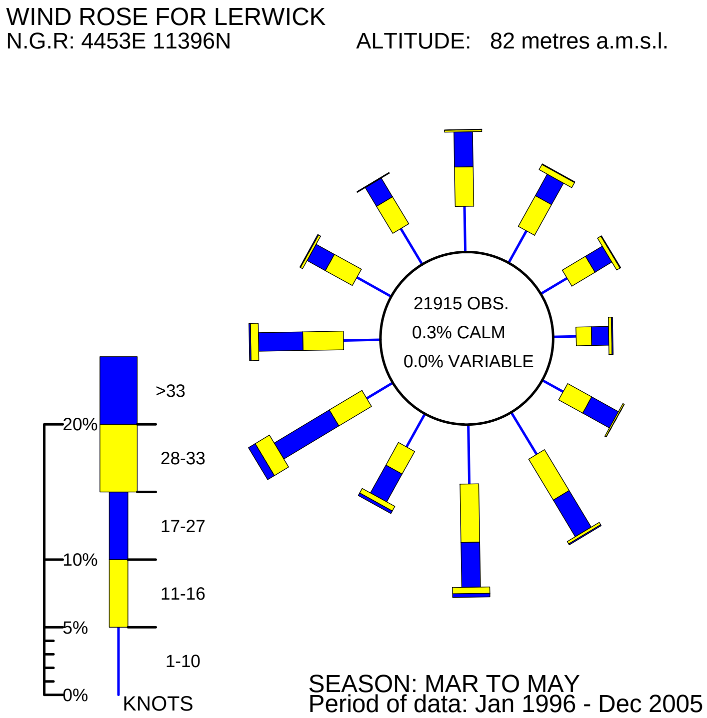


Figure 9.5 Prevailing winds at Lerwick March to May

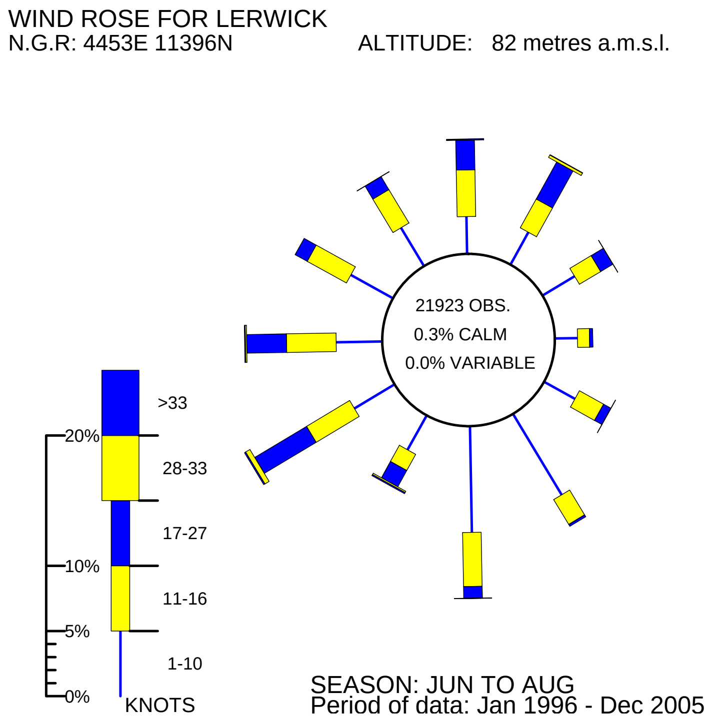


Figure 9.6 Prevailing winds at Lerwick June to August

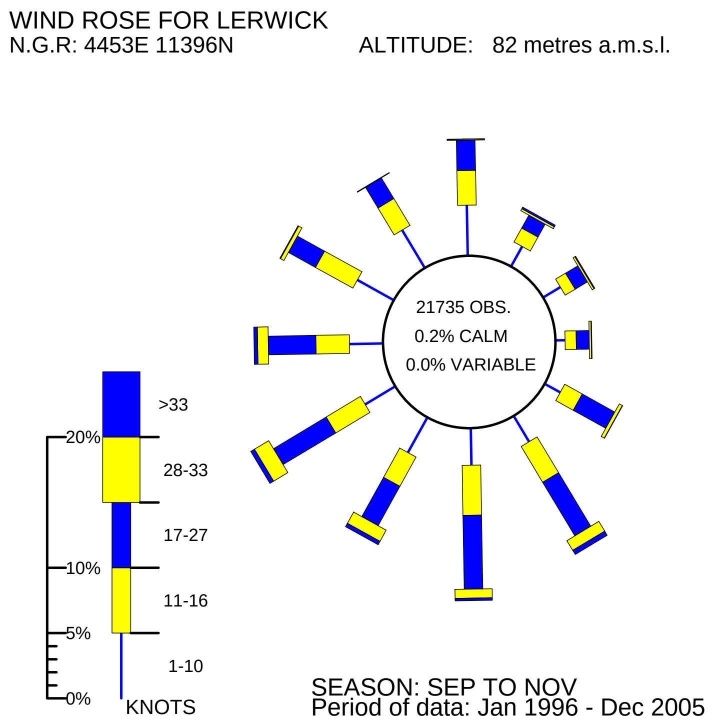


Figure 9.7 Prevailing winds at Lerwick September to November

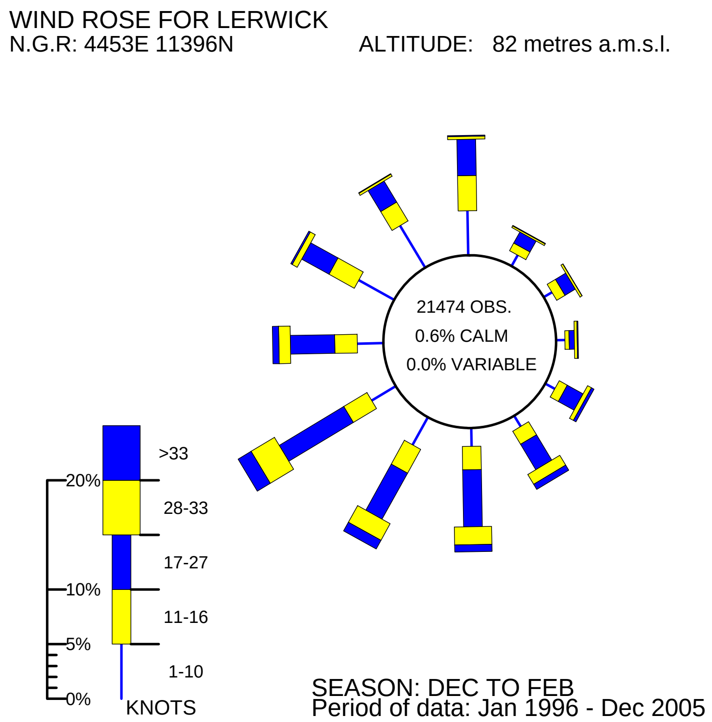


Figure 9.8 Prevailing winds at Lerwick December to February

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. Sandsound Voe is narrow, faces south, and the production sites is sheltered in from Atlantic swells by a bend and constriction half way up the voe. The surrounding high ground will have the effect of channelling the wind up or down the voe.

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

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 12). Winds typically drive surface water at about 3% of the wind speed (J. Aldridge, pers. comm.) 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, the path of which will depend on wind direction and local bathymetry. Strong winter winds will increase the circulation of water and hence dilution of contamination from point sources within the voe. A southerly wind will carry any contamination originating from the settlements of Sand and Sandsound up the voe towards the production site, and a north-easterly wind will carry contamination from the settlement of Tresta towards the production site.

10. Current and historical classification status

Sandsound Voe (SI 242) was first classified in January 2003. Since then, the area has either been classified as a seasonal A/B split classification or a straight A classification. One farm is located within this area. The classification history is presented in Table 10.1. Currently, the area is classified as a seasonal A/B (2007/8). Although the RMP is officially 2.2 km away from the Crown Estates lease, it is assumed that the samples used for the classification were gathered from the actual farm located within the Crown Estates lease boundaries. A map of the current production area is presented in Figure 10.1.

Table 10.1 - Classification history

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	B	B	B	B	B	A	A	A	A	A	B	B
2004	A	A	A	A	A	A	A	A	A	A	A	A
2005	A	A	A	A	A	A	A	A	A	A	A	A
2006	B	B	A	A	A	A	A	B	B	B	B	B
2007	B	B	A	A	A	A	A	B	B	B	A	A

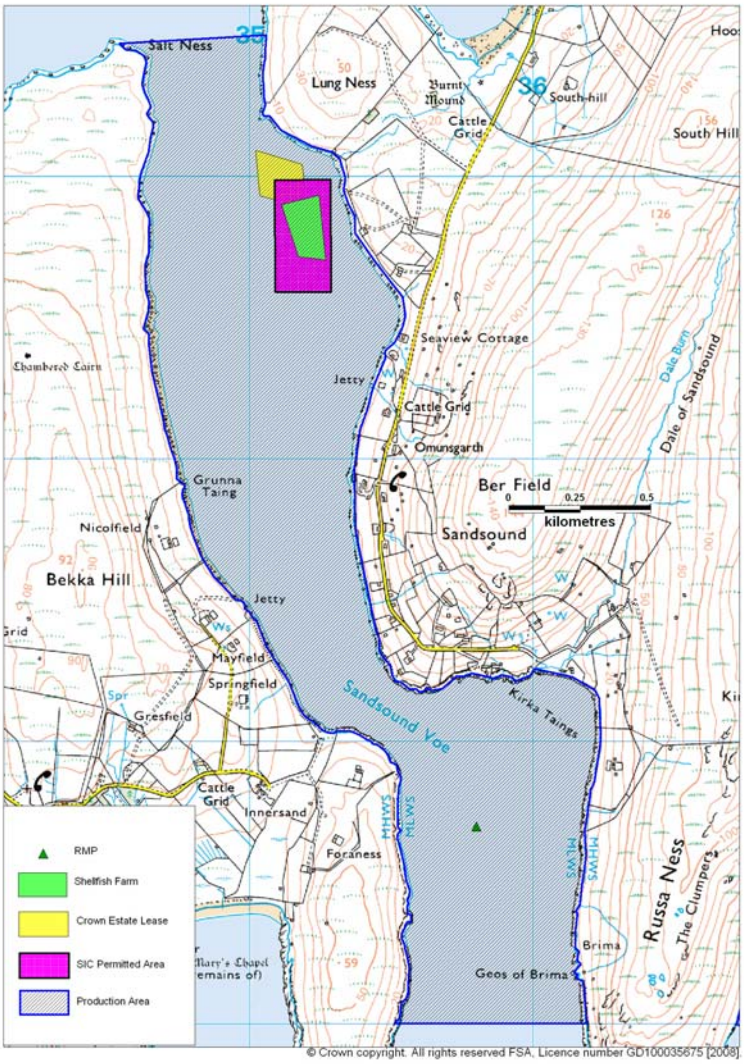


Figure 10.1 Map of current Sandsound Voe production area

11. Historical *E. coli* data

11.1 Validation of historical data

All mussel samples taken from Sandsound Voe (SI 242) up to the end of 2006 were extracted from the database and validated according to the criteria described in the standard operating procedure for validation of historical *E. coli* data. Although the RMP (where all samples were reported as being gathered from) fell within the production area boundaries, it is approximately 2.3 km away from the location of the Crown Estates lease and the fishery. For the purposes of this analysis it is assumed that these samples were taken from the existing farm, and so no samples were rejected on the basis of geographical discrepancies. In the 10 instances where the result was reported as <20, it was given a nominal value of 10 for statistical assessment and graphical representation. All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intervalvular fluid.

11.2 Summary of microbiological results by sites

Common mussels were sampled from one site within the production area (at the RMP), as discussed in the previous paragraph and shown on Figure 11.1.

Table 11.1 Summary of results from Sandsound Voe (SI 242)

Sampling Summary	
Production area	Sandsound Voe
Site	Sandsound Voe
Species	Common mussels
SIN	SI24244308
Location of RMP	HU358477
Location sampled	Reported as HU358477 (see section 11.1)
Total no of samples	53
n 1999	1
n 2000	0
n 2001	0
n 2002	6
n 2003	12
n 2004	12
n 2005	12
n 2006	10
Results Summary (*E. coli* mpn/100g)	
Minimum	<20
Maximum	9100
Median	50
Geometric mean	64.1
90 percentile	500
95 percentile	1180
No. exceeding 230/100g	10 (19%)
No. exceeding 1000/100g	4 (8%)
No. exceeding 4600/100g	1 (2%)
No. exceeding 18000/100g	0 (0%)

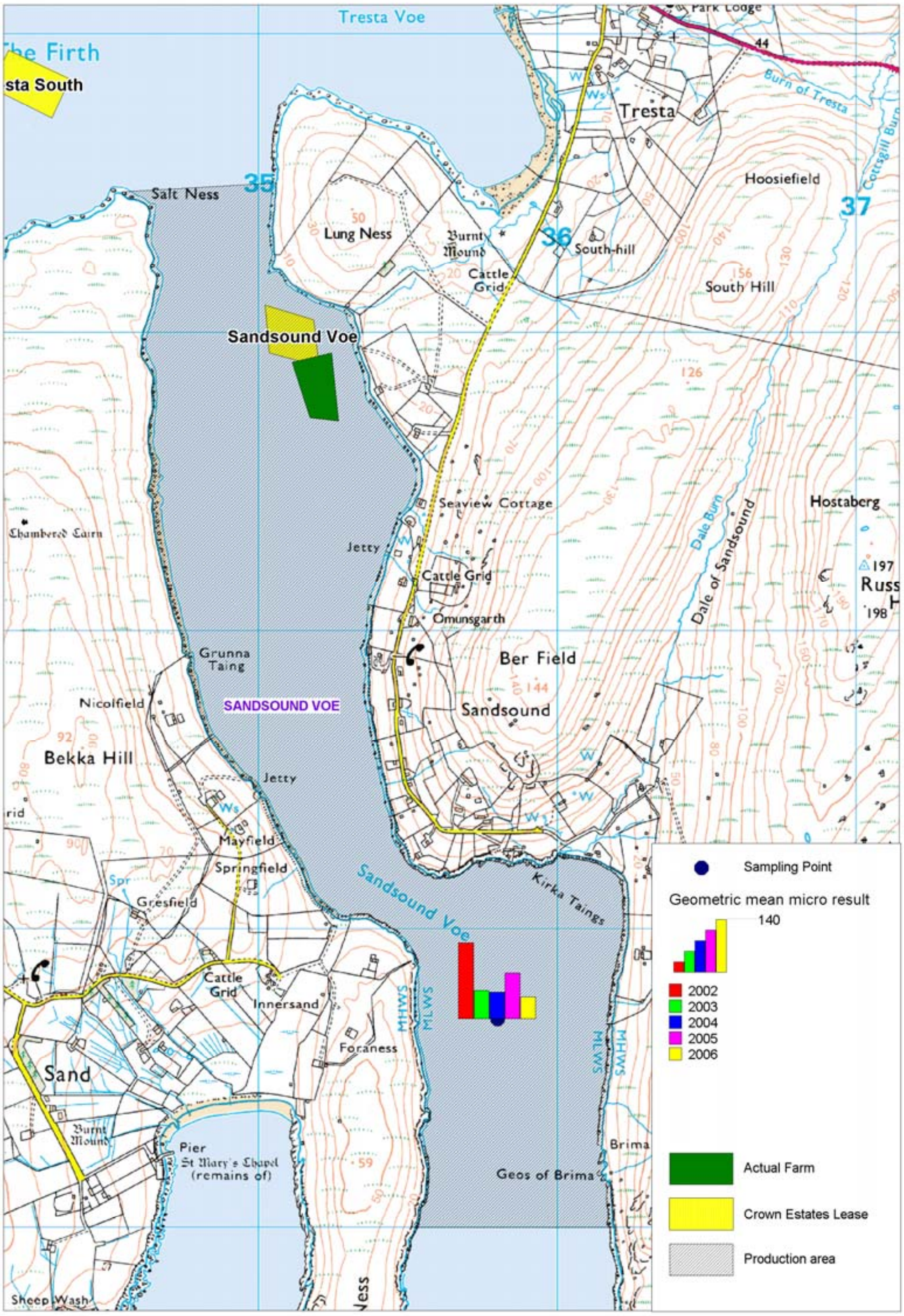


Figure 11.1 Map of geometric mean result by year (1999 result omitted)

11.3 Temporal pattern of results

Figures 11.2 and 11.3 present scatter plots of individual results against date for all samples taken from Sandsound Voe (SI 036). Both are fitted with trend lines to help highlight any apparent underlying trends or cycles. Figure 11.2 is fitted with a line indicating the geometric mean of the previous 5 samples, the current sample and the following 6 samples. Figure 11.3 is fitted with loess smoother, a regression based smoother line calculated by the Minitab statistical software. Figure 11.4 presents the geometric mean of results by month (+ 2 times the standard error).

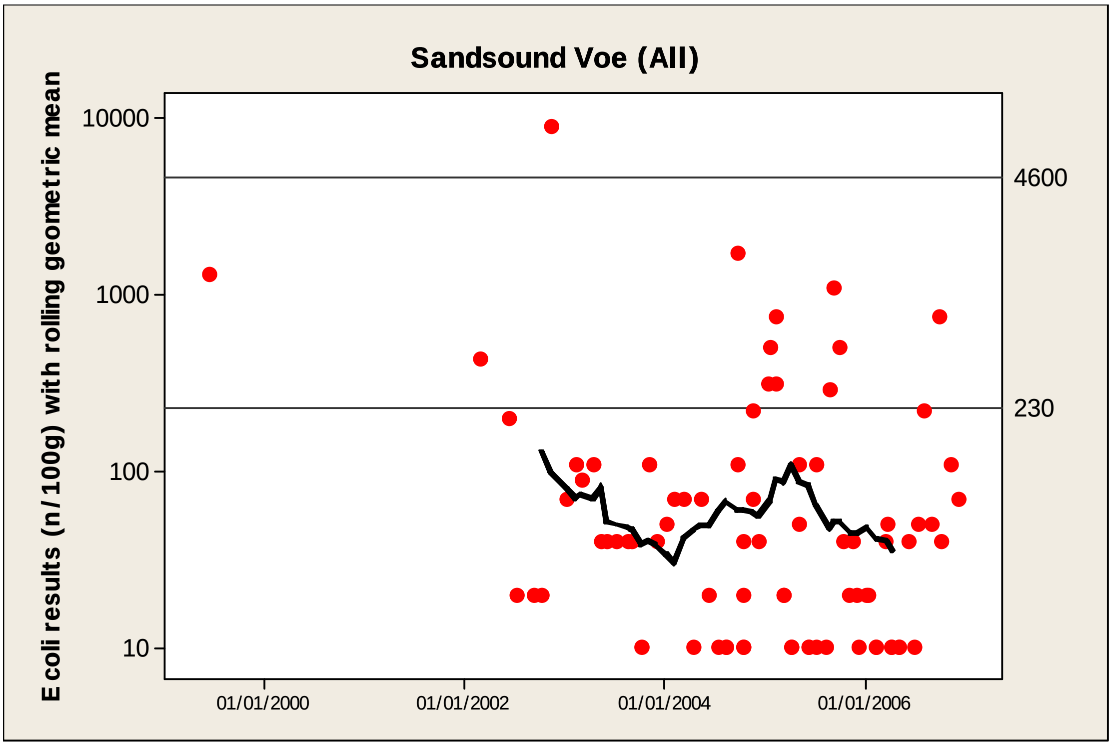


Figure 11.2 Scatterplot of results by date with rolling geometric mean

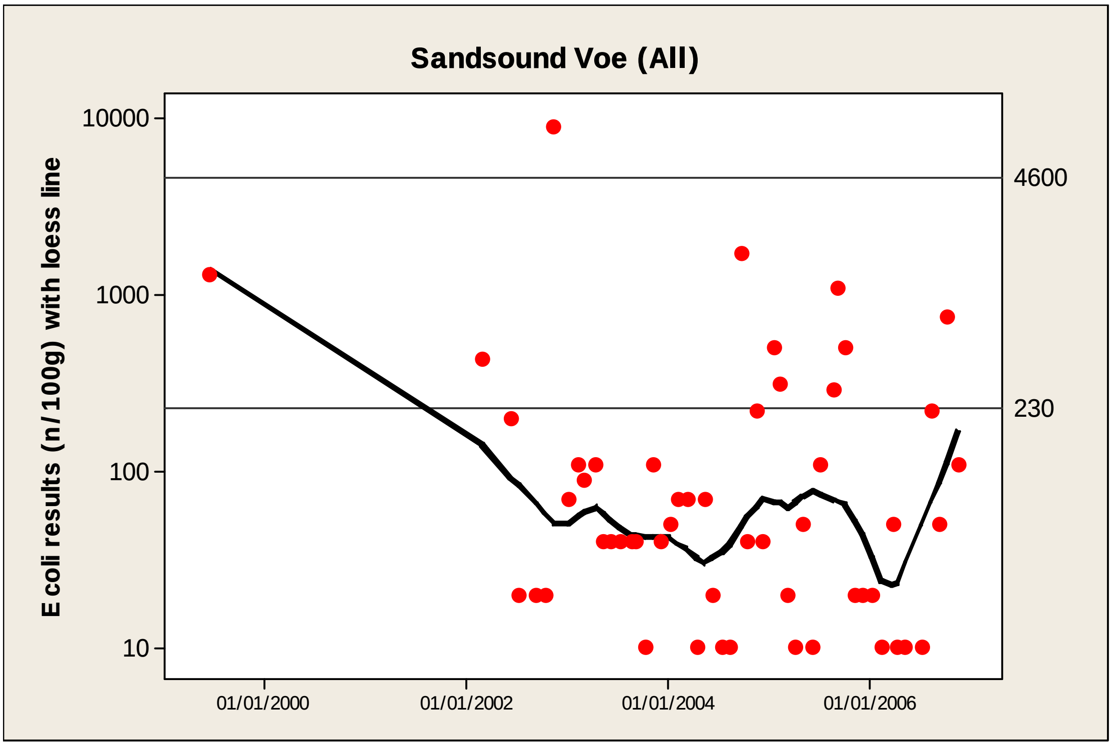


Figure 11.3 Scatterplot of results by date with loess smoother

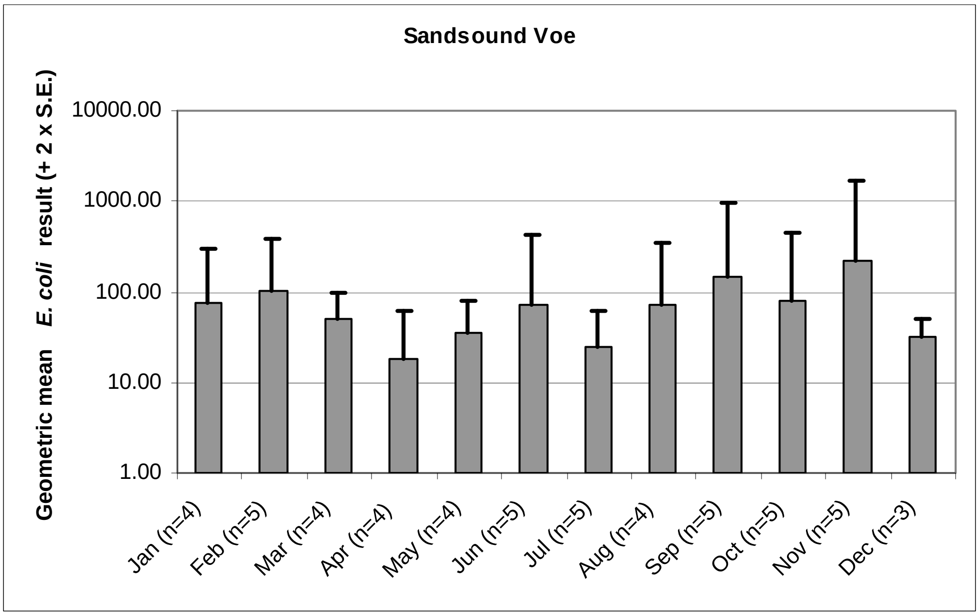


Figure 11.4 Geometric mean result by month

No particular trend is visible on Figures 11.2 or 11.3. Higher results occurred in September and November, but differences were generally small.

11.4 Analysis of results against environmental factors

Environmental factors such as rainfall, tides, 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. This section aims to investigate and describe the influence of these factors individually (where appropriate environmental data is available) on the sample results using basic statistical techniques. As stated previously this analysis considers the 53 samples taken from Sandsound Voe (SI 036) from the start of sampling in 1999 to the end of 2006.

11.4.1 Analysis of results by season

Although not strictly an environmental variable in the same way as rainfall for example, season dictates not only weather patterns, but livestock numbers and movements, presence of wild animals and patterns of human occupation. Seasons were split into spring (March - May), summer (June - August), autumn (September - November) and winter (December - February).

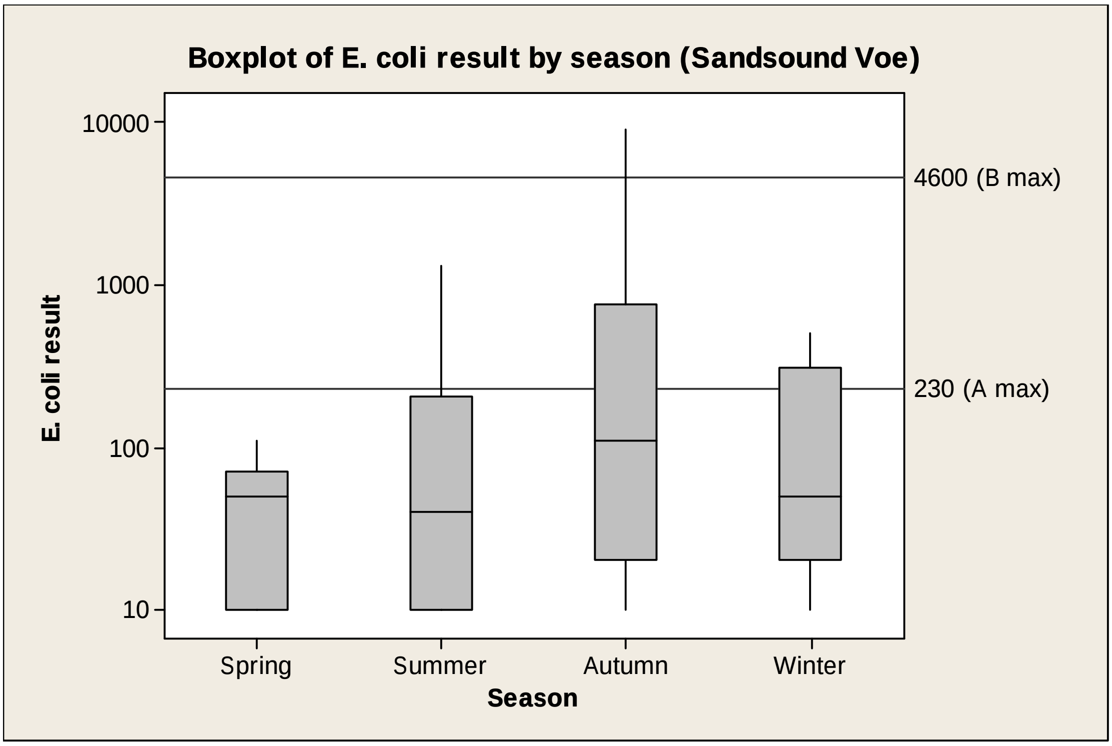


Figure 11.5 Boxplot of *E. coli* result by season

There appears to be a weak seasonal effect with highest results in the autumn. However, using analysis of variance the effect was not statistically significant (One-way ANOVA, p=0.103). Early autumn is the period when livestock numbers peak before lambs are sent to market. Autumn also marks the start of the wetter period of the year, so at this time faecal contamination from agricultural runoff (probably the most important source of contamination in the area) will be at its highest level.

<u>11.4.2 Analysis of results by recent rainfall</u>

The nearest weather station is Lerwick, approximately 12 km to the south east of the production area for which uninterrupted rainfall data is available for 2003-2006 inclusive.

The coefficient of determination was calculated for the *E. coli* results and rainfall in the previous 2 days at Lerwick. Figure 11.6 presents a scatterplot of *E. coli* result and rainfall, with a best fit line derived by regression. Figure 11.7 presents a boxplot of results by rainfall quartile (quartile 1 being the lightest rainfall in the previous 2 days, and quartile 4 the heaviest).

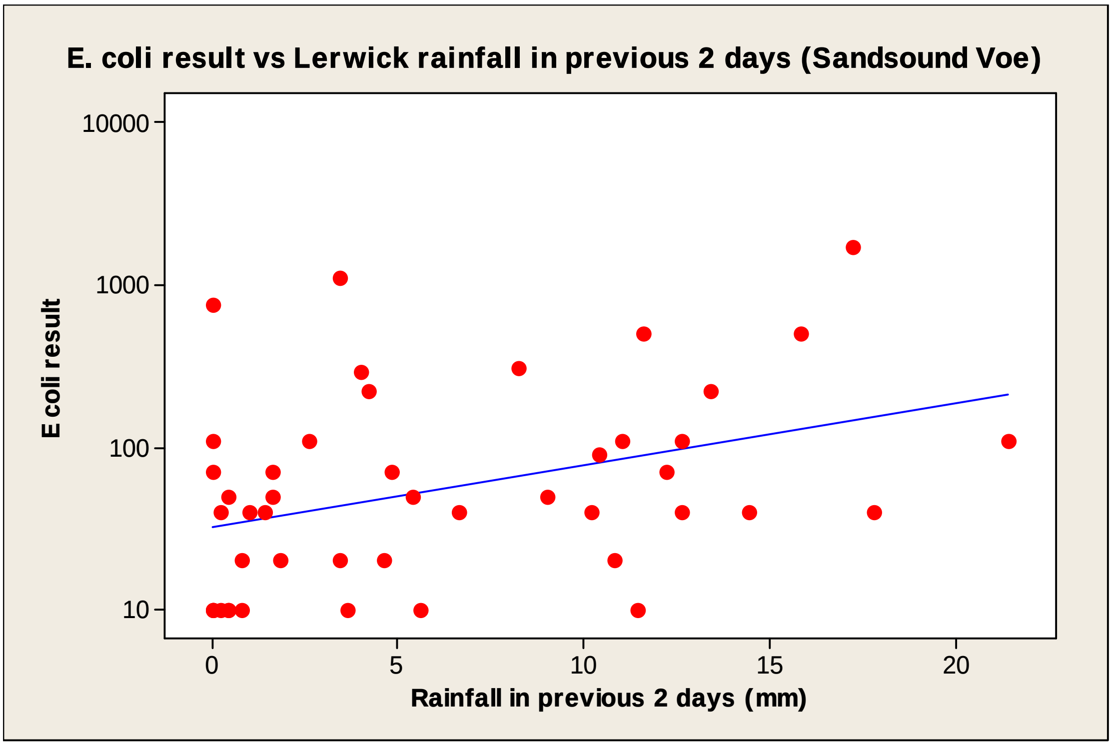


Figure 11.6 E*. coli* result by rainfall in previous 2 days

The coefficient of determination indicates that there is a very weak positive relationship between the *E. coli* result and the rainfall in the previous two days (Adjusted R-sq=12.4%, p=0.010).

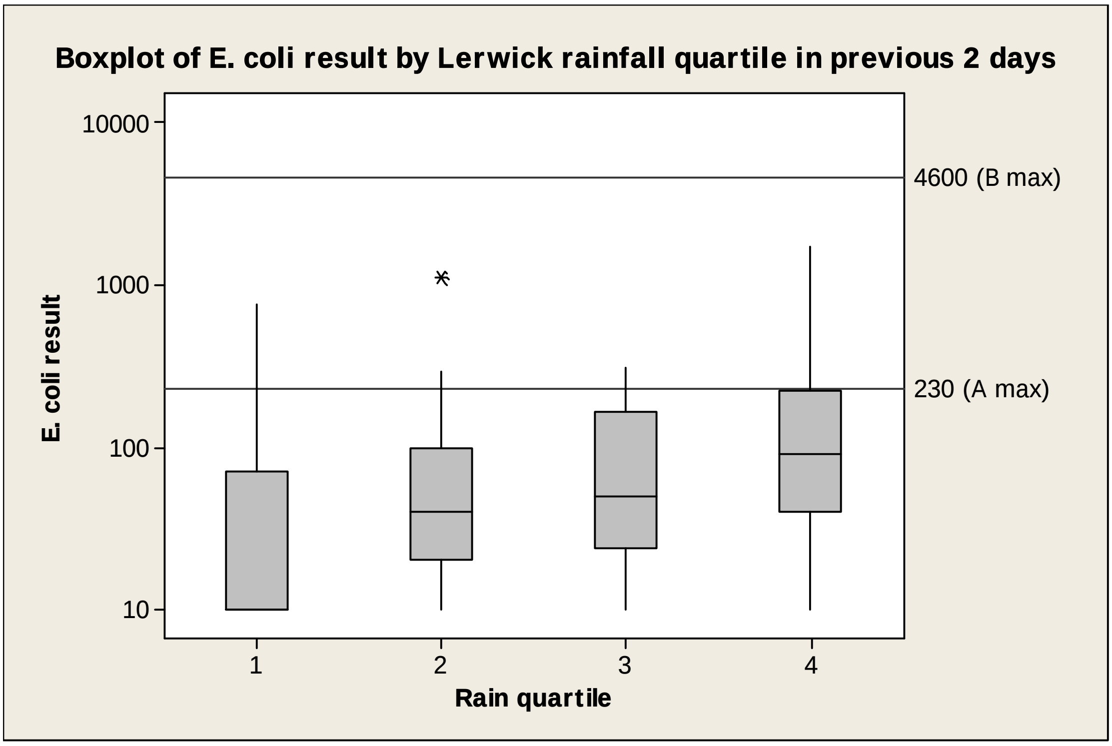


Figure 11.7 Boxplot of *E. coli* result by rainfall in previous 2 days

A trend for higher results following higher rainfall can be seen, but there was no statistically significant difference between results for the four quartiles (one way ANOVA, p=0.185).

As the effects of heavy rain may take differing amounts of time to be reflected in shellfish sample results in different systems, the relationship between rainfall in the previous 7 days and sample results for Sandsound Voe was investigated in an identical manner to the above.

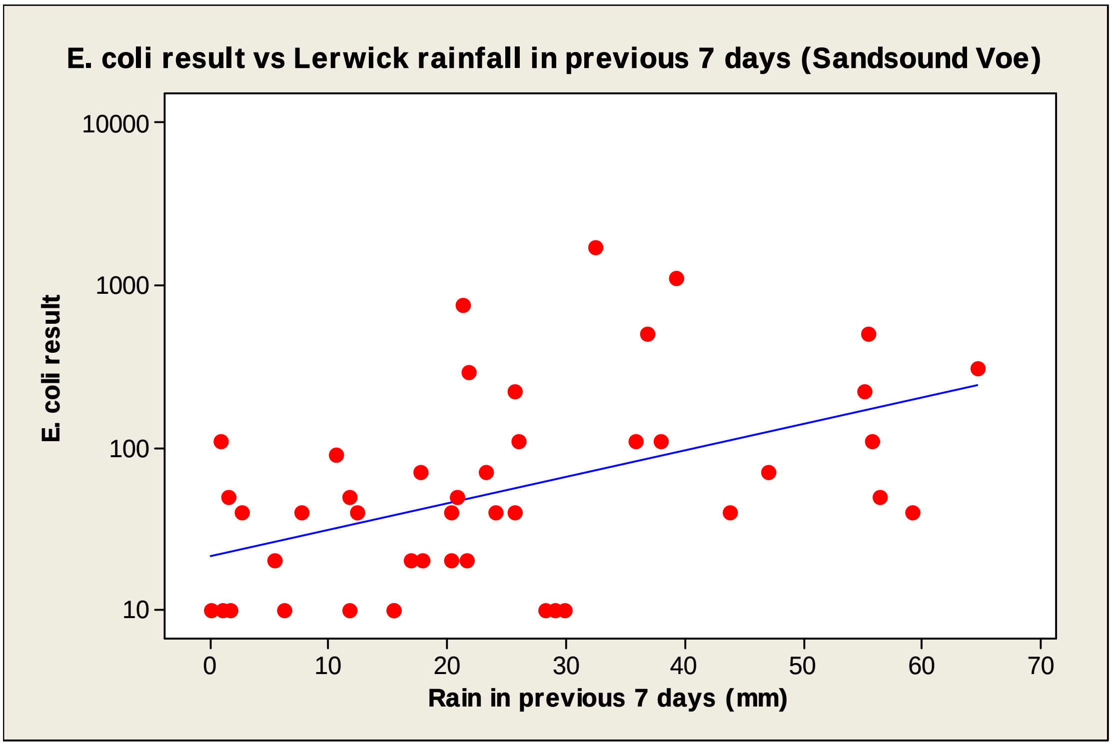


Figure 11.8 *E. coli* result by rainfall in previous 7 days

The coefficient of determination indicates that there is a weak positive relationship between the *E. coli* result and the rainfall in the previous 7 days (Adjusted R-sq=20.7%, p=0.001).

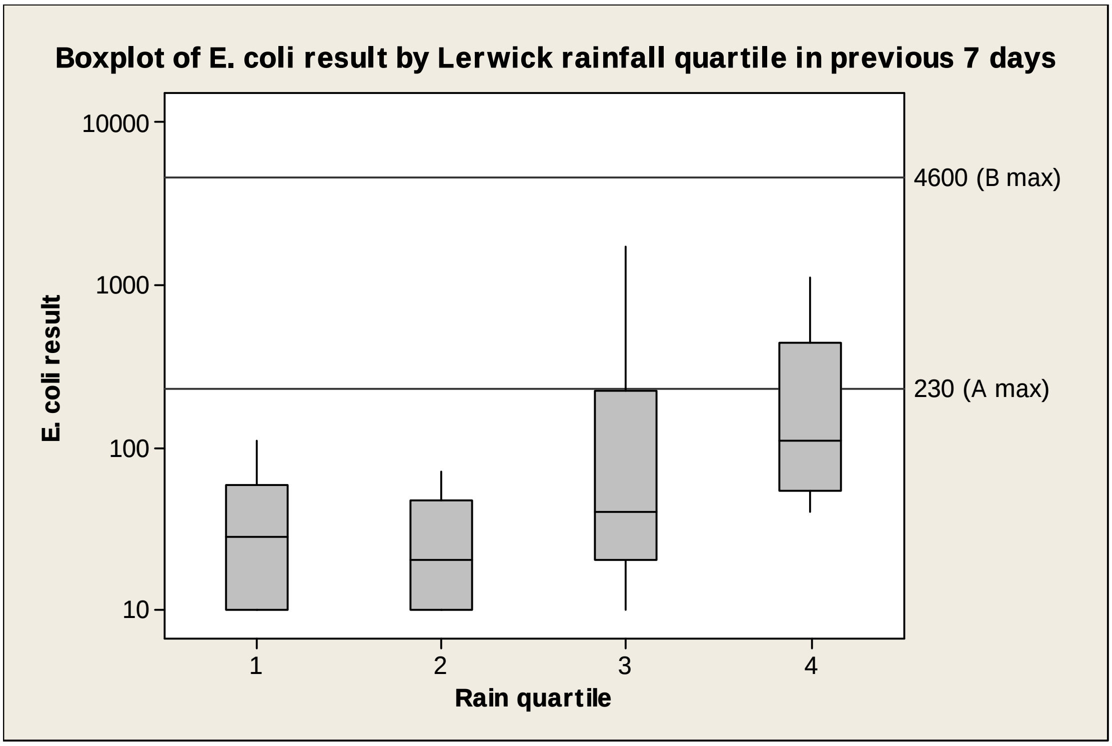


Figure 11.9 Boxplot of *E. coli* result by rainfall in previous 7 days

A statistically significant positive relationship between rain quartile and *E. coli* result was found (One way ANOVA, p=0.003).

Overall, higher recent rainfall is associated with higher contamination of shellfish in Sandsound Voe. Any rainfall related effects might be expected to be at their greatest in the autumn and winter months when rainfall is at its' highest (see section 9). The influence of rainfall on microbiological quality will depend on factors such as local geology, topography and land use.

11.4.3 Analysis of results against lunar state

Lunar state dictates tide size, with the largest tides occurring 2 days after either a full or new moon. With the larger tides, circulation of water in the voe will increase, and more of the shoreline will be covered, potentially washing more faecal contamination from livestock into the voe. Tidal ranges in the voe (as described in section 12) are small, in the region of 0.7 to 1.1m. Figure 11.10 presents a boxplot of *E. coli* results by size of tide categorised by lunar state at the time of sampling. It should be noted however that local meteorological conditions such as wind strength and direction can influence the height of tides and this is not taken into account in Figure 11.10.

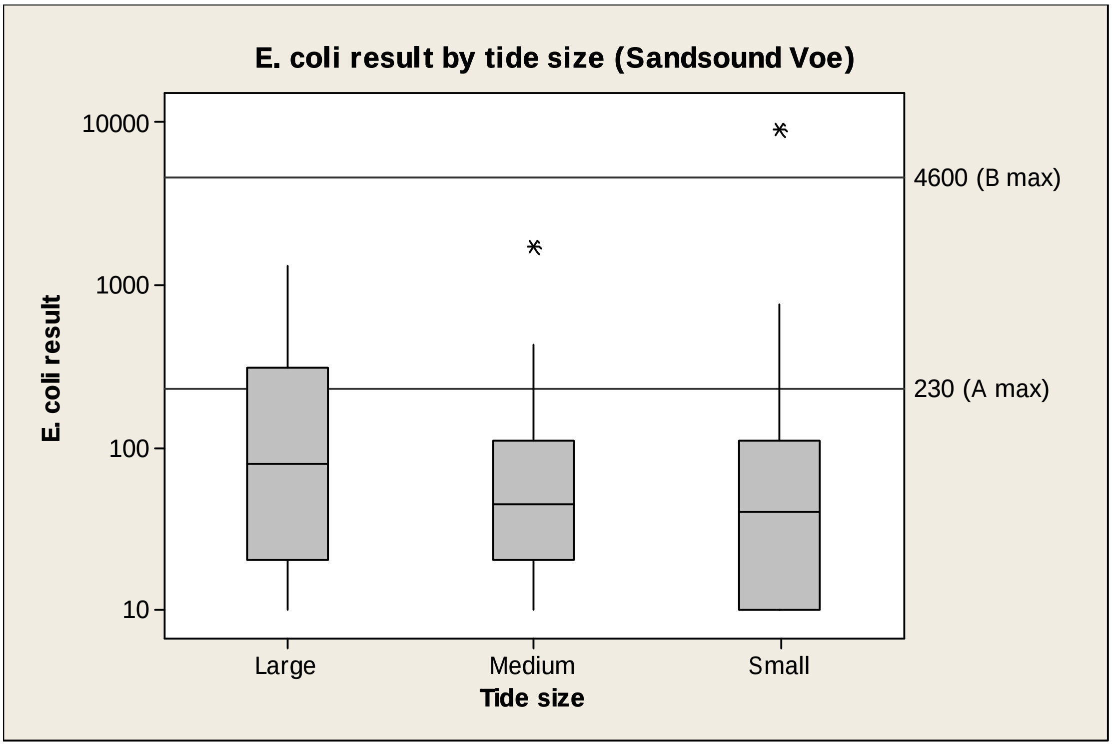


Figure 11.10 E. *coli* result by tide size

There was no statistically significant influence of tide size detected by this analysis (One way ANOVA, p=0.505). This may be expected, as the tidal range is small and the voe is large and deep.

<u>11.4.4 Water temperature</u>

Water temperature is likely to affect the survival time of bacteria in seawater (Burkhardt *et al*, 2000) as well as the feeding and elimination rates of shellfish and therefore may be an important predictor of *E. coli* levels in shellfish flesh. It is, of course, closely related to season, and so any correlation between temperatures and *E. coli* levels in shellfish flesh may not be directly attributable to temperature, but to other factors such as seasonal differences in livestock grazing patterns.

No data on water temperature either at the time of collection or from automatic data loggers deployed in the voe so no analysis was possible.

<u>11.4.5 Wind direction</u>

As discussed in section 9, wind speed and direction is likely to significantly change water circulation patterns in Sandsound voe. Mean wind direction for the 7 days prior to each sample being collected was calculated from wind data recorded at the Lerwick weather station, and mean result by wind direction in the previous 7 days is plotted in Figure 11.11. Wind direction data was available for 26 of the 53 samples.

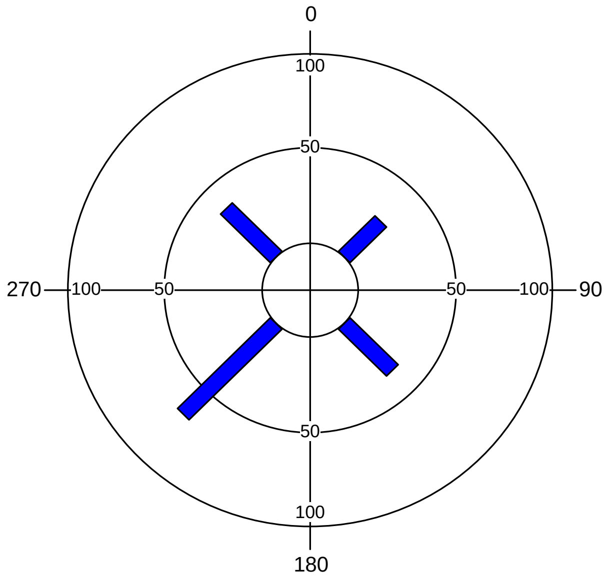


Figure 11.11 Circular histogram of geometric mean *E. coli* result by wind direction

A higher mean result was obtained when the wind was blowing from the south west, but the relationship between wind direction and *E. coli* result was not statistically significant (circular-linear correlation, r=0.247, p=0.229). The prevailing wind direction is from the south west, so more samples were gathered when the wind was in this direction, and when the wind is blowing in this direction it is likely to be stronger.

11.4.6 Discussion of environmental effects

All analyses presented in this section should be treated with caution due to the low number of samples considered (53). A seasonal effect was found, with results in the autumn being higher than in other seasons, but this was not statistically significant. A significant positive relationship between recent rainfall and levels of contamination was found. No influence of tide size was apparent. No significant influence of wind direction was found. 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.

11.5 Sampling frequency

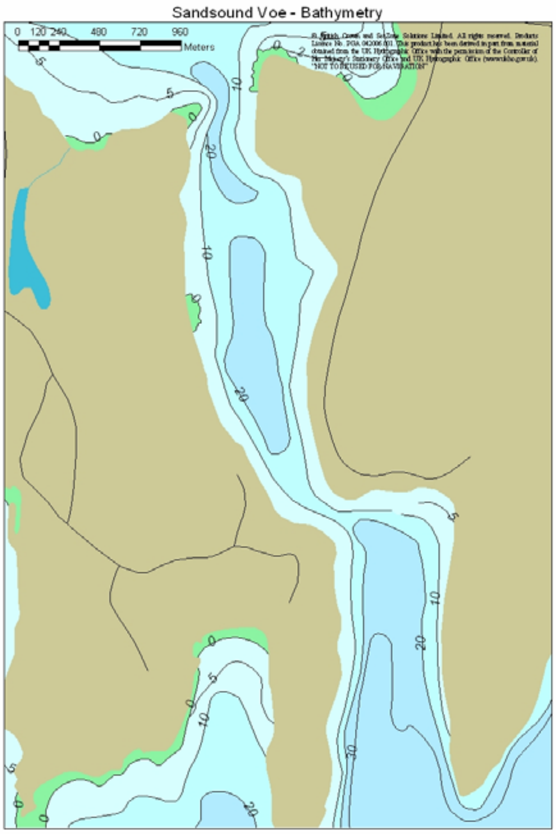
When a production area has had the same (non-seasonal) classification for 3 years, and the geometric mean of the results falls within a certain range it is recommended that the sampling frequency may be decreased from monthly to bimonthly. This is not appropriate in the case of Sandsound Voe as it has had a seasonal classification in 2006.

12. Designated Shellfish Growing Waters Data

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

13. Bathymetry and Hydrodynamics

13.1 Tidal Curve and Description



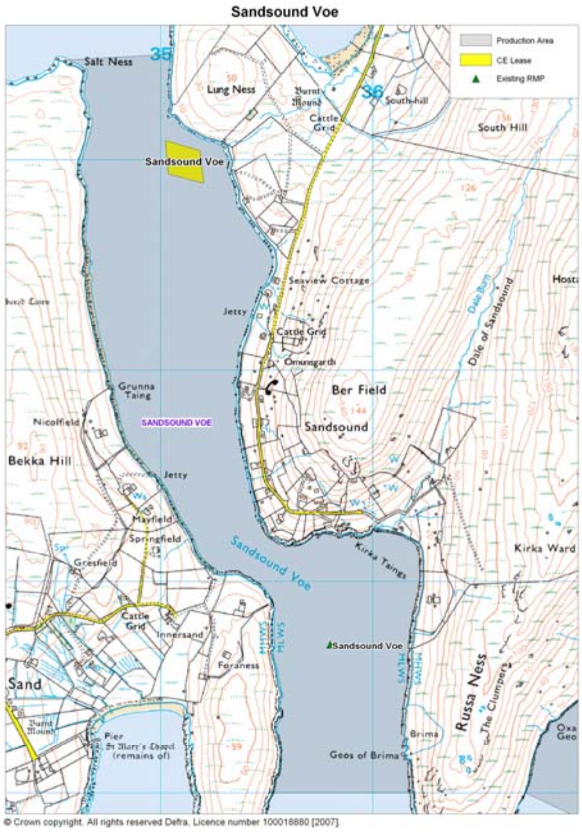


Figure 13.1 Bathymetry map (UKHO)   Figure 13.2 OS Map

The chart (figure 13.1) above shows that the voe comprises two distinct areas with differing characteristics. The northern portion of Sandsound Voe slopes away fairly gently to a maximum depth of more than 20 metres, with drying areas indicating sediment deposition located at the northern end where Sandsound Voe meets The Firth and a smaller area midway along the western shore.

A shallow neck where the voe narrows to 0.21 km wide divides the northern half of the voe from the southern half.

The southern portion of Sandsound Voe is characterised by steeply shelving edges and a maximum depth of in excess of 30 metres. It presents an open aspect to seas from the south.

Table 13.1 Sandsound Voe characteristics

O S Reference	HU350460
Chart number	3294
Chart scale	25000
Loch length (km)	8.6
Tidal range (m)	1.1
Maximum depth (m)	42.0
HW area (sq km)	6.7
LW area (sq km)	6.1
2m area (sq km)	5.1
5m area (sq km)	4.0
10m area (sq km)	2.9
LW Vol (million m3)	79.1
Watershed (sq km)	39
Annual rainfall (mm)	1150
Runoff (mm3/year)	34.7
K.E. Supply (Kw)	**
Mean depth at LW (m)	12.9
Fresh/tide, per thousand	10.0
Run off/width (m2/day)	128
Sill Data	There are no basins in this loch

The aspect ratio (length to width) is given as 10.0.

The flushing time is given as 8 days, the 16th longest flushing time in a list of 110 sea lochs studied (1991, Scottish Sea Loch Catalog).

The two tidal curves below (Figure 13.3) are for the port of Scalloway (how far from the sound?) – they have been output from UKHO TotalTide. The first is for seven days beginning 00.00 GMT on 9/05/07, the date of the shoreline survey. The second is for seven days beginning 00.00 GMT on 16/05/07. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle.

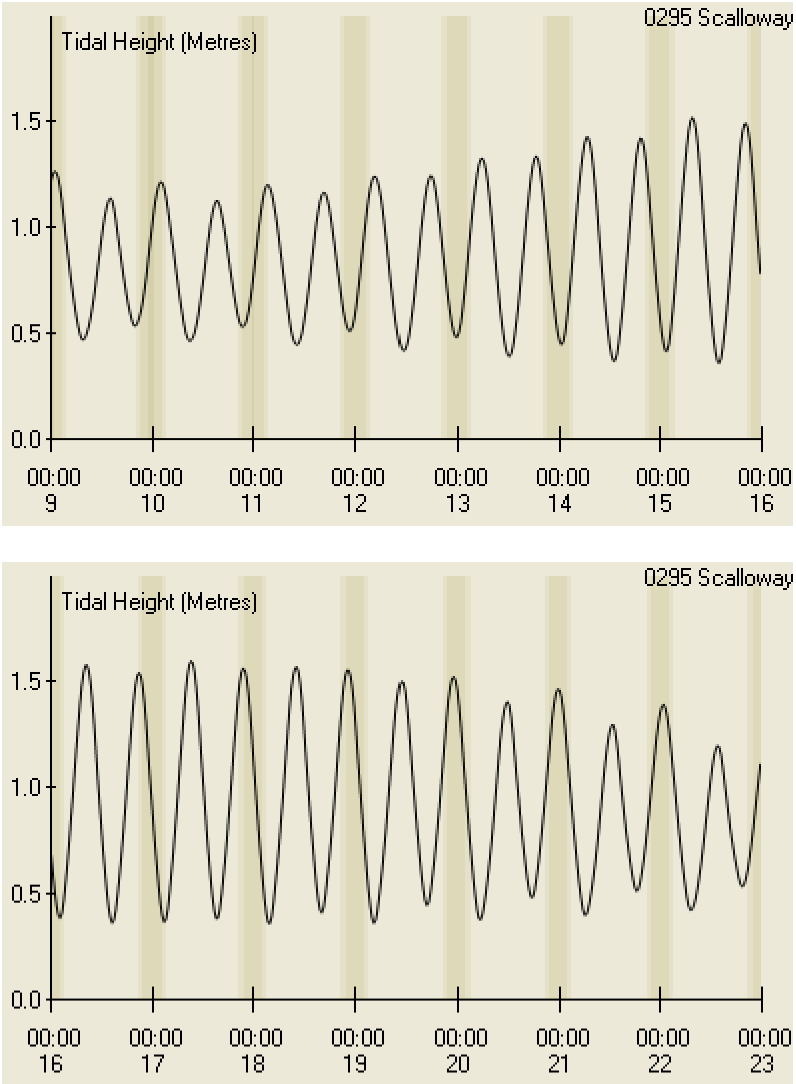


Figure13.3 Tidal curve for Scalloway harbour

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 therefore approximately 1.1 m and at neap tide 0.7 m.

13.2 Currents – tidal stream software output and description

No tidal stream information is available for Sandsound Voe. Tidal currents are expected to be weak in the vicinity of the shellfish site, as indicated by the extended flushing time (see above). Wind effects will therefore be significant. Currents would be expected to be stronger in the areas of constriction at the northern end and centre of the voe.

Conclusions – regarding effect on impacting sources

Given the expected weak tidal currents in the area, small local sources of faecal contamination might be expected to have a more significant effect compared to more remote sources.

Winds would be expected to drive current movements within the voe. Due to the natural constrictions of cliffs and hills on either side, prevailing winds from the southwest would tend to be channelled up the voe in a northerly direction. This would drive water at the surface in the direction of wind travel until natural restrictions at the neck and top of the voe would turn some of the water back along the sides and in eddies. The precise direction and strength of these is difficult to predict based on the information available.

The nearest community discharges lie within the Firth to the north. On an outgoing tide, the stronger currents expected through the opening to Sandsound may draw pollutants from the Firth southwards through the shellfish farm.

14. Shoreline Survey Overview

A physical survey of the shoreline in the vicinity of the production area was conducted on 9 May 2007. This included viewing the sound by boat as well as walking the shoreline, recording the location of the mussel lines on site, and collecting both water and shellfish samples.

Fewer than 30 homes were observed along Sandsound Voe, and it was presumed that most if not all of these would all be on individual septic systems.

Livestock were observed grazing and on the shoreline near the fishery. Stable waste consisting of straw and animal faeces were observed tipped down the embankment adjacent to the mussel farm. A water sample was taken from the voe at this location contained only 1 cfu *E. coli* per 100ml. However, with sufficient rain this could be a potentially significant source of faecal bacteria to the mussel farm.

Mussel samples were collected from three locations on the mussel farm and three depths along the droppers (< 1m, 4m and 8m). Surface water samples were also collected at the same time and locations as the mussel samples.

The sample results are summarised in Table 14.1. Levels of contamination found in the shellfish were much higher at the north west corner of the mussel lines. Water samples taken at these locations showed no *E. coli* contamination even though all of the mussels taken from near the surface showed some contamination.

The highest *E. coli* levels were found in two fresh water samples – one taken from a stream feeding into the southwestern end of Tresta Voe and the other from what was presumed to be a small surface water drain located to the south east of the mussel site. Results are illustrated on the map in Figure 14.1. A small amount of sanitary debris was found on the shore near the farm, but the source was not immediately apparent.

There were relatively few sources of fresh water observed around the voe. Some of these were sampled and measured, but flows were not measured at the time of survey. South of the mussel site, the land slopes steeply away from the shoreline leaving little or no foreshore. Little in the way of wildlife was observed during the survey.

Further details regarding the shoreline survey, including a full table of observations and photographs, can be found in the Shoreline Survey Report in the appendix.

Table 14.1 Shoreline Survey Sample Results

Sample	Grid Reference	Type	*E. coli* (cfu/100ml)	Salinity (g/L)	*E. coli* (mpn/100g)	Depth
Sandsound 1	HU 35236 49744	Water	<1	29.0	-	-
Sandsound 2	HU 35250 49921	Water	<1	29.0	-	-
Sandsound 3	HU 35116 49883	Water	<1	27.6	-	-
Sandsound 4	HU 35335 49927	Water	1	29.5	-	-
Sandsound 5	HU 35499 49601	Water	6	28.1	-	-
Sandsound 6	HU 35528 49578	Water	11	0.3	-	-
Sandsound 7	HU 35518 49413	Water	$>3x10^3$	0.1	-	-
Sandsound 9	HU 35979 50557	Water	69	0.1	-	-
Sandsound 10	HU 35992 50668	Water	11	8.0	-	-
Sandsound 11	HU 35510 49396	Water	7	0.1	-	-
Sandsound 12	HU 35803 50377	Water	$>3x10^3$	0.8	-	-
Sandsound 1	HU 35236 49744	Mussel	-	-	110	7
Sandsound 2	HU 35236 49744	Mussel	-	-	70	3
Sandsound 3	HU 35236 49744	Mussel	-	-	40	<1
Sandsound 4	HU 35250 49921	Mussel	-	-	70	<1
Sandsound 5	HU 35250 49921	Mussel	-	-	50	3
Sandsound 6	HU 35250 49921	Mussel	-	-	40	7
Sandsound 7	HU 35116 49883	Mussel	-	-	220	<1
Sandsound 8	HU 35116 49883	Mussel	-	-	310	3
Sandsound 9	HU 35116 49883	Mussel	-	-	40	7

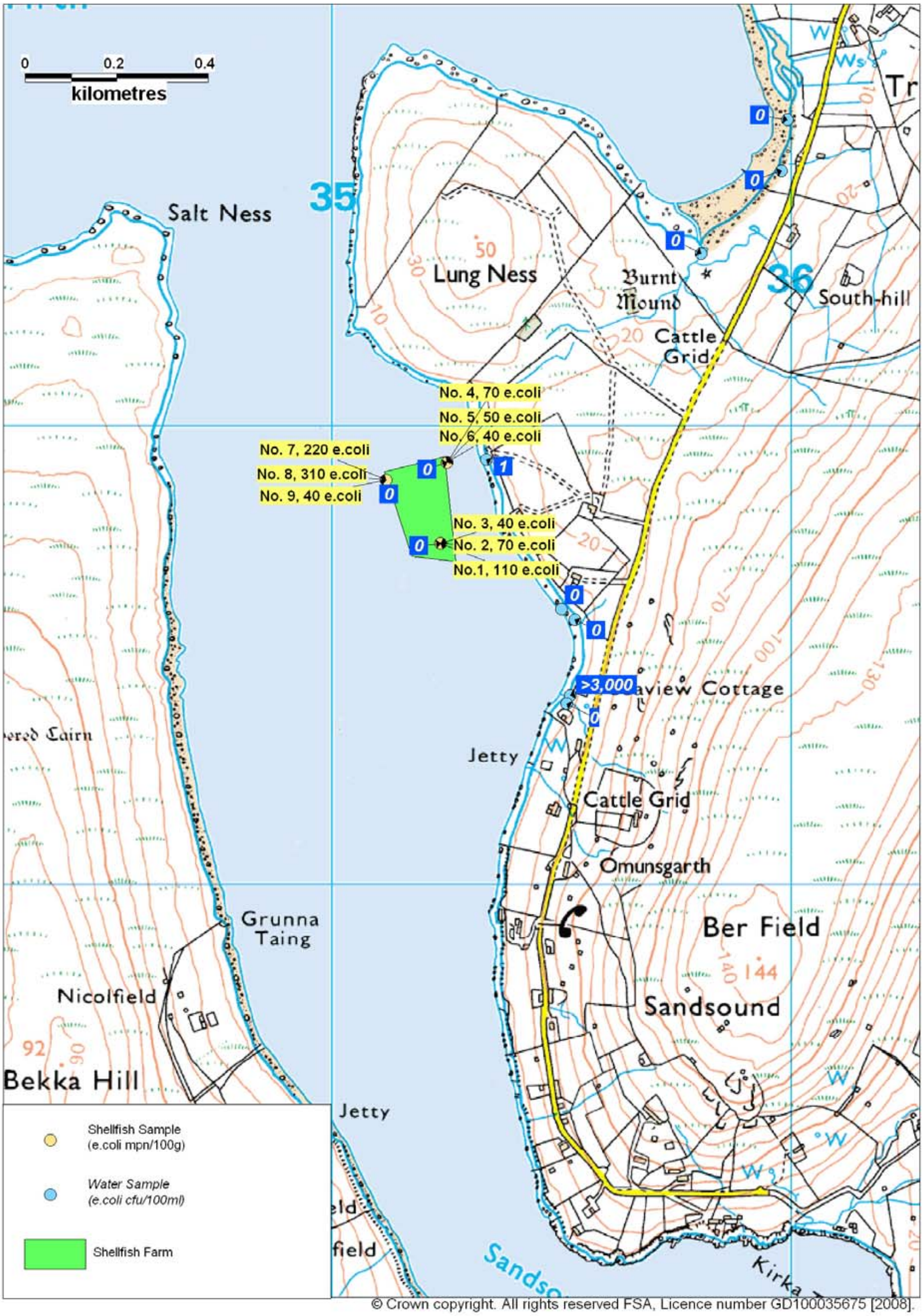


Figure 14.1 Map of shoreline survey sampling results

15. Overall Assessment

Sandsound Voe receives relatively little impact from human sources of faecal contamination. Analysis of historical *E. coli* results and rainfall data would seem to indicate that a slightly higher risk of faecal contamination occurs in the autumn months.

The reason for this is not clear, but it can be hypothesised that this may be due to the increase in rain observed during the autumn. Sheep excrement accumulating in fields during the summer months would then be washed in a flush into the voe when the rainfall increases in the early autumn. While statistical analysis of rainfall data from the Lerwick weather station did not positively correlate with *E. coli* results at Sandsound Voe, it is possible that local rainfall conditions were not accurately reflected in the Lerwick data.

Human Sewage Impacts

The population around the island is scattered and while there are some community septic systems it appears that many homes are on private septic tanks, which are in an unknown state of repair or function. The Shetland population has remained steady and construction observed about the island is generally replacement for older housing. This should lead to an increasing number of households using modern, and presumably properly functioning, septic systems.

There is no accurate record of the number of private septic tanks in Shetland generally and in Sandsound Voe specifically because there has historically been no requirement to register them with 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.

An analysis of the human population distribution in Section 3 shows a higher concentration of people along the northeastern shore of the voe and particularly to the north in the Firth. This coincides with the known septic tank discharges in the area as can be seen in Figure 15.1. Soils on the east side of the voe are classed as poorly draining (Figure 5.1) and a review of land cover shows that this area also has the highest concentration of developed land and hard standing which would contribute higher loadings of faecal bacteria in rain runoff.

While there is some settlement on the western side of the voe, soils here are freely draining and effluent from properly functioning septic tanks would be unlikely to wash into the voe with surface runoff.

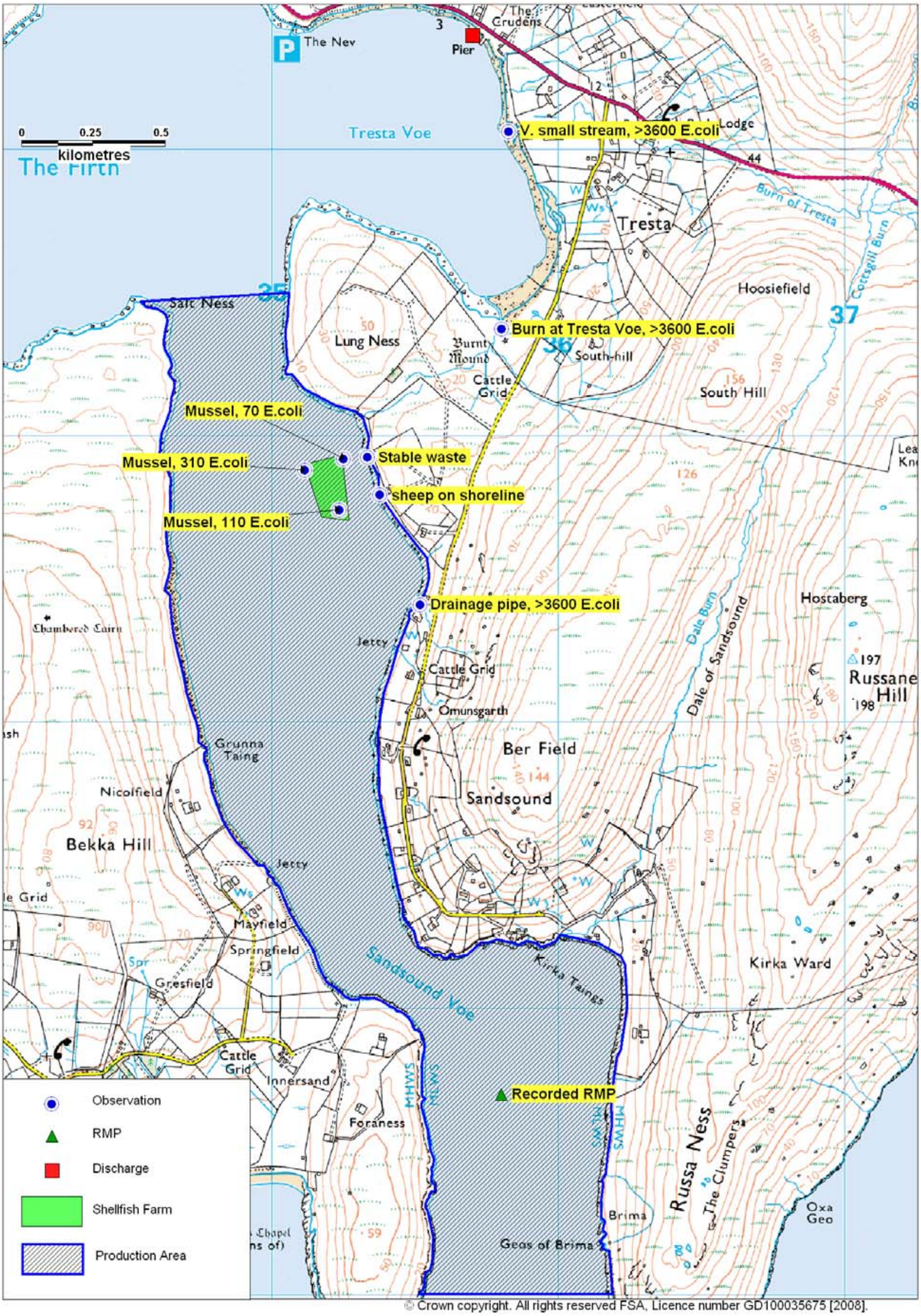


Figure 15.1 Sandsound Voe significant findings

Agricultural Impacts

Livestock and farming activities are an important factor in the use of land around the voe. Much of the area is used for grazing and a number of crofts line both shores of the northern end of the voe with rough grazing occurring along the southern shores.

Land cover here (Figure 6.1) is predominantly improved grassland, with some acid grassland and bog. Improved grassland has been shown to provide a moderate contribution to faecal coliform loadings in runoff. The soils along the eastern side of the voe are poorly draining, indicating a greater likelihood of surface runoff that would carry with it faecal bacteria from livestock droppings.

Agricultural practices can have a dramatic impact locally on water quality. Sheep are grazed throughout the area and can be observed accessing the shoreline. In addition, straw bedding waste and faeces were observed tipped down the bank at the shoreline and would have contributed to bacterial contamination of the water during rainy conditions. The Scottish Government has published a set of guidelines for management of farm waste and are working with farmers and crofters to encourage implementation of these guidelines. Further changes in the way agricultural subsidies are applied and paid are anticipated to lead to a decline in sheep population and hence the amount of sheep droppings in the area.

Wildlife Impacts

Wildlife impact, as discussed in section 8, is unpredictable. While large wild mammals such as dolphins and seals do enter and use the voe, their presence is of limited duration and not temporally predictable. As there are no known seal haulout sites within or near the production area, these are not considered to be a significant contributor to contamination levels. Seabirds may be contributors, with some seabird breeding areas reported along the lower reaches of the voe. The mussel farm is are likely to receive faecal inputs from birds such as cormorants, gulls, and arctic terns that rest on the floats and lines. While these impacts may be significant very locally (directly under the birds) the impact to the wider fishery is unpredictable.

Spatial Considerations

Most of the contamination input to the voe will occur from rainfall runoff of the grazed land along either side of the voe. The effects of wind on currents in the area of the fishery are difficult to predict, as it is relatively sheltered. It is likely that the most significant sources of faecal contamination will be from land in the near vicinity of the fishery.

The upper section of the voe would be more likely to see higher levels of contamination due to the greater number of dwellings and crofts along the shores there as well as its proximity to sources of contamination within The Firth. The relatively slow flushing time of 8 days would indicate that faecal contamination would tend to hang around near to the source.

The Sandsound Voe mussel site lies within the northern half of the voe, near to the eastern shore where runoff is likely to be higher due to the predominantly poorly drained soils found there, as discussed previously.

Faecal contamination due to runoff from land used to graze sheep is highly likely to impact the Sandsound Voe site due to its proximity to the crofts. In addition, stable bedding waste was observed tipped down the shoreline in close proximity to the mussel farm. A water sample taken from the voe near the waste on the day of survey did not contain high numbers of *E. coli*, however. Water samples taken from two freshwater sources, one feeding into Sandsound Voe and the other into Tresta Voe did show high levels of *E. coli* contamination (Shoreline Survey, Figure 3).

During the shoreline survey, mussel samples were taken from three locations within the mussel farm. Results near or above the limit for A classification were found in mussels from the samples taken near the north western corner of the mussel farm. This would seem to indicate that contamination flowing southward from Tresta Voe and The Firth may be impacting that corner of the fishery.

RMP

It was noted that the recorded RMP does not accurately reflect the location from which monitoring samples have been taken.

Seasonal Variation

There was no statistically significant correlation between season, tidal state, or wind direction and *E. coli* levels observed in the monitoring results. The only significant correlation found was between rainfall in the 7 days previous to sampling and *E. coli* result.

The classification history of the existing production area shows that the classifications have changed with time, with the area currently classified B from August to October.

As with many other Shetland farms, harvest does not normally take place between May and September. However this may change depending upon market pressures and timing of closures due to the presence of biotoxins.

Meteorology and Movement of Contaminants

Analysis of wind and rainfall indicated a correlation between wind direction and *E. coli* results and no correlation between rainfall for the previous 48 hours and *E. coli* results (see section 9). The sample size is small, however, and this could be an artificial effect. Winds from the west and southwest at Lerwick were correlated with higher results. Local wind effects may differ somewhat as wind funnels through the voe and around headlands.

The bathymetry and hydrodynamics analysis provided in section 12 indicates that wind driven water movement would have a more significant effect than tides on the movement of contaminants around the voe. Mixing is likely to be wind driven as well as occurring down stream of either constriction. This would seem to be corroborated by the sampling results obtained during the shoreline survey, which showed higher levels of contamination at the end of the farm nearest the northern constriction to the voe.

As bacterial contamination is likely to occur with fresh water runoff, it is expected that higher contamination levels may be seen in shallower water. For this reason, samples should ideally be taken from a depth of 1m or less. In this case, the levels of contamination seen at the proposed RMP were high at the top and mid-depth of the lines. This may be due to mixing occuring below the area of shoaling at the top of the voe and so a sampling depth of 2 meters is suggested as a mid point between the two.

16. Recommendations

The current Sandsound Voe production area is given as the area bounded by lines drawn between HU 3553 4700 and HU 3619 4700 and HU 3454 5047 and HU 3506 5050 to MHWS. The nominal RMP at HU 358 477 lies 2.2km south of the existing mussel farm. It was confirmed that samples were coming from locations on the farm but have been reported against the nominal RMP, which is incorrect.

A smaller production area is proposed for Sandsound Voe based on the following:

1) The bathymetry and hydrodynamic characteristics of the northern and southern segments of the voe are likely to be very different.

2) The northern segment has more potential sources of faecal contamination.

3) There do not appear to be any outstanding seabed leases elsewhere in Sandsound Voe.

4) The boundaries should preclude siting mussel production near the stream from which high *E. coli* results were obtained as well as any further north than the existing farm and lease.

The recommended production area boundaries are proposed to encompass the area bounded by lines drawn between HU 3466 5019 to HU 3505 5022 and HU 3464 4954 to HU 3554 4954, extending to MHWS as illustrated in Figure 16.1.

It is recommended that the RMP be moved to HU 3515 4988 to reflect the higher levels of contamination, and hence risk to public health, observed in the northern portion of the farm. A tolerance of 20 metres is proposed in order to allow for movement of the long lines with the tides.

Recommended sampling depth is 1 metre as higher levels of contamination in this area is more likely to occur near the surface.

Assessment of stability of monitoring results indicates that due to seasonal classification within the past three years, area is not suitable for reduced monitoring. Therefore a continuation of monthly sampling is recommended.

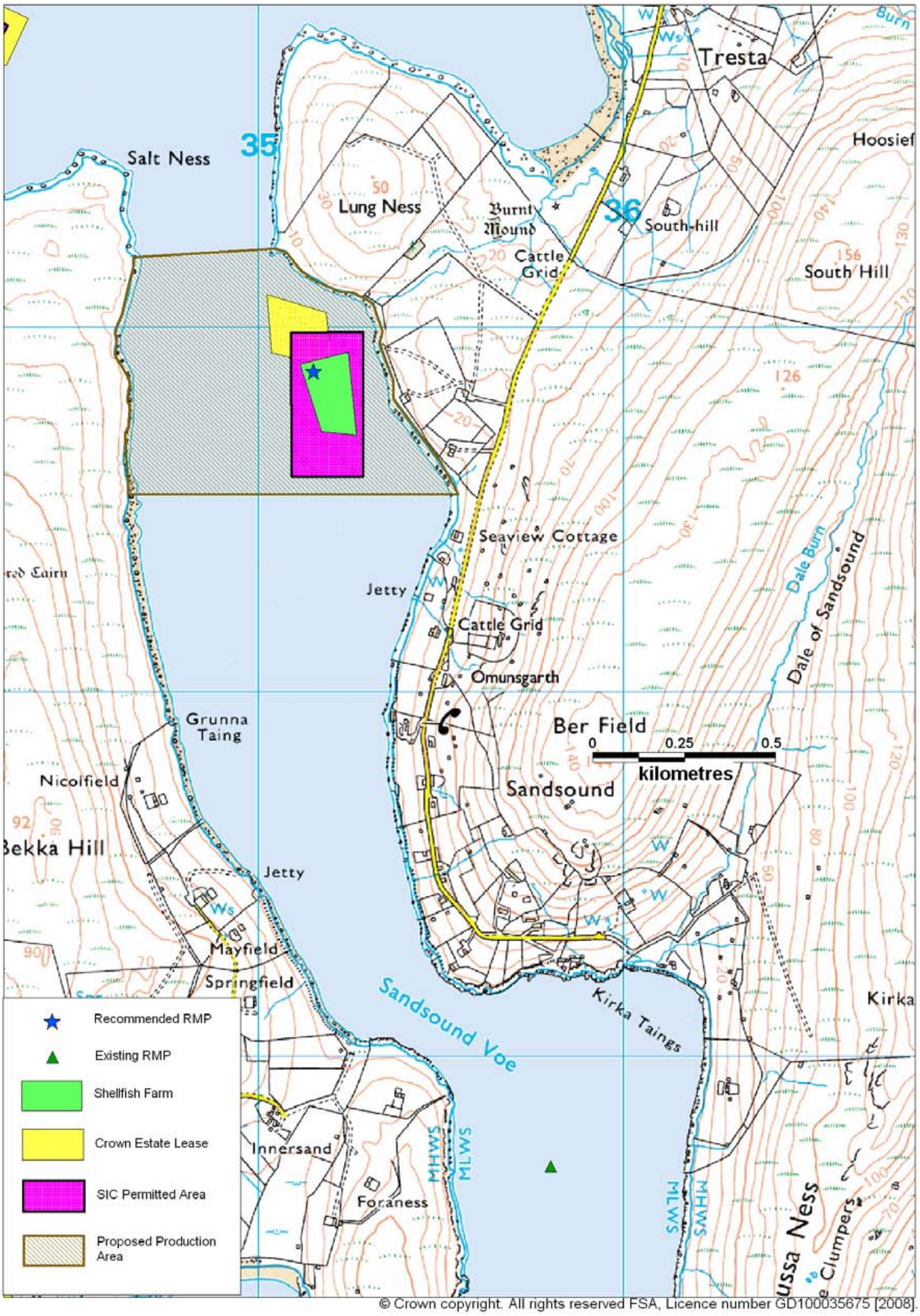


Figure 16.1 Map of proposed production area for Sandsound Voe

17. References

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18. 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

Sandsound Voe
SI 242

Scottish Sanitary Survey Project

Shoreline Survey Report

Prod. area:	Sandsound Voe
Site name:	Sandsound (SI 242 433 08)
Species:	Common mussels
Harvester:	S. Anderson/R. Anderson
Local Authority:	Shetland Islands Council
Status:	Existing Site
Date Surveyed:	9 May 2007
Surveyed by:	Michelle Price-Hayward and Alastair Cook
Existing RMP:	HU358477
Area Surveyed:	See Map in Figure 1

Weather observations

Dry, partly cloudy. Rain reported over 7-8 May. Wind NNW, Force 3-4.

Mr. Robert Anderson provided boat and assistance in conducting the shoreline survey and associated sampling.

Site Observations

Fishery

Mussels are grown to 8m depths on 5 long lines. The boundary of the area currently occupied by mussel lines was recorded using GPS to 10m accuracy. Both this areas and the area of the crown estate lease are illustrated on the map in Figure 1.

Harvesting on site occurs year round when there is stock ready for market. Mussels grown in this area take two to two and a half years to reach marketable size.

The recorded RMP was not located within the crown estate lease or the actual fishery. Samples have been submitted from various locations within the mussel farm, depending upon availability of stock.

Sewage/Faecal Sources

There are no public septic tanks or sewage treatment works located within the Sandsound production area itself. There is however a public septic tank located 2 km to the northeast in Tresta Voe as well as 3 others located in Weisdale Voe which lies to the east of Sandsound. These assets were viewed in conjunction with shoreline surveys in those areas.

Individual houses were observed along the east shore of Sandsound. Mr. Anderson indicated some of these were only occupied during part of the year. All homes in the area would be on private septic tanks, though these were not in all cases readily apparent. No flowing discharges were observed. In some cases, pipes were seen running to the shoreline, but the actual outfall itself was buried under rocks and sand or otherwise inaccessible.

Some evidence of construction was observed on the farm adjacent to the site, with a dump truck present. Sheep have free access to shoreline (Table 1, nos. 3, 28). Approx. 100 sheep were observed in fields above the farm on the east side of Sandsound (Table 1, no. 28).

Some evidence of sanitary debris observed on shoreline adjacent to farm (two cotton buds, Table 1, no. 25). There was one fish cage on site, just inshore of the mussel lines. Mr. Anderson stated this was not in use for fish, but was an experiment for growing mussels on a commercial scale that wasn't currently in use. Additional lines were scheduled to be added to the site during the subsequent week.

Stable bedding waste was tipped down the bank on shore adjacent to the mussel farm. Large numbers of mushrooms were observed growing from the waste, which appeared to be a mixture of wood shavings and manure (Table 1, no. 22). A water sample was collected from the shoreline at this point (sample no. 4).

One soak away pipe was noted on shoreline at high tide mark, though no flow was observed from it.

Seasonal Population

Discussion with the harvester indicated that not all the houses along the voe were in year-round occupation. Further details were requested from Shetland Islands Council regarding the numbers of homes permanently occupied vs. those only in seasonal use.

Boats/Shipping

Two work boats were observed in the area during the survey. These were engaged in placing additional lines within the Sandsound Voe mussel site.

Land Use

Land use in the area of the mussel farm was primarily sheep grazing. While there were no horses observed on the day, the harvester informed us that the stable bedding found on the shore was from the horse stable on their farm.

Wildlife/Birds

A very small number of birds were observed during the survey. These included approximately 10 Eider ducks and 10 gulls, scattered along the survey route.

Specific observations taken on site are mapped in Figures 1 and 2 and listed in Table 1.

Figure 1 Map of Shoreline Observations -North

Sandsound Voe Shoreline Survey

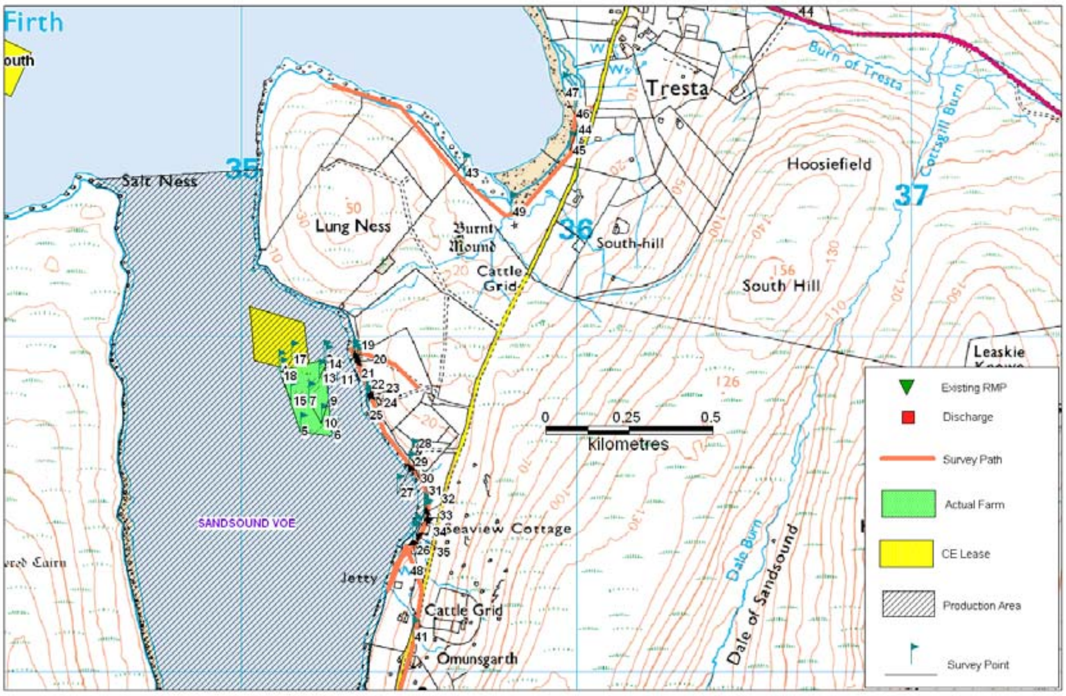


Figure 2 Map of Shoreline Observations - South

Sandsound Voe Shoreline Survey

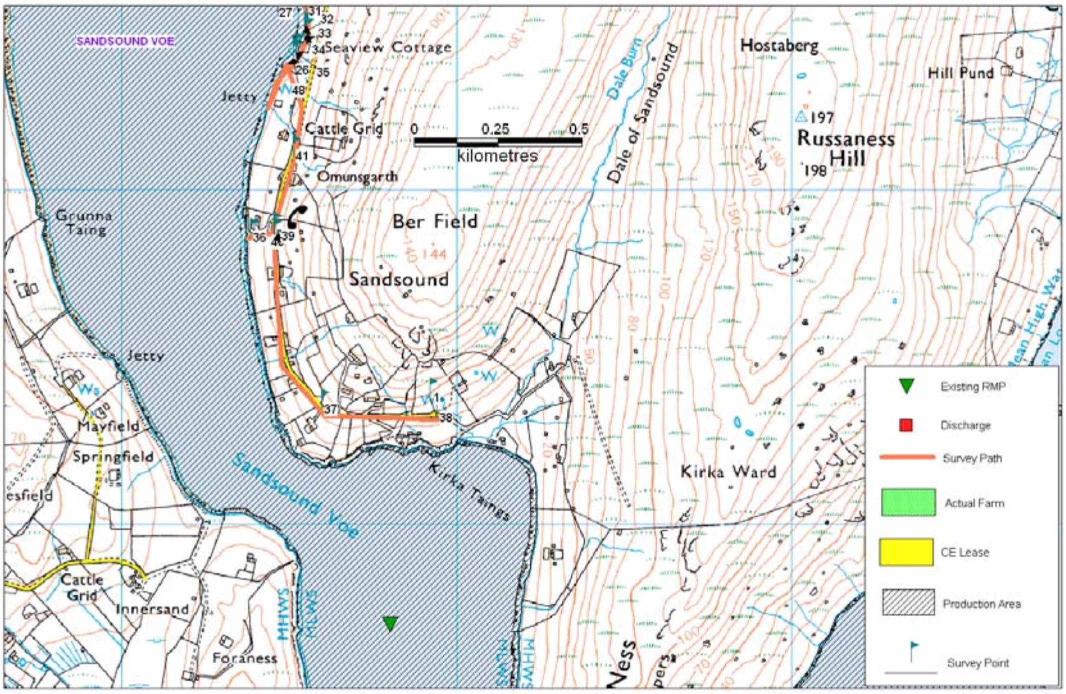


Table 1. Shoreline Observations

No.	Date	NGR	East	North	Associated photograph	Description
1	09/05/2007	HU 35939 48322	435939	1148322	Figure 5	Southern end of shoreline survey
2	09/05/2007	HU 35992 50668	435992	1150668		Northwestern end of shoreline survey
3	09/05/2007	HU 35244 49933	435244	1149933	Figure 7	NE corner of Sandsound Voe mussel rope area
4	09/05/2007	HU 35110 49902	435110	1149902	Figure 8	NW corner of Sandsound Voe mussel rope area
5	09/05/2007	HU 35173 49717	435173	1149717	Figure 10	SW corner of Sandsound Voe mussel rope area
6	09/05/2007	HU 35268 49705	435268	1149705	Figure 11	SE corner of Sandsound Voe mussel rope area
7	09/05/2007	HU 35236 49744	435236	1149744		Water sample Sandsound 1 (salt)
8	09/05/2007	HU 35236 49744	435236	1149744		Mussel sample Sandsound 1 (7m depth)
9	09/05/2007	HU 35236 49744	435236	1149744		Mussel sample Sandsound 2 (3m depth)
10	09/05/2007	HU 35236 49744	435236	1149744		Mussel sample Sandsound 3 (<1m depth)
11	09/05/2007	HU 35250 49921	435250	1149921		Water sample Sandsound 2 (salt)
12	09/05/2007	HU 35250 49921	435250	1149921		Mussel sample Sandsound 4 (<11m depth)
13	09/05/2007	HU 35250 49921	435250	1149921		Mussel sample Sandsound 5 (3m depth)
14	09/05/2007	HU 35250 49921	435250	1149921		Mussel sample Sansound 6 (7m depth)
15	09/05/2007	HU 35116 49883	435116	1149883		Water sample Sandsound 3 (salt)
16	09/05/2007	HU 35116 49883	435116	1149883		Mussel sample Sandsound 7 (<1m depth)
17	09/05/2007	HU 35116 49883	435116	1149883		Mussel sample Sandsound 8 (3m depth)
18	09/05/2007	HU 35116 49883	435116	1149883		Mussel sample Sansound 9 (7m depth)
19	09/05/2007	HU 35330 49937	435330	1149937		Surface water drain adjacent to jetty (dribble coming out not sampled)
20	09/05/2007	HU 35335 49927	435335	1149927	Figure 9	Wood chippings and straw dumped down rock face appeared to contain animal droppings (mushrooms growing out of it) Water sample sandsound 4 (salt) taken from just off here.
21	09/05/2007	HU 35344 49915	435344	1149915		Surface water drain (small trickle coming from it)
22	09/05/2007	HU 35371 49842	435371	1149842	Figure 12	Square concrete opening, vertical shaft, standing water inside, no odour
23	09/05/2007	HU 35376 49823	435376	1149823	Figure 13	2 purple cotton buds in tideline debris
24	09/05/2007	HU 35374 49830	435374	1149830	Figure 14	Small natural stream (sample see no 49) not measured
25	09/05/2007	HU 35378 49796	435378	1149796	Figure 15	Sheep on shoreline, 15 sheep
26	09/05/2007	HU 35510 49391	435510	1149391		Stream 45 cm wide 2 cm deep. 100 sheep on hills behind.

27	09/05/2007	HU 35499 49601	435499	1149601	Figure 16	line of rocks/concrete leading out inot the sea from the bottom of the rockface immediately under the house
28	09/05/2007	HU 35499 49601	435499	1149601		Water sample Sandsound 5 (salt)
29	09/05/2007	HU 35528 49578	435528	1149578		Stream 50cm wide, 2 cm deep. Sheep droppings 50 cm away
30	09/05/2007	HU 35528 49578	435528	1149578		Water sample Sandsound 6 (fresh)
31	09/05/2007	HU 35549 49538	435549	1149538	Figure 18	Small natural stream
32	09/05/2007	HU 35544 49475	435544	1149475	Figure 17	More sheep droppings
33	09/05/2007	HU 35544 49454	435544	1149454		Septic tank overflow to soakaway on beach at high tide mark
34	09/05/2007	HU 35518 49413	435518	1149413		Surface water runoff pipe
35	09/05/2007	HU 35518 49413	435518	1149413		Water sample Sandsound 7 (fresh)
36	09/05/2007	HU 35383 48858	435383	1148858		circa 10 houses all on septic tanks within around 100m of this point. One possibly has overflow to shoreline soakaway, but unalbe to access shoreline to verify
37	09/05/2007	HU 35594 48344	435594	1148344		another approx 10 houses on septic tanks, no overflow to shore observed but unable to access shoreline
38	09/05/2007	HU 35939 48322	435939	1148322		another 6 houses all presumably on septic tank, road ends here
39	09/05/2007	HU 35454 48858	435454	1148858		1 mooring 50-100m out to sea from this point
40	09/05/2007	HU 35452 48874	435452	1148874		Bearing 328 to fish farm barge (2 moorings near barge)
41	09/05/2007	HU 35509 49103	435509	1149103		Bearing 250 to fish farm barge
42	09/05/2007	HU 35803 50375	435803	1150375		Fresh water input 144cm wide, 29cm deep (flowing very slowly at this point)
43	09/05/2007	HU 35661 50493	435661	1150493		Small jetty, 1 mooring just out from it, 3 boats and one abandoned van on land behind
44	09/05/2007	HU 35979 50557	435979	1150557		small stream 34 cm wide 3 cm deep, no flow taken
45	09/05/2007	HU 35979 50557	435979	1150557		Water sample Sandsound 9 (fresh)
46	09/05/2007	HU 35992 50668	435992	1150668		Small stream 110cm wide 2 cm deep, no flow taken
47	09/05/2007	HU 35992 50668	435992	1150668		Water sample Sandsound 10 (fresh)
48	10/05/2007	HU 35510 49396	435510	1149396		Water sample Sandsound 11 (fresh) (see stream in no. 26)
49	10/05/2007	HU 35803 50377	435803	1150377		Burn emptying into Tresta Voe. water sample Sandsound 12 (fresh)
	09/05/2007	Whole shoreline			Figure 6	Sheep can access most of the shoreline
	09/05/2007	Whole shoreline				Frequent sightings of sheep droppings, 200 sheep counted

Photographs referenced in the table can be found attached as Figures 5-18.

General Observations

Sheep droppings were widely distributed in the area as sheep are the main agricultural output of the island.

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.

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.

Sampling

Water and shellfish samples were collected at sites marked on the map. Water samples were tested for salinity in the field using a hand-held refractometer, giving results in parts per thousand (ppt) salt.

Samples were also tested for salinity by the laboratory using a salinity meter under more controlled conditions. These results are more precise than the field measurements and are shown in Table 2, given in units of grams salt per litre of water. This is the same as ppt.

Bacteriology results follow in Tables 2 and 3.

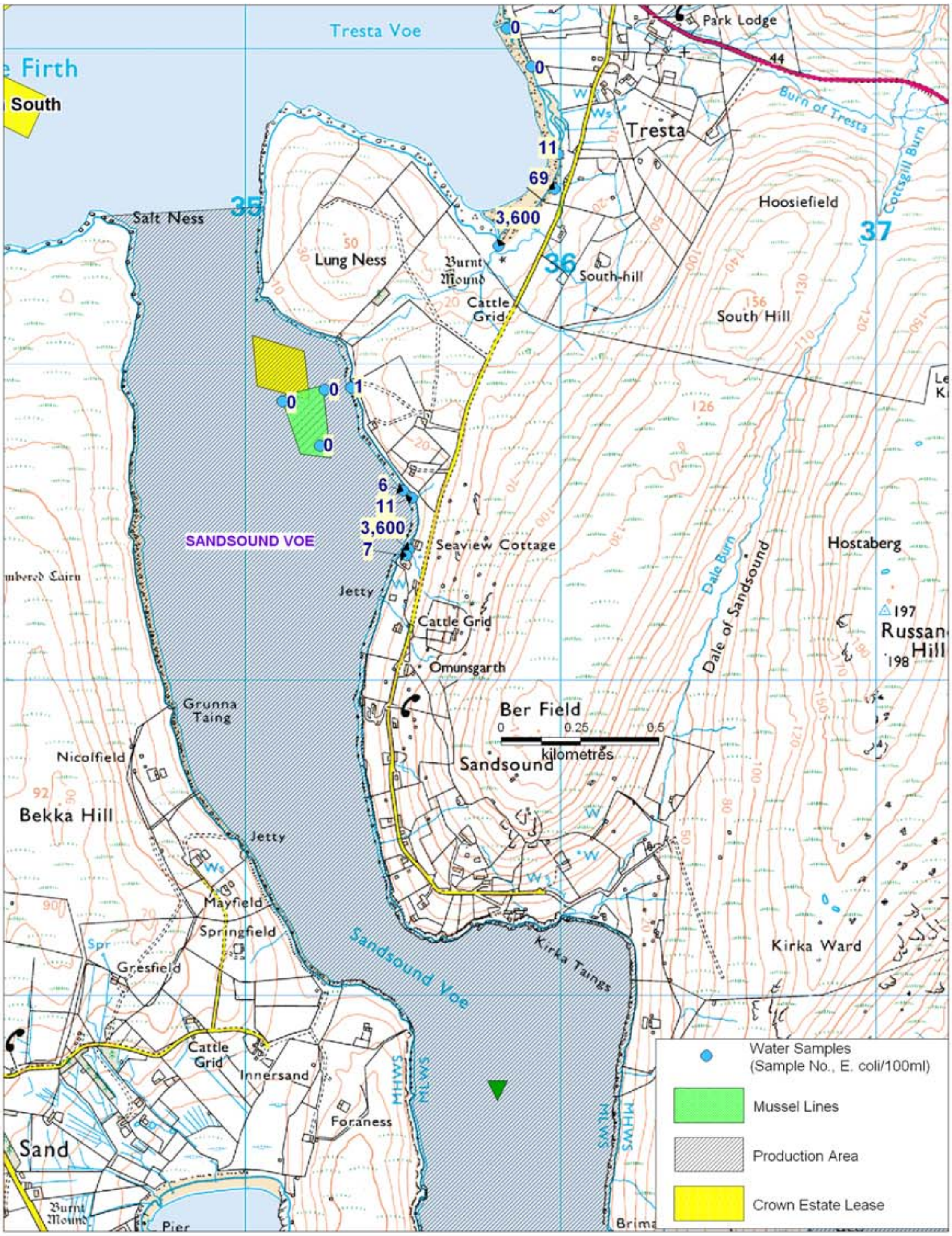
Table 2 Water Sample Results

Sample	Type	E. coli(cfu/100ml)	Salinity(g/L)
Sandsound 1	Water	<1	29.0
Sandsound 2	Water	<1	29.0
Sandsound 3	Water	<1	27.6
Sandsound 4	Water	1	29.5
Sandsound 5	Water	6	28.1
Sandsound 6	Water	11	0.3
Sandsound 7	Water	$>3x10^3$	0.1
Sandsound 9	Water	69	0.1
Sandsound 10	Water	11	8.0
Sandsound 11	Water	7	0.1
Sandsound 12	Water	$>3x10^3$	0.8

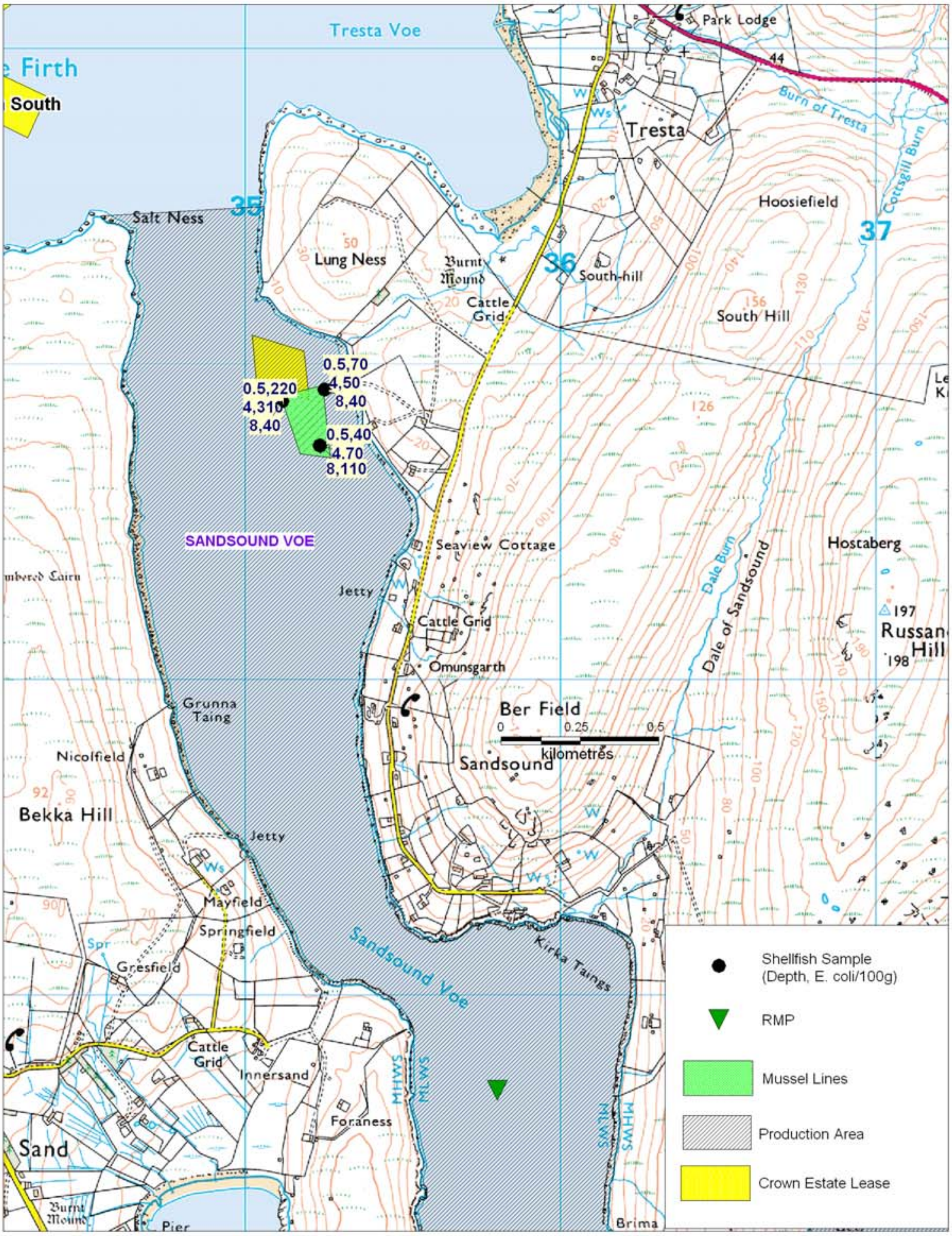
Table 3 Shellfish Sample Results

Sample	Type	E. coli(cfu/100g)	Depth
Sandsound 1	Mussel	110	7
Sandsound 2	Mussel	70	3
Sandsound 3	Mussel	40	<1
Sandsound 4	Mussel	70	<1m
Sandsound 5	Mussel	50	3m
Sandsound 6	Mussel	40	7m
Sandsound 7	Mussel	220	<1m
Sandsound 8	Mussel	310	3m
Sandsound 9	Mussel	40	7m

Sandsound Voe - Water Results



Sandsound Voe - Shellfish Results



Photographs

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17


Figure 18


Sampling Plan for Sandsound Voe

PRODUCTION AREA	SITE NAME	SIN	SPECIES	TYPE OF FISHERY	NGR OF RMP	EAST	NORTH	TOLER ANCE (M)	DEPTH (M)	METHOD OF SAMPLING	FREQ OF SAMPLING	LOCAL AUTHOR ITY	AUTHORISED SAMPLER(S)	LOCAL AUTHORITY LIAISON OFFICER	OTHER INFO
Sandsound Voe	Sands ound Voe	SI 242 433 08	Common mussels	Long line	HU 3515 4988	43515	114988	20	1	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 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

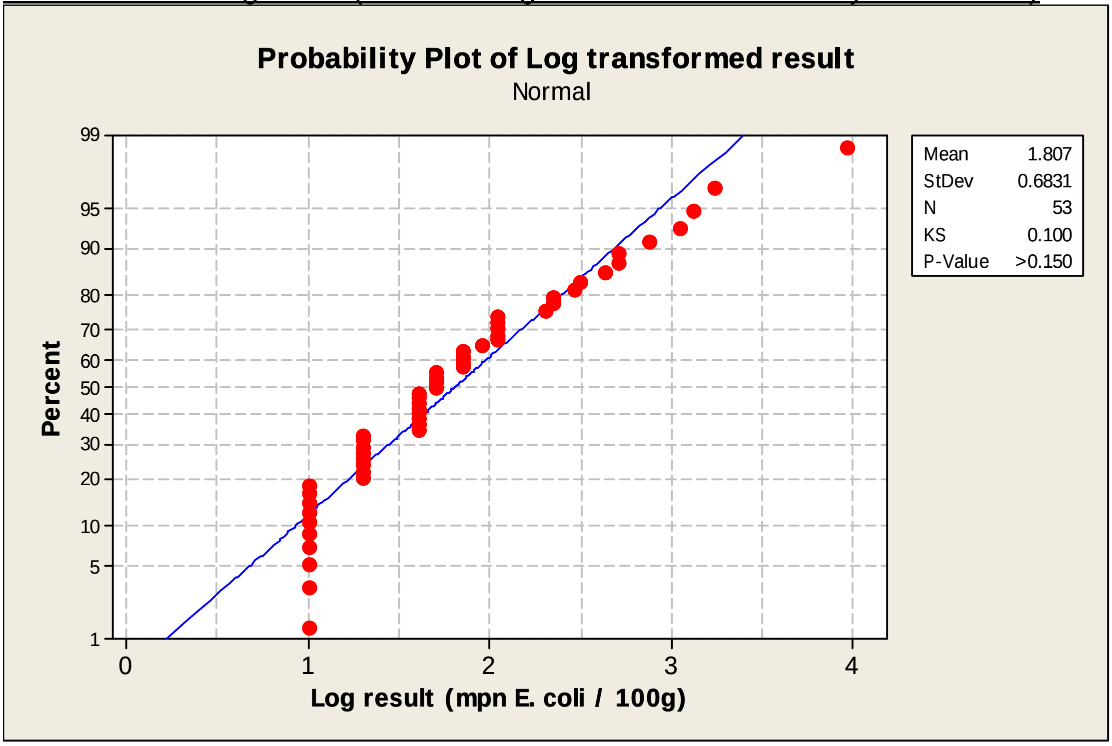
Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^8
Cow	230,000	23,600	5.4×10^9
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^8
Pig	3,300,000	2,700	8.9×10^8
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^8
Human	13,000,000	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 (aside from the circular linear correlation) as this gives a more normal distribution.

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



Section 11.4.1 ANOVA comparison of results by season

```
Source   DF      SS     MS     F      P
season    3   2.851  0.950  2.17  0.103
Error    49  21.414  0.437
Total    52  24.265

S = 0.6611   R-Sq = 11.75%   R-Sq(adj) = 6.35%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  -------+---------+---------+---------+--
Autumn  15  2.1358  0.8622                    (---------*---------)
Spring  13  1.5255  0.4059  (----------*---------)
Summer  14  1.6907  0.6666       (---------*---------)
Winter  11  1.8378  0.5703          (-----------*----------)
                            -------+---------+---------+---------+--
                                 1.40      1.75      2.10      2.45

Pooled StDev = 0.6611
```

Section 11.4.2 Regression analysis (log Result versus rain in previous 2 days).

```
The regression equation is
log result for rain = 1.51 + 0.0380 rain in previous 2 days


Predictor                    Coef  SE Coef      T      P
Constant                   1.5053   0.1183  12.72  0.000
```

```
rain in previous 2 days  0.03801  0.01402   2.71  0.010

S = 0.558163   R-Sq = 14.3%   R-Sq(adj) = 12.4%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   2.2887  2.2887  7.35  0.010
Residual Error  44  13.7080  0.3115
Total           45  15.9968


Unusual Observations

      rain in
     previous  log result
Obs    2 days    for rain     Fit  SE Fit  Residual  St Resid
 21      17.2      3.2304  2.1591  0.1766    1.0714     2.02R
 33       3.4      3.0414  1.6346  0.0904    1.4068     2.55R
 45       0.0      2.8751  1.5053  0.1183    1.3697     2.51R
 46      21.4      2.0414  2.3187  0.2303   -0.2773    -0.55 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Section 11.4.2 ANOVA comparison of log Result versus rainfall quartile (previous 2 days).

```
Source         DF      SS     MS     F      P
rain quartile   3   1.718  0.573  1.68  0.185
Error          42  14.279  0.340
Total          45  15.997

S = 0.5831   R-Sq = 10.74%   R-Sq(adj) = 4.36%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
1      11  1.4602  0.6193  (-----------*-----------)
2      12  1.6830  0.6024          (----------*----------)
3       8  1.7475  0.4929         (-------------*-------------)
4      15  1.9736  0.5826                     (---------*---------)
                           ---+---------+---------+---------+------
                            1.20      1.50      1.80      2.10

Pooled StDev = 0.5831
```

Section 11.4.2 Regression analysis (log Result versus rain in previous 7 days).

```
The regression equation is
logres rain prev 7 = 1.33 + 0.0162 rain pev 7


Predictor       Coef   SE Coef     T      P
Constant      1.3324    0.1388  9.60  0.000
rain pev 7  0.016215  0.004587  3.53  0.001


S = 0.536683   R-Sq = 22.5%   R-Sq(adj) = 20.7%


Analysis of Variance

Source          DF       SS      MS      F      P
Regression       1   3.5993  3.5993  12.50  0.001
```

```
Residual Error  43  12.3852  0.2880
Total           44  15.9845


Unusual Observations

           logres
      rain   rain
Obs  pev 7  prev 7     Fit  SE Fit  Residual  St Resid
 20   32.4  3.2304  1.8578  0.0874    1.3727     2.59R
 25   64.6  2.4914  2.3799  0.1996    0.1115     0.22 X
 32   39.2  3.0414  1.9680  0.1040    1.0734     2.04R
 44   21.2  2.8751  1.6762  0.0816    1.1989     2.26R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

<u>Section 11.4.2 ANOVA comparison of log Result versus rainfall quartile (previous 7 days).</u>

```
Source          DF      SS     MS     F      P
rain q prev 7    3   4.633  1.544  5.58  0.003
Error           41  11.351  0.277
Total           44  15.985

S = 0.5262   R-Sq = 28.99%   R-Sq(adj) = 23.79%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
1      10  1.4200  0.4130     (-------*--------)
2       8  1.3435  0.3386  (---------*--------)
3      15  1.7936  0.6835               (------*------)
4      12  2.1788  0.4742                        (------*-------)
                           ------+---------+---------+---------+---
                               1.20      1.60      2.00      2.40

Pooled StDev = 0.5262
```

<u>Section 11.4.3 ANOVA comparison of results by tide size</u>

```
Source     DF      SS     MS     F      P
tide size   2   0.653  0.327  0.69  0.505
Error      50  23.612  0.472
Total      52  24.265

S = 0.6872   R-Sq = 2.69%   R-Sq(adj) = 0.00%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  ----+---------+---------+---------+-----
Large   16  1.9751  0.6900           (-------------*-------------)
Medium  18  1.7438  0.5694   (------------*------------)
Small   19  1.7244  0.7802  (------------*------------)
                            ----+---------+---------+---------+-----
                              1.50      1.75      2.00      2.25
Pooled StDev = 0.6872
```

CIRCULAR-LINEAR CORRELATION

Variables: Wind bearing & *E. coli* (observations)
Result   r0.247   p0.229 (27)

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.

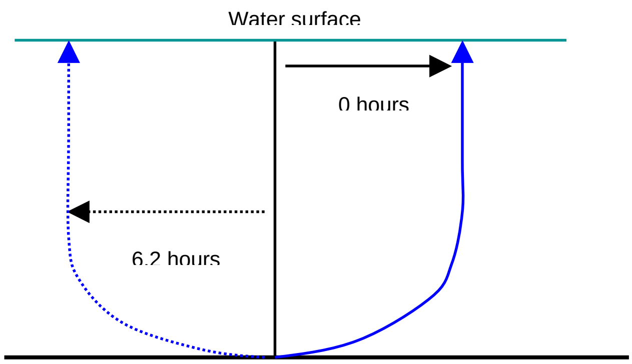
The hydrography at most sites will be assessed on the basis of bathymetry and tidal flow software only and is not discussed in any detail in this document. Selected sites will be assessed in more detail using either: 1) a hydrodynamic model, or 2) an extended consideration of sources, available field 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.

a)



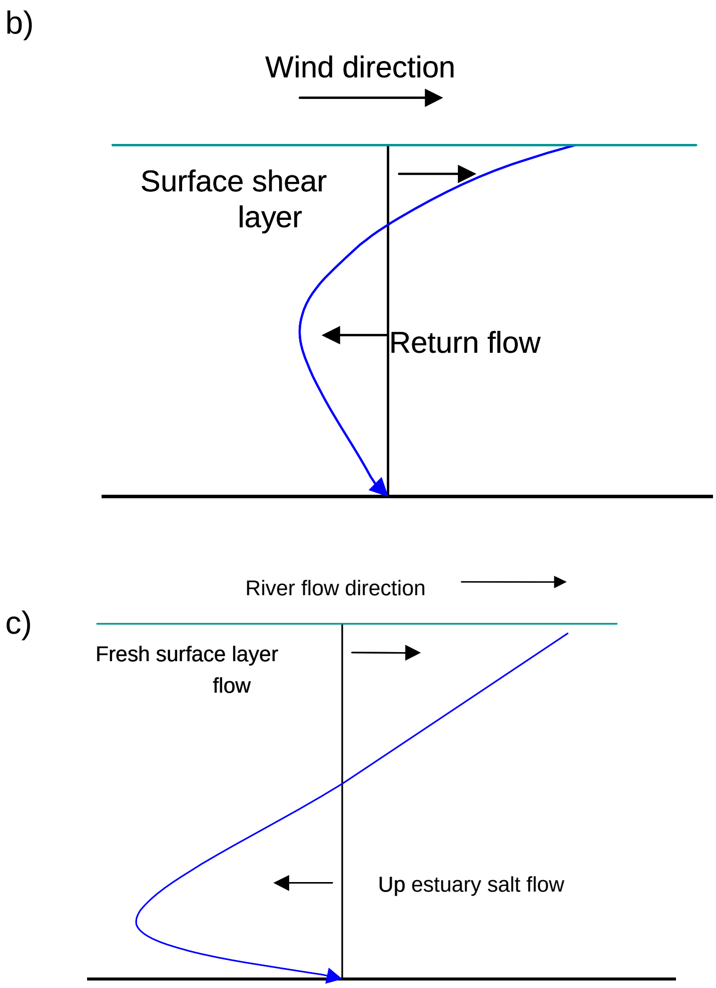


Figure 1. Typical vertical profiles for currents generated by different mechanisms. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main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

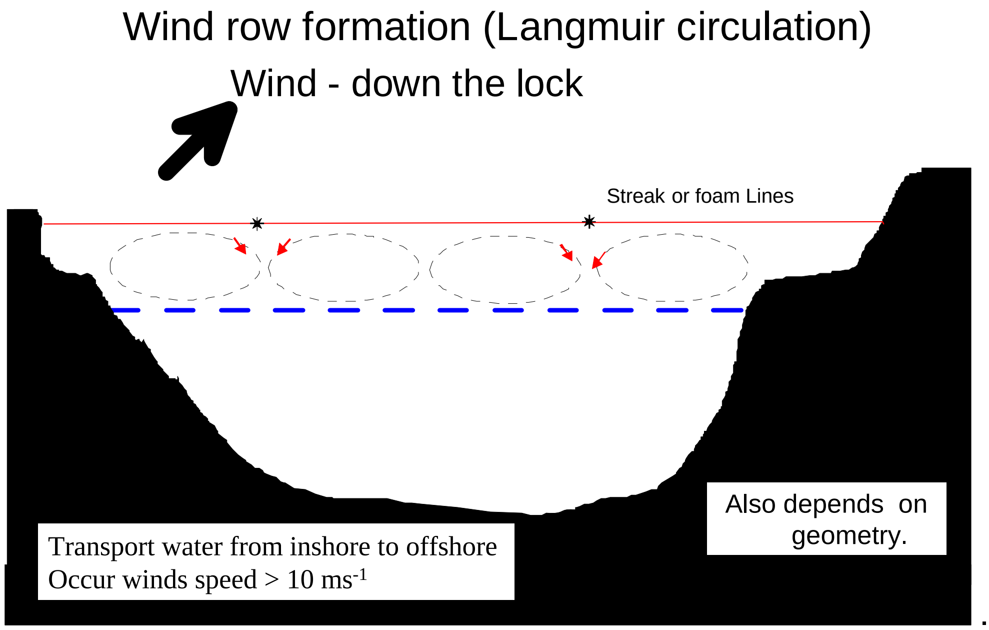


Figure 2: Schematic of wind driven 'wind row' currents. View is down the loch.The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.