Scottish Sanitary Survey Project

Sanitary Survey Report
Weisdale Voe and Weisdale Voe Upper
SI 297 and SI 378
November 2007

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1. General Description

Weisdale Voe is located on the southwestern side of the main island of Shetland (Fig. 1.1). It is a south facing voe and receives freshwater input from the Burn of Weisdale at the head of the voe, and from Calders Creek and Loch of Hellister on the eastern side of the voe. The settlement of Heglibister is located near the head of the voe and Hagersta further inland between Weisdale Voe and Loch of Strom. A third settlement, Hellister, is located on the eastern shore of the voe approximately 1 mile northeast of the new harvesting area.

Shetland

Figure 1.1 Location of Weisdale Voe on Shetland.

2. Fishery

The fishery at Weisdale Voe is comprised of three long line mussel (*Mytilus* sp.) farms, two of which are located in the existing production area of Weisdale Voe. These are Greena (SI 297 468) and North Flotta (SI 297 469). The third farm, Vedri Geo (SI 378 768), lies within a new production area of Weisdale Voe Upper.

In all three cases, 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 all three farms in Weisdale Voe are harvested between September and May.

Spawning occurs in May, during which 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.

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

Weisdale Voe Fishery

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Figure 2.1. Location of Weisdale Voe mussel fisheries.

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 Weisdale Voe.

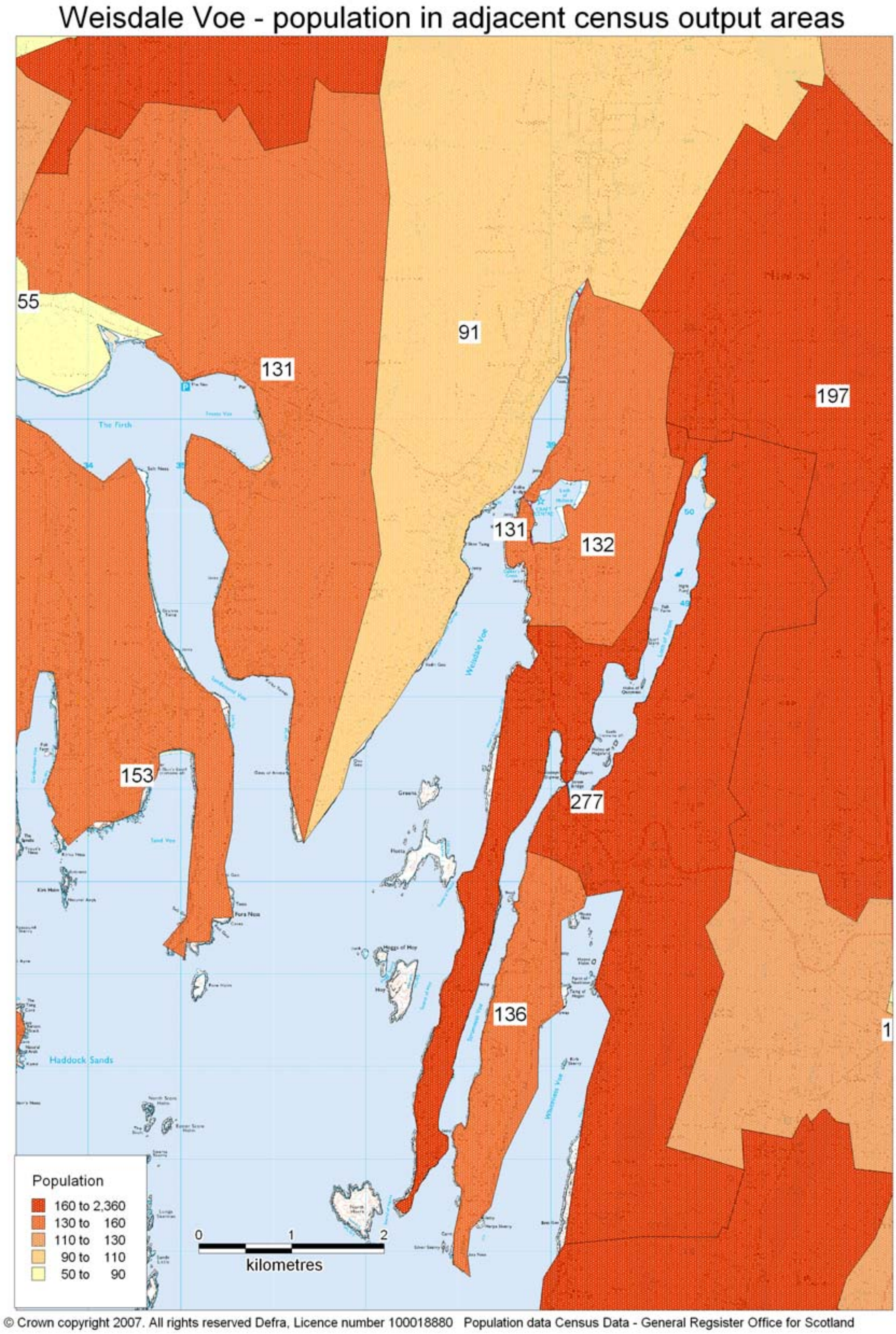

Figure 3.1 Population map for Weisdale Voe

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

60RD000026	91
60RD000155	132
60RD000156	131
60RD000023	255

On the eastern side of the voe are the settlements of Hellister, Kalliness, Cova with Haggersta between the voe and the Loch of Strom. On the western side of the voe are the settlements of Cott and Heglibister. Most of the population is concentrated towards the upper eastern shore of the voe and, given the absence of public sewerage systems, 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

The area around Weisdale Voe is sparsely populated. Scottish Water have provided information on the following discharges from community septic tanks to the voe:

Table 4.1

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?
Weisdale Voe	HU 388484	Clach-na-Strom Whiteness	continuous	Septic Tank			250	N
Weisdale Voe	HU 38804990	Kalliness West Weisdale	continuous	Septic Tank	15		70	N
Weisdale Voe	HU 39305200	Swedish Houses Weisdale	continuous	Septic Tank		7.5m3/d max	30	N

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 Weisdale 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 16.1, Shoreline Survey.

Figure 4.1 Map of Weisdale Voe sewage discharges

5. Geology and Soils

Understanding the soil composition and drainage characteristics of Shetland is important as it can help to indicate whether there would be any potential for surface runoff, contaminated with *E. coli* from animal waste.

Using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute, component soils and their associations were identified. The relevant soils 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 regosoils, brown calcareous regosoils, calcareous gleys, 4) peaty gleys, podzols, rankers, 5) non-calcareous gleys, peaty gleys: some humic gleys, peat, 6) organic soils and 7) alluvial soils.

Humus-iron podzols are generally infertile and physically limiting soils for productive use[i]. 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 (Macaulay Institute 2007).

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.

Calcareous regosoils, brown regosoils 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 are 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.

Maps have been produced using these seven soil type groups and whether they are characteristically freely or poorly draining (for an example see figure 5.1).

Weisdale Voe Soil Drainage Classes

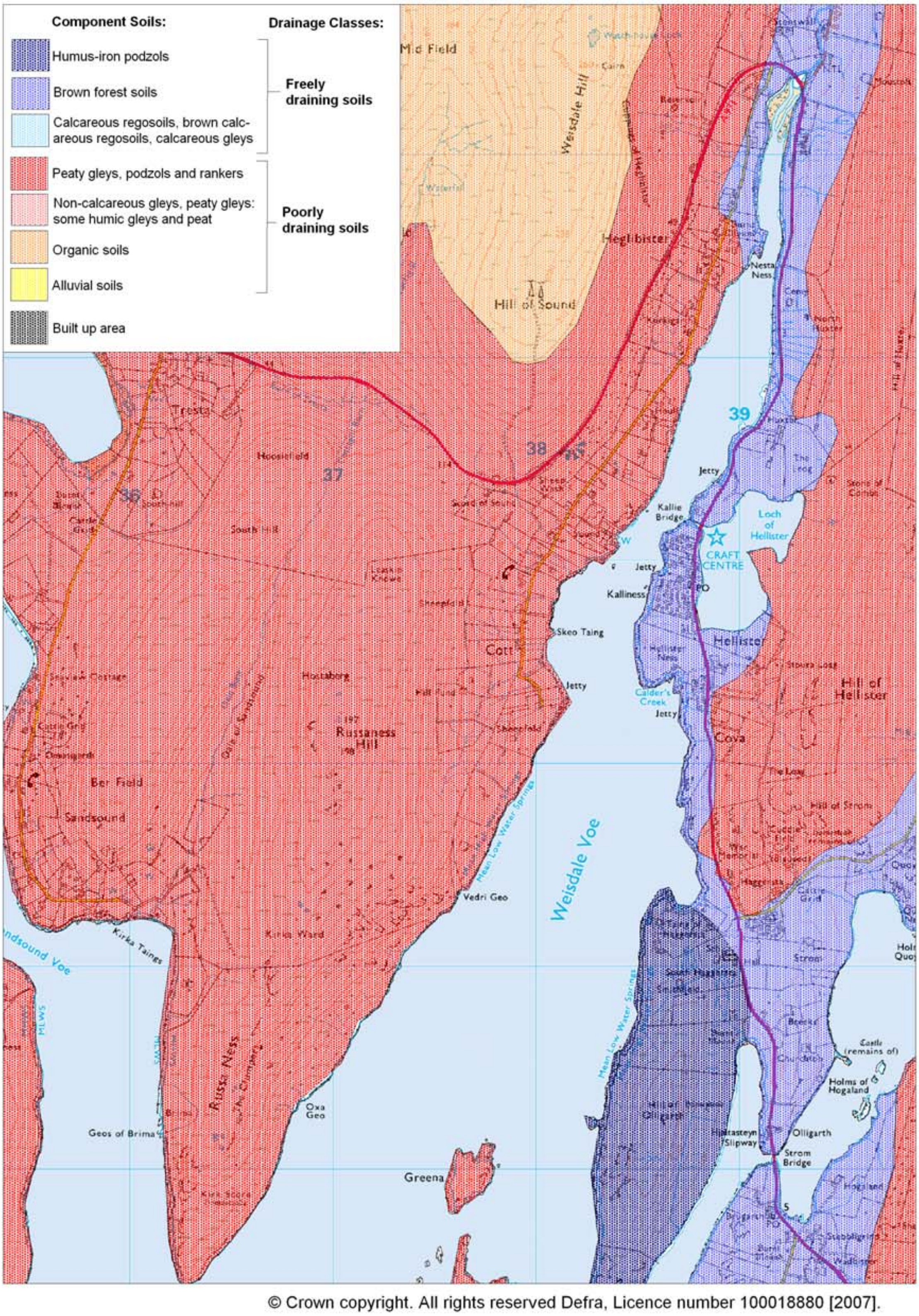

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Figure 5.1. Component soils and drainage characteristics

Figure 5.1 shows a map of component soils and their associated drainage classes for the area of Weisdale Voe. Component soils have been identified using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute.

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 western coast of Weisdale Voe and the Isles of Flotta and Greena to the south.

The second dominant component soil is brown forest soil. This covers a band of land beginning at the north-western tip of Weisdale Voe, travelling east round the coastline to about half way down where it becomes the third component soil class of humus-iron podzols.

In figure 5.1, these component soils have been classed into two groups based upon whether they are freely or poorly draining. Drainage classes were created based on information obtained from the both the Macaulay Institute website and personal communication with Dr. Alan Lilly. The peaty gleys, podzols and rankers are classed as poorly draining soils and the brown forest soils and humus-iron podzols are freely draining soils.

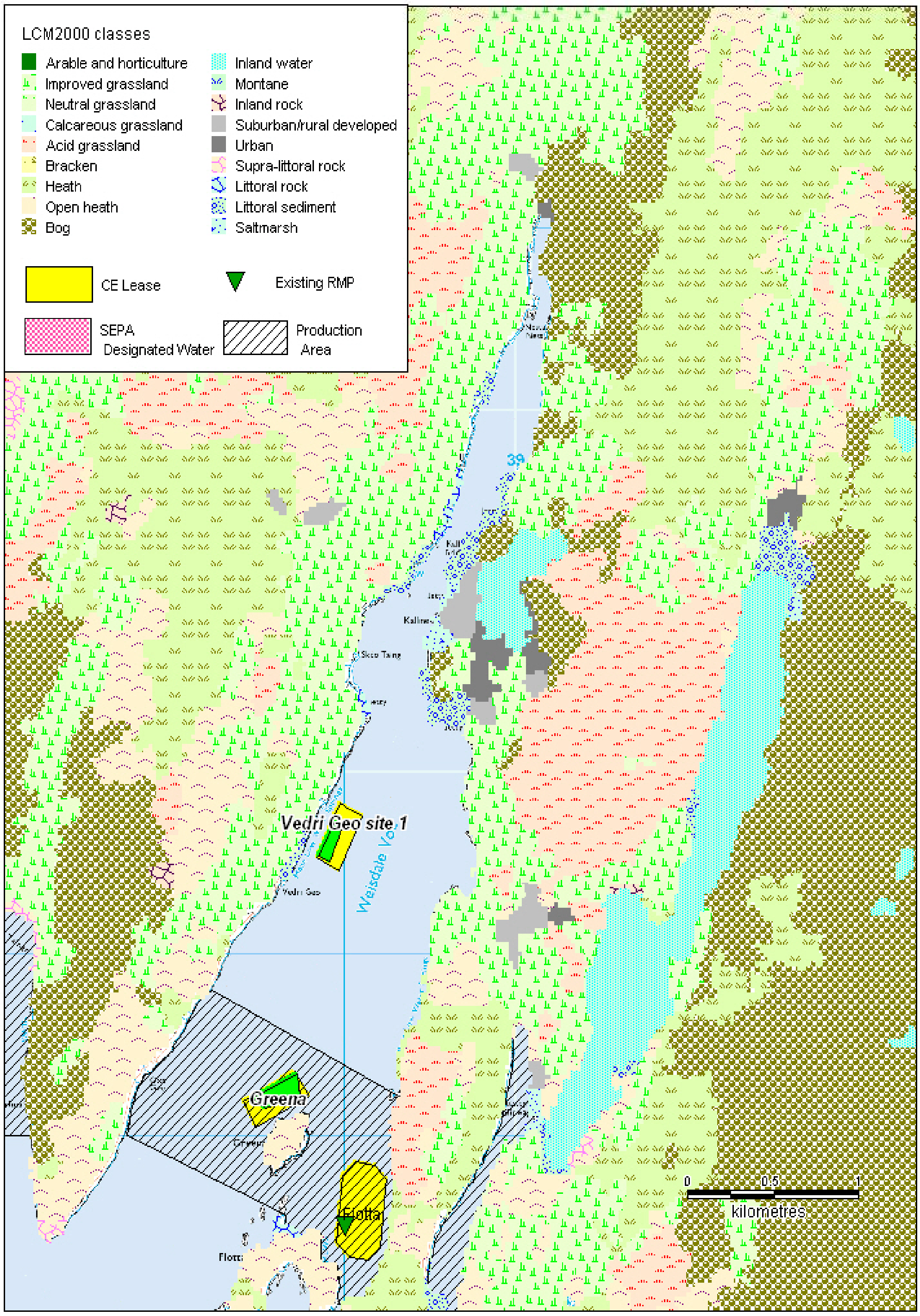
Understanding whether the land surrounding Weisdale Voe is either freely or poorly draining help to indicate how much surface runoff and soil leaching could occur. In poorly draining soils (such as those found along the western coastline of Weisdale Voe) surface run off is likely to be high, as peaty gleys, podzols and rankers are often waterlogged. Whereas, in the more freely draining soils found along the eastern coastline of Weisdale Voe, surface runoff is reduced as the permeability of the soil has increased. This provides an indication as to the potential for contamination due to diffuse pollution from livestock and whether it is higher in certain areas

In the case of Weisdale Voe, the potential for runoff contaminated with *E. coli* from animal waste is higher along the western side of the voe.

6. Land Cover

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

Weisdale Voe - Land Cover



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LCM2000 © NERC

Figure 6.1 LCM2000 class data for Weisdale Voe

Most of the land on the west side of the voe is shown as improved grassland, with open heath towards the southern end of Russa Ness. The land cover on the east side of the voe is more mixed, with patches of improved grassland, bog, open heath, acid grassland and developed areas. There are also areas of littoral rock and littoral sediment on the edges of the voe near the developed areas of Kalliness and Hellister.

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.

7. Farm Animals

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

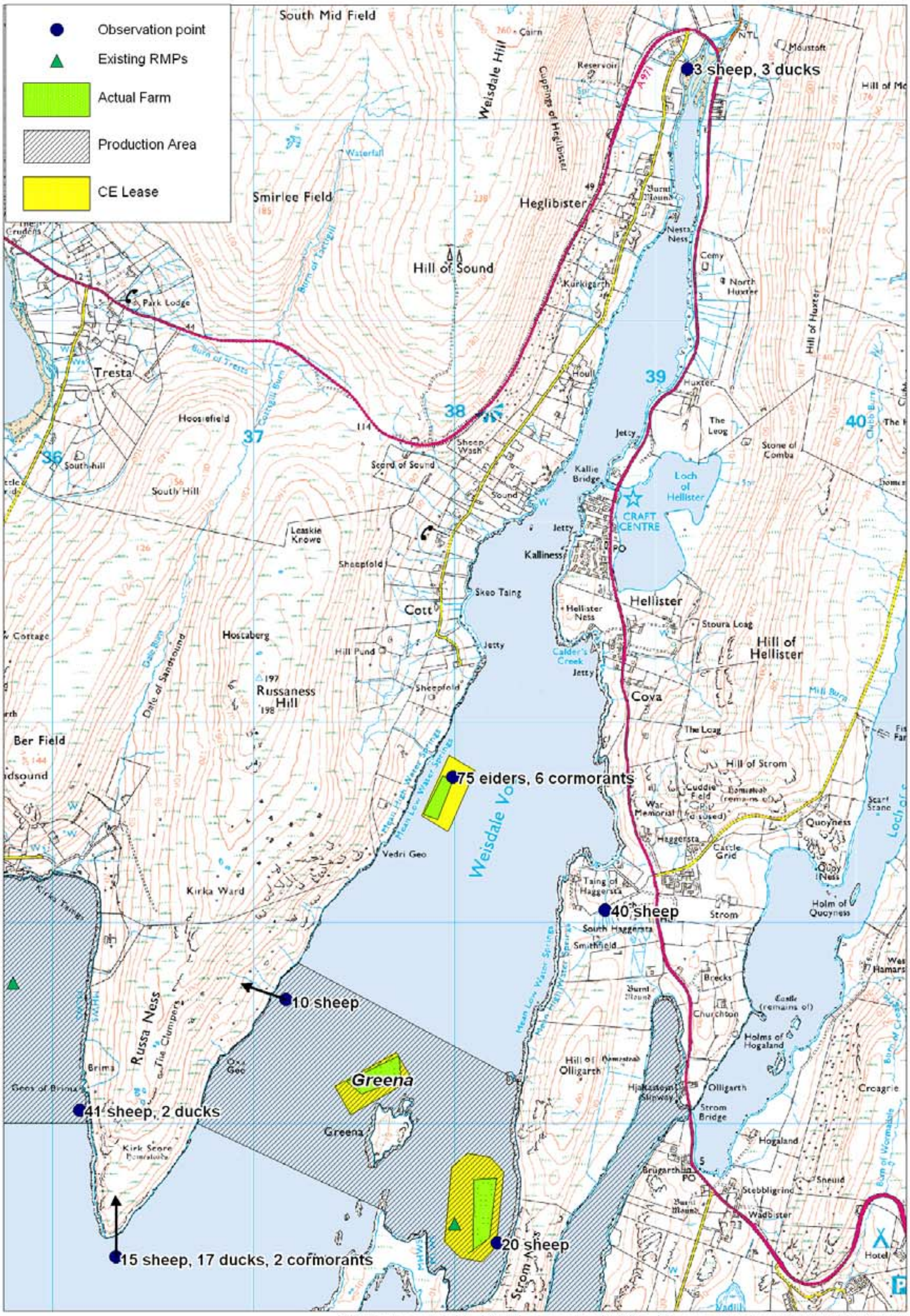
(a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;
(b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human 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 SEERAD. The request was denied on the grounds of confidentiality. The only significant source of information was therefore the shoreline survey (see Appendix 17.1) 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 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 animals observed and noted during the shoreline survey is illustrated in Figure 7.1.



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Note: observation samples with arrows have been observed from a boat.

Figure 7.1 Livestock Observations at Weisdale 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 Shetland (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.

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

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*. There have been some sightings in and around Weisdale Voe, however these accounts are sparse. 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 Weisdale Voe numbering somewhere between 500 and 4,300 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.

It is not known what the *E. coli* content of their droppings is, however 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).

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 Weisdale Voe area, the voe is not considered to be home to 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 fisheries as Weisdale Voe is likely to be mostly that of Eider ducks feeding on the mussel lines.

Other birds, including rooks and other small birds, use the small plantation of trees at Kergord for roosting and nesting. The impact from their droppings is not likely to be significant in the voe itself.

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 Lerwick, approximately 9.5 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 Weisdale Voe 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, Weisdale 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 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 *.

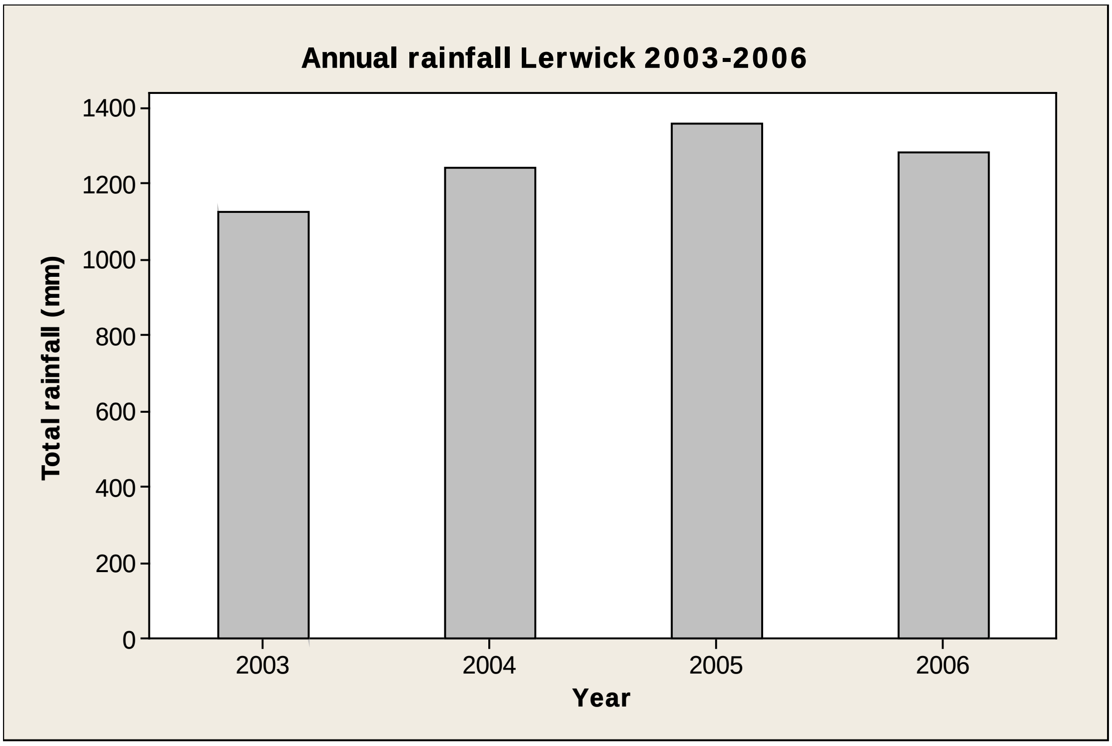


Figure 9.1

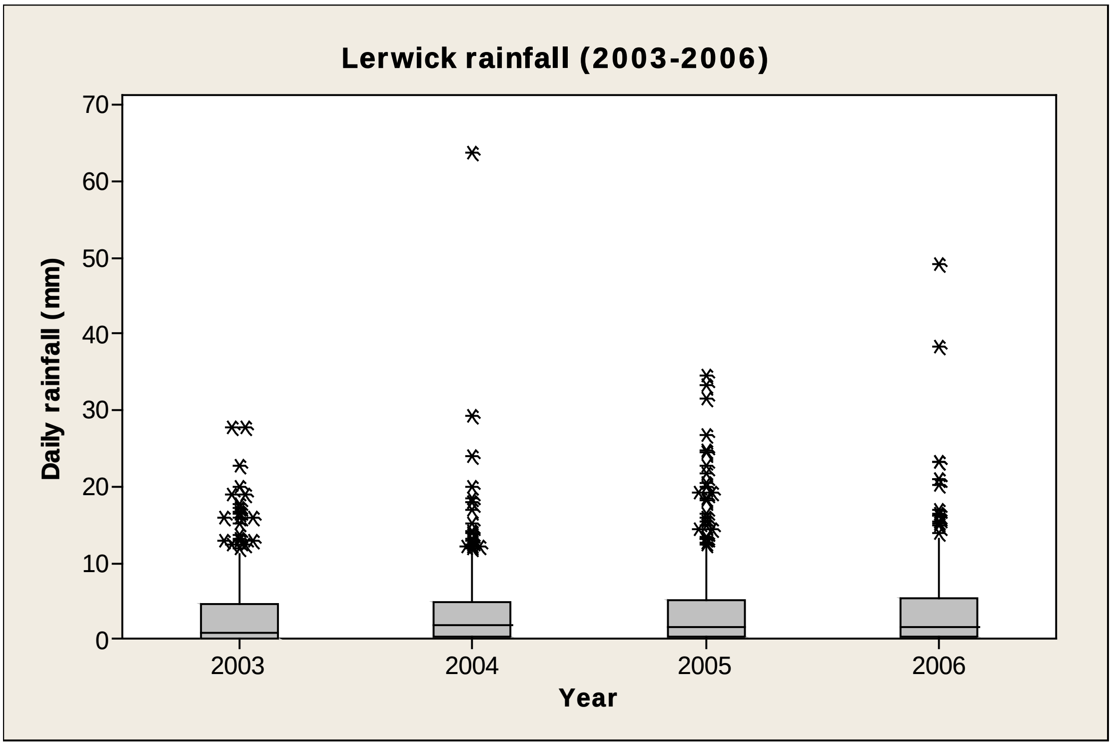


Figure 9.2

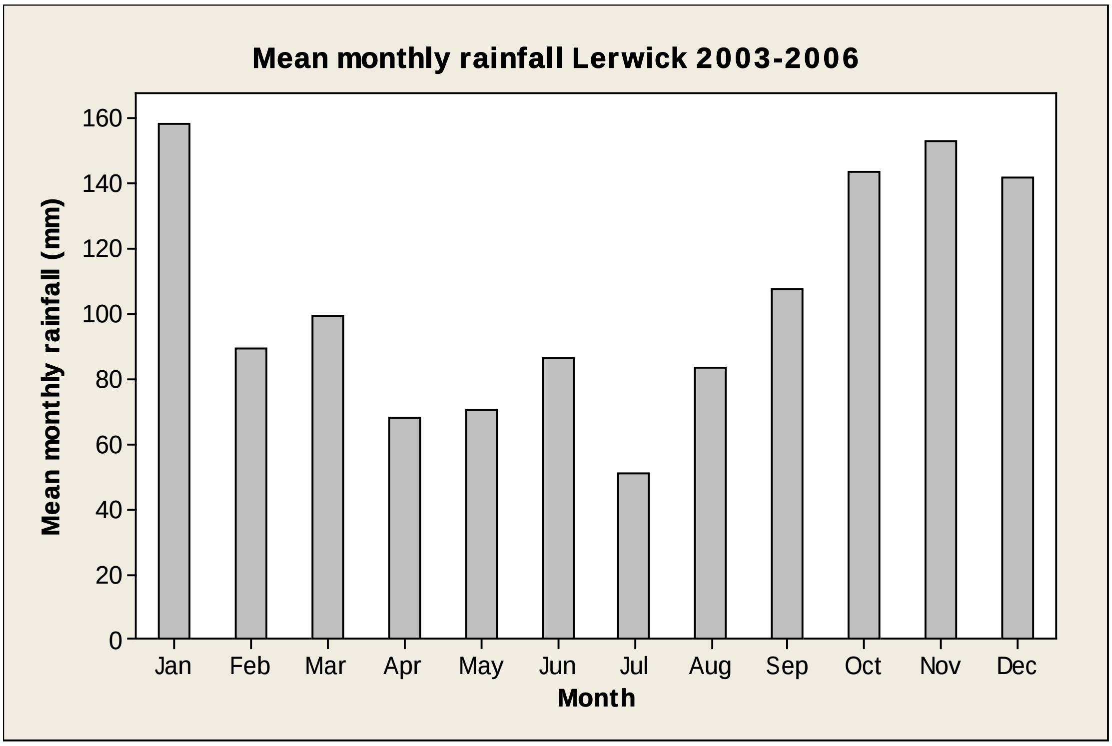


Figure 9.3

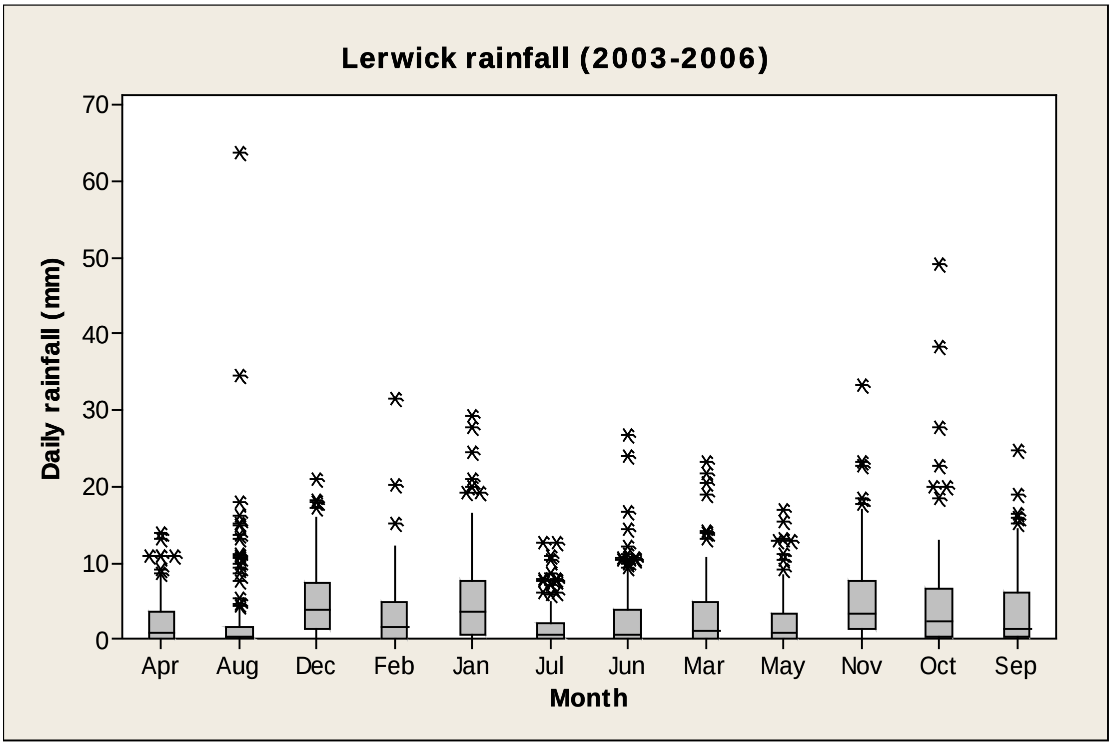


Figure 9.4

Table 9.1 - Lerwick total annual rainfall 2003-6

Year	Total Rainfall (mm)
2003	1125
2004	1242
2005	1358
2006	1284

Table 9.2 - Lerwick mean monthly rainfall 2003-6

Month	Mean total rainfall (mm)
Jan	158.25
Feb	89.25
Mar	99.25
Apr	68
May	70.5
Jun	86
Jul	51
Aug	83.25
Sep	107.75
Oct	143.75
Nov	153.25
Dec	142

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 9.3 - 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 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 in the autumn.

9.2 Wind

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

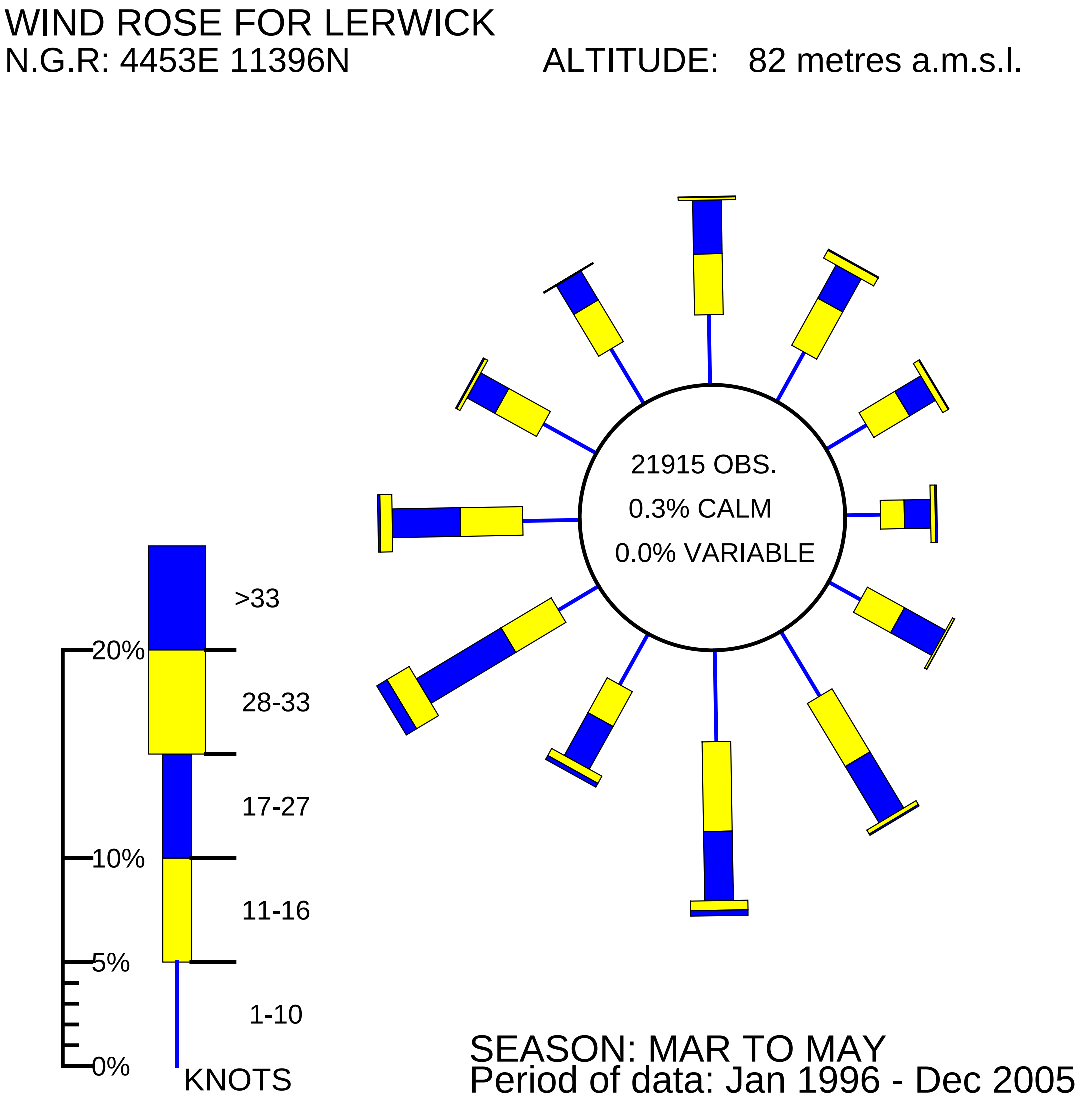
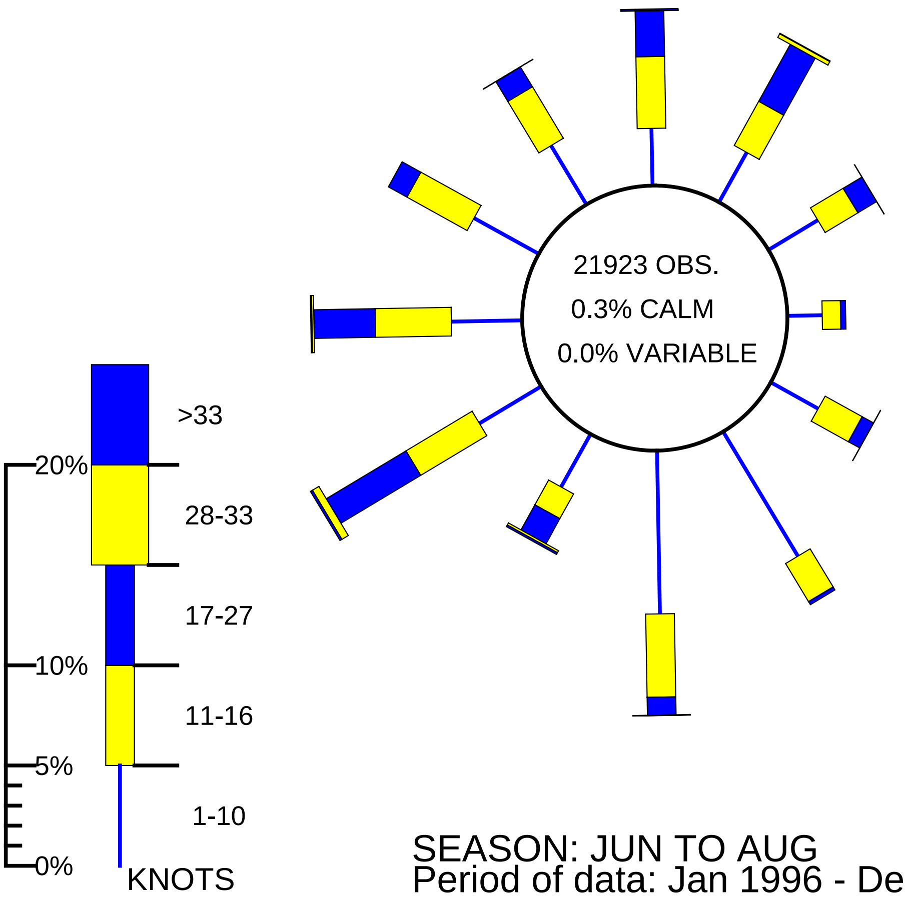


Figure 9.5

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



SEASON: JUN TO AUG
Period of data: Jan 1996 - Dec 2005

Figure 9.6

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

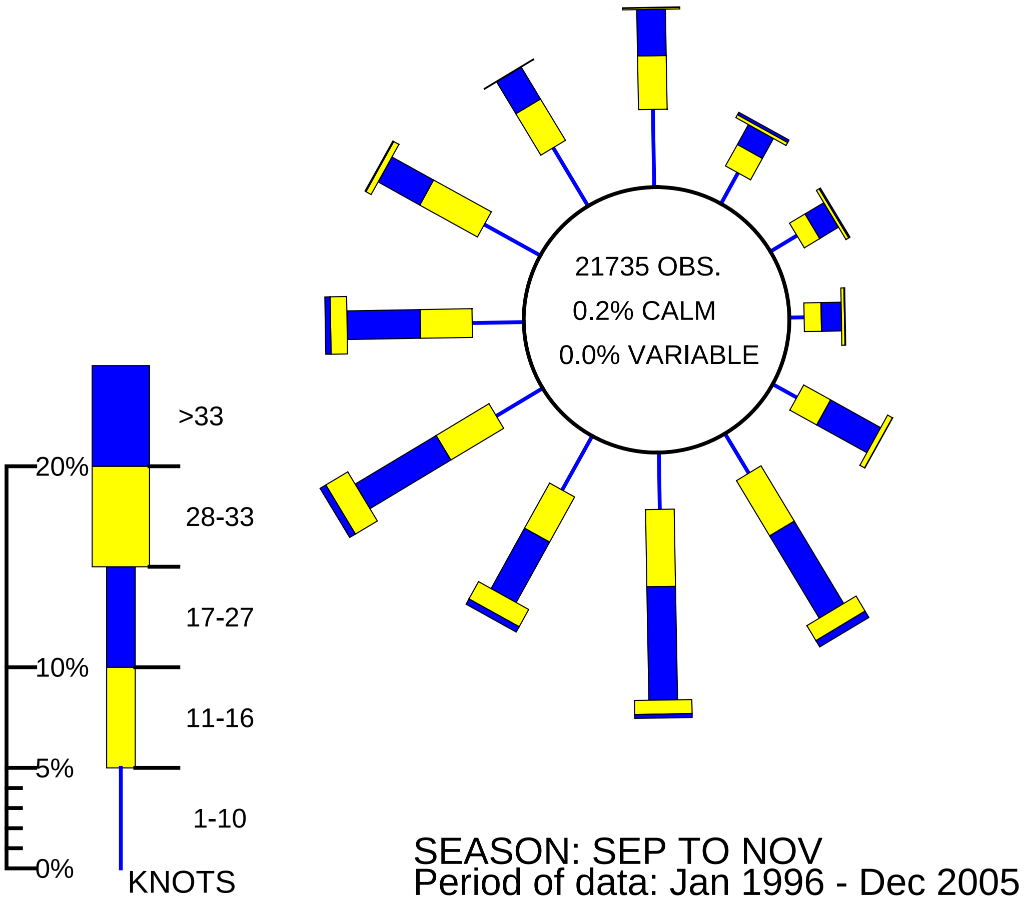


Figure 9.7

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

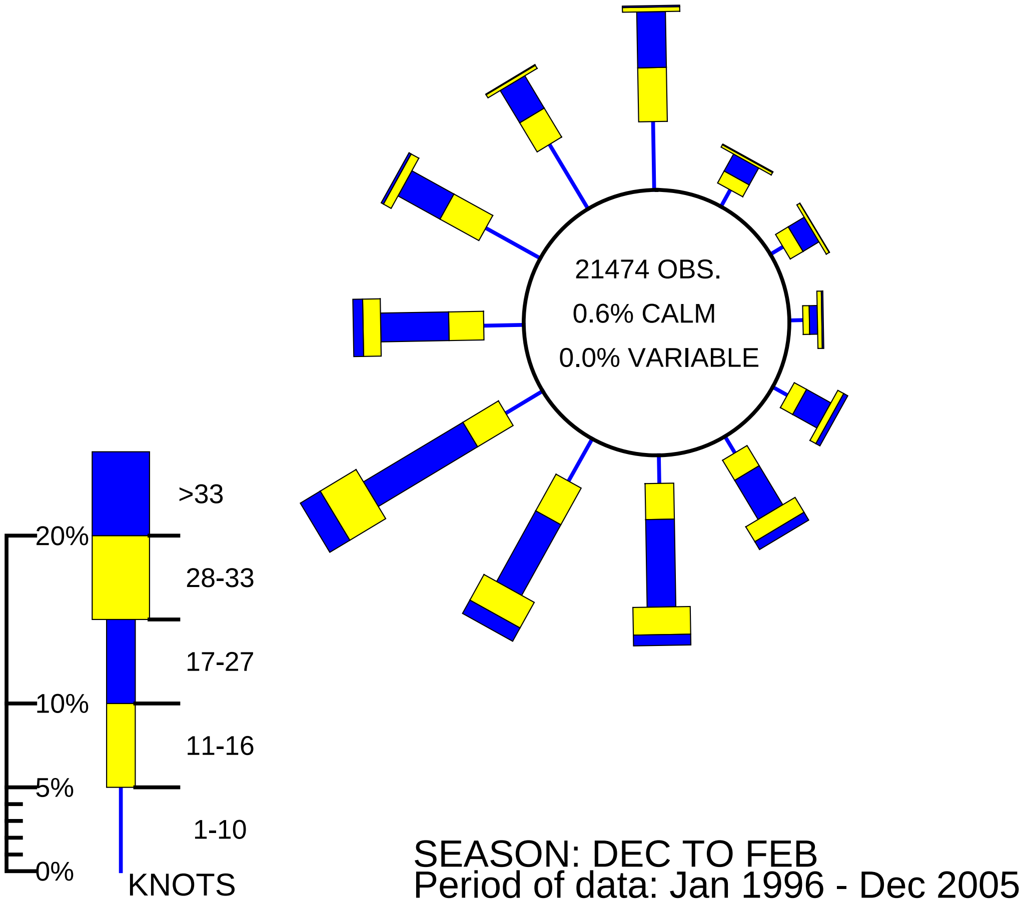


Figure 9.8

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. Weisdale Voe is narrow, faces SSW, and is sheltered in part from winds and Atlantic swells by small islands in and around its mouth. The surrounding high ground will have the effect of channelling the wind up or down the voe.

A strong SW 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 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 which may travel along the bottom or sides of the voe 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. If the return currents travel along the sides of the voe, then a south westerly wind would result in contamination from the population centres carried south along the shore towards the production sites. If the return currents are along the bottom of the voe, then a strong SW wind would carry contamination from the population centres away from the production sites, then eventually back past them (at depth) on the return current.

10. Current and Historical Classification Status

Weisdale Voe Upper (SI 378) is a new production area and so has no classification history and is not currently classified. The Weisdale Voe (SI 297) production area was first classified for production in 2005. A map of the current production area is presented in Figure 10.1. The classification history is presented in Table 10.1. Currently, the area is classified as an 'A' throughout the entire year (2007/8).

Table 10.1 - Classification history

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

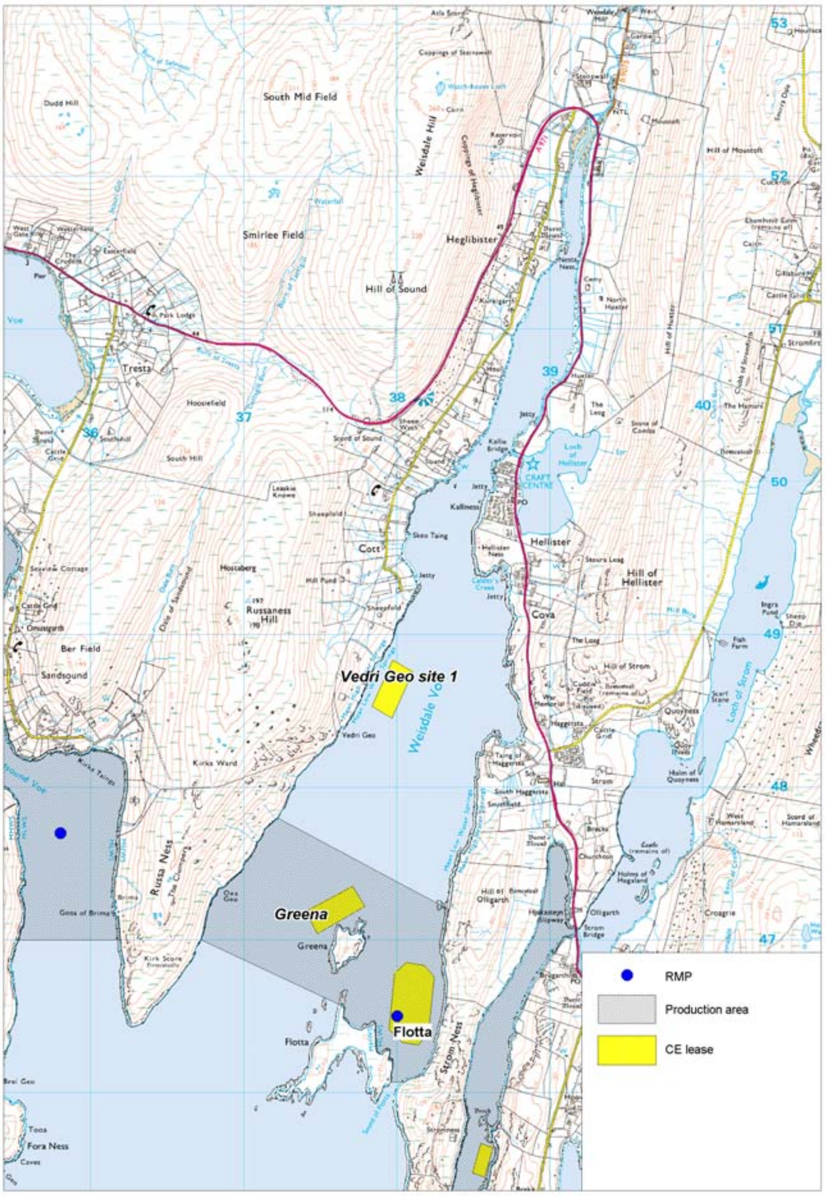


Figure 10.1 - Map of current Weisdale Voe production area

11. Historical *E. coli* Data

11.1 Validation of historical data

All samples taken from Weisdale Voe (SI 297) 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. Three samples were discarded from the analysis due to geographical discrepancies, and in the 15 instances where the result was reported as <20, it was adjusted to 10. No samples were taken from the new production at Weisdale Voe Upper (SI 378) before the end of 2006 so this site does not feature anywhere in this analysis. All *E. coli* results are reported in most probably number per 100g of shellfish flesh and intervalvular fluid.

11.2 Summary of microbiological results by sites

Common mussels were sampled from two sites within the Weisdale Voe production area. At the North Flotta site, all samples were collected from the RMP which falls within the production area, the crown estate lease, and the actual farm boundaries as measured on the shoreline survey. At the Greena site, which has no RMP, all samples were collected from exactly the same location, which falls within the production area, the crown estate lease, and the actual farm boundaries as measured on the shoreline survey. No samples were reported from the Weisdale Voe Upper production area prior to the end of 2006. Only 11% of samples exceeded 230 *E. coli* per 100g, so 89% of results returned an 'A' result.

Table 11.1 - Summary of results from all sites within Weisdale Voe (SI 297)

Sampling summary			
Production area	Weisdale Voe	Weisdale Voe	Weisdale Voe
Site	North Flotta	Greena	All sites (2)
Species	Common mussels	Common mussels	Common mussels
SIN	SI 29746913	SI 29746813	SI 297
Location of RMP	HU380465	None listed	HU380465
Location sampled	HU380465	HU376472	All locations (2)
Total no of samples	25	13	38
Number in 2004	4	4	8
Number in 2005	12	8	20
Number in 2006	9	1	10
Results Summary (*E. coli* mpn)			
Minimum	10	10	10
Maximum	1300	750	1300
Median	10	40	20
Geometric mean	25.5	46.9	31.4
90 percentile	188	288	247
95 percentile	292	486	376
No. exceeding 230/100g	2 (8%)	2 (15%)	4 (11%)
No.exceeding 1000/100g	1 (4%)	0 (0%)	1 (3%)
No. exceeding 4600/100g	0 (0%)	0 (0%)	0 (0%)
No. exceeding 18000/100g	0 (0%)	0 (0%)	0 (0%)

A comparison of results reveals that although the mean result from Greena was slightly higher, there was no significant difference between sites (T-test, T-value=-1.33, p=0.195; Appendix 18.5). Sample numbers are small however, and it must be noted the samples from the different sites were mostly gathered on different days. Due to the small number of samples, the similar results obtained from each site, and the proximity of the two sites, data from both was combined for all further analysis (sections 10.3 and 10.4). Information on interpretation of the boxplots represent is detailed in section 9, paragraph 2.

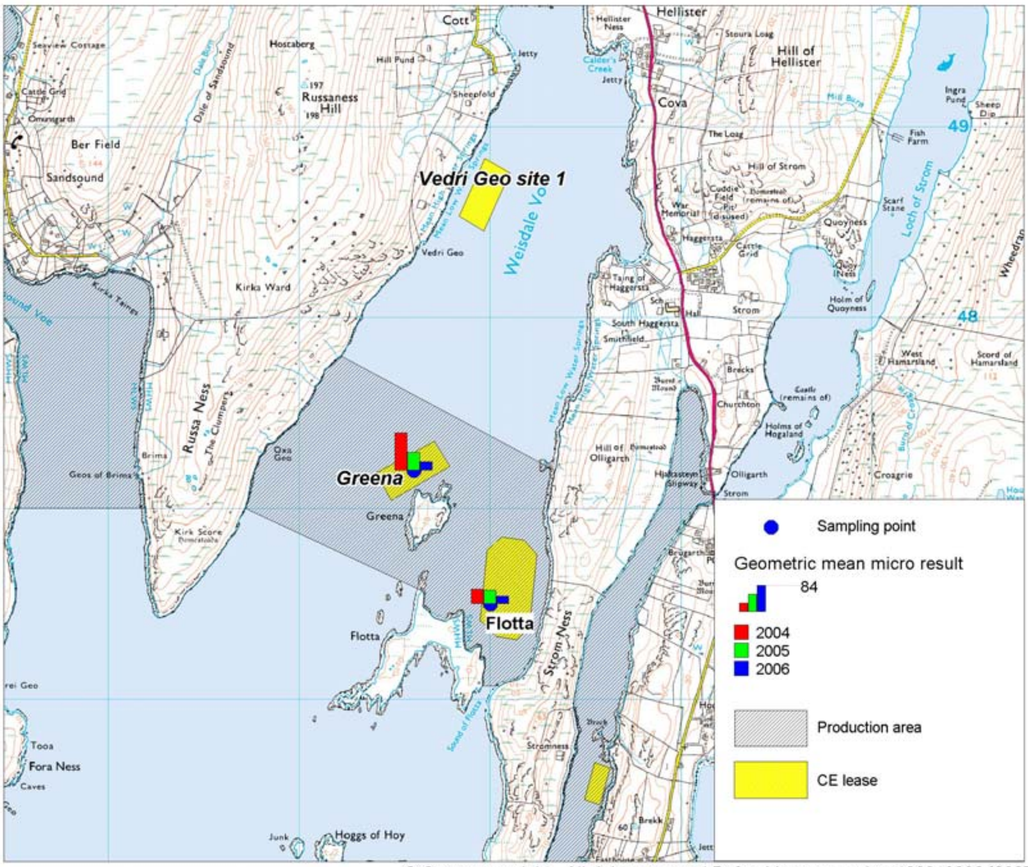


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Figure 11.1 - Map showing geometric mean result by year

Table 11.2 - Comparison of results (*E. coli* mpn) obtained from the 2 sites

	Flotta		Greena	
	Geometric mean	n	Geometric mean	n
2004	33.4	4	83.9	4
2005	30.5	12	39.0	8
2006	17.8	9	20.0	1
Total	25.5	25	46.9	13

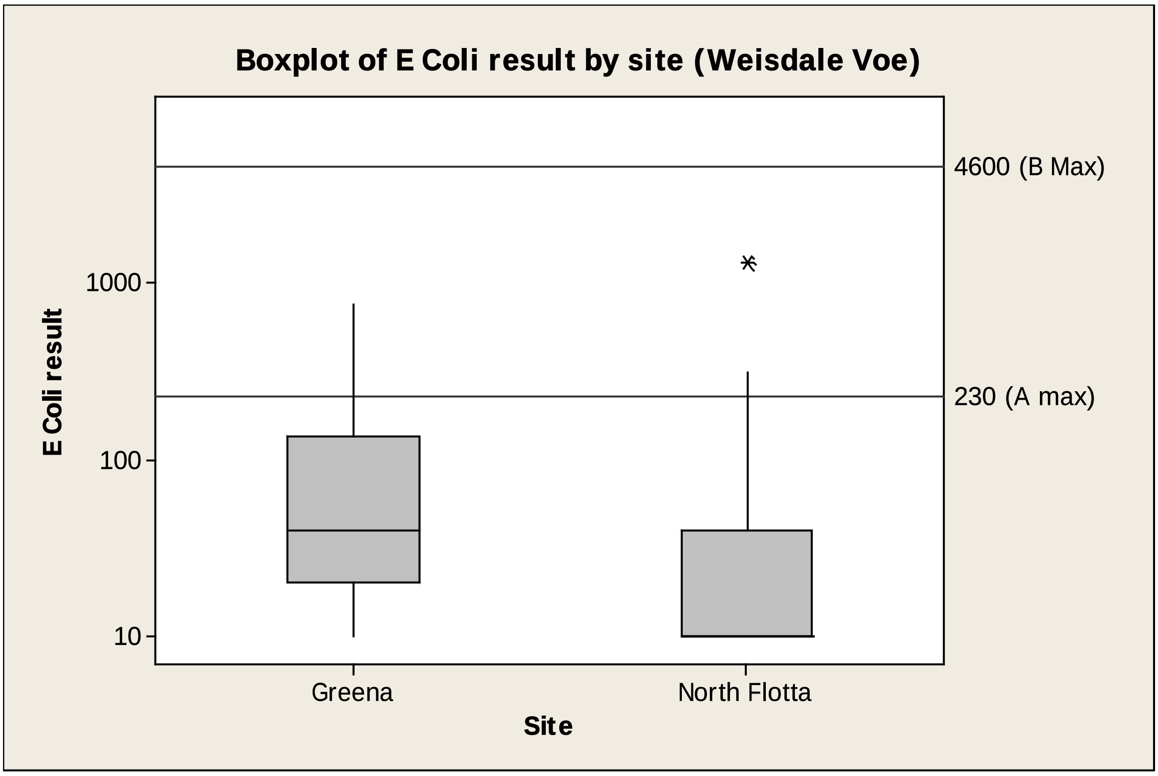


Figure 11.2

11.3 Temporal pattern of results

Figures 11.3 and 11.4 present scatter plots of individual results against date for all samples taken from Weisdale Voe (SI 297). Both are fitted with calculated lines to help highlight any apparent underlying trends or cycles. Figure 11.3 is fitted with a line indicating the geometric mean of the previous 5 samples, the current sample and the following 6 samples. Figure 11.4 is fitted with a loess smoother, a regression based smoother line calculated by the Minitab statistical software. Figure 11.5 presents the geometric mean of results by month (± 2 times the standard error).

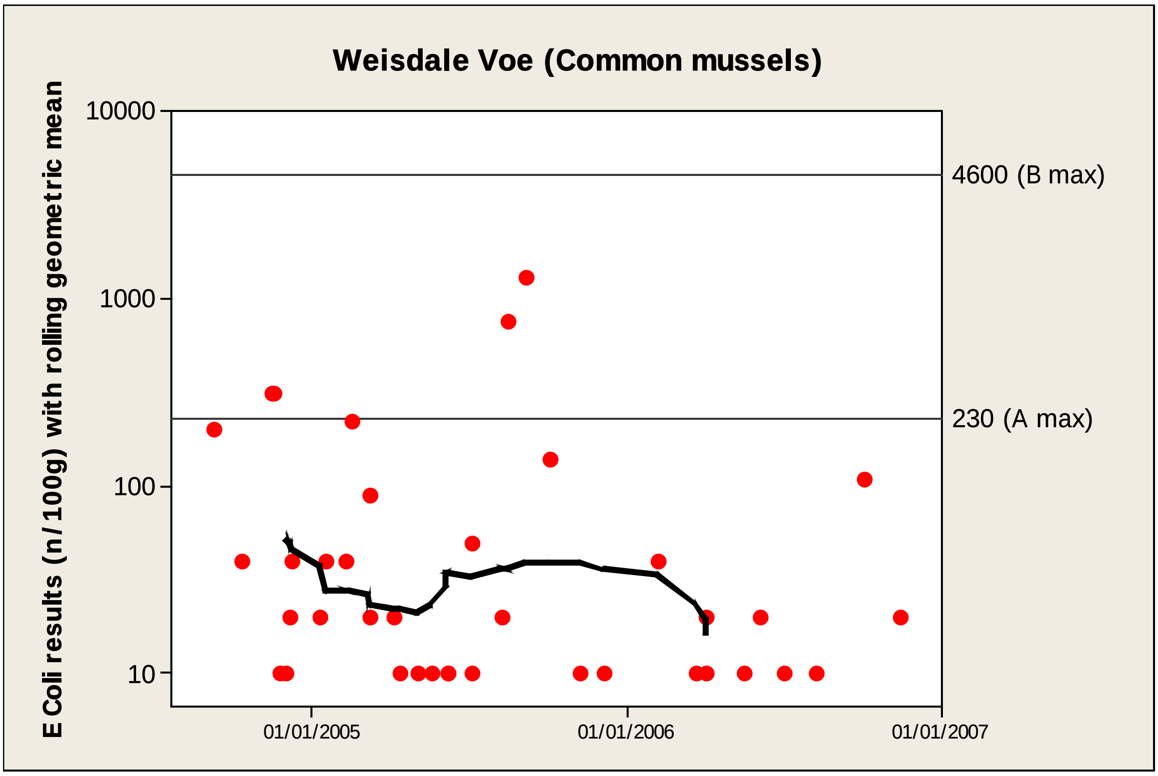


Figure 11.3 - Scatterplot of results by date with rolling geometric mean

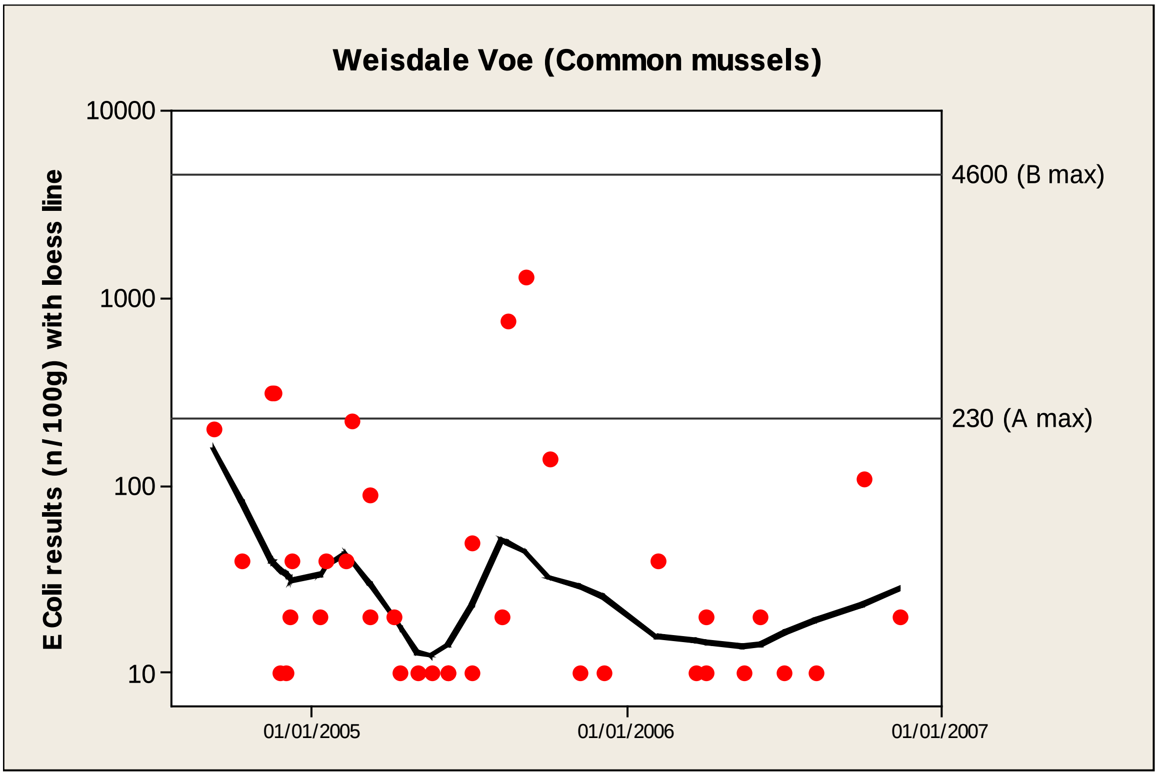


Figure 11.4 - Scatterplot of results by date with loess smoother

Tentatively, a slight underlying improvement can be seen in Figures 11.1, 11.3 and 11.4 although this is based on only 3 years data and a total of 38 samples and may just as likely be attributable to random fluctuations.

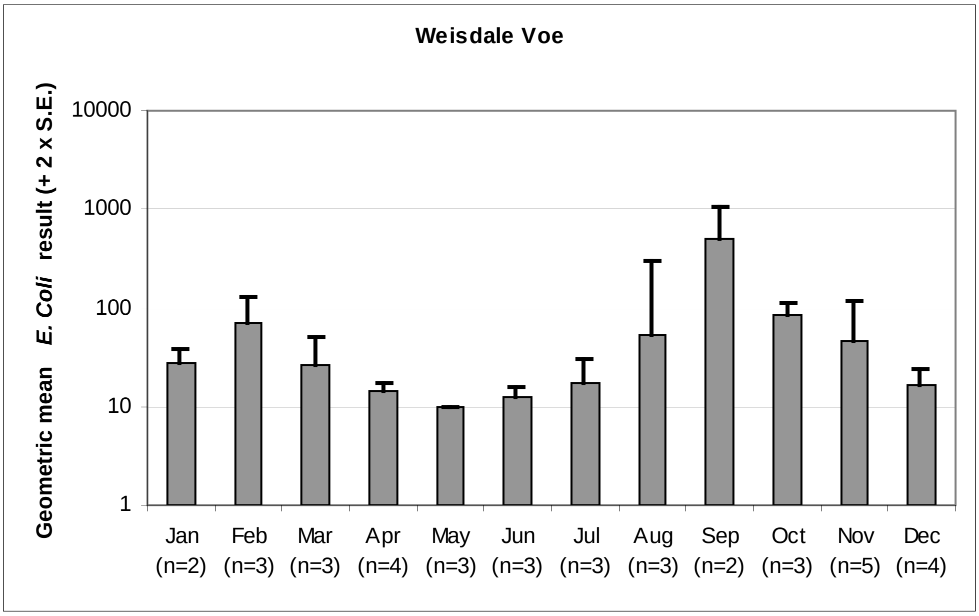


Figure 11.5 - Geometric mean result by month

Highest results were in September and October, but these results must be interpreted with caution due to the low number of samples taken.

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 38 samples taken from Weisdale Voe (SI 297) from the start of sampling in 2004 to the end of 2006.

<u>11.4.1 Analysis of results by season</u>

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).

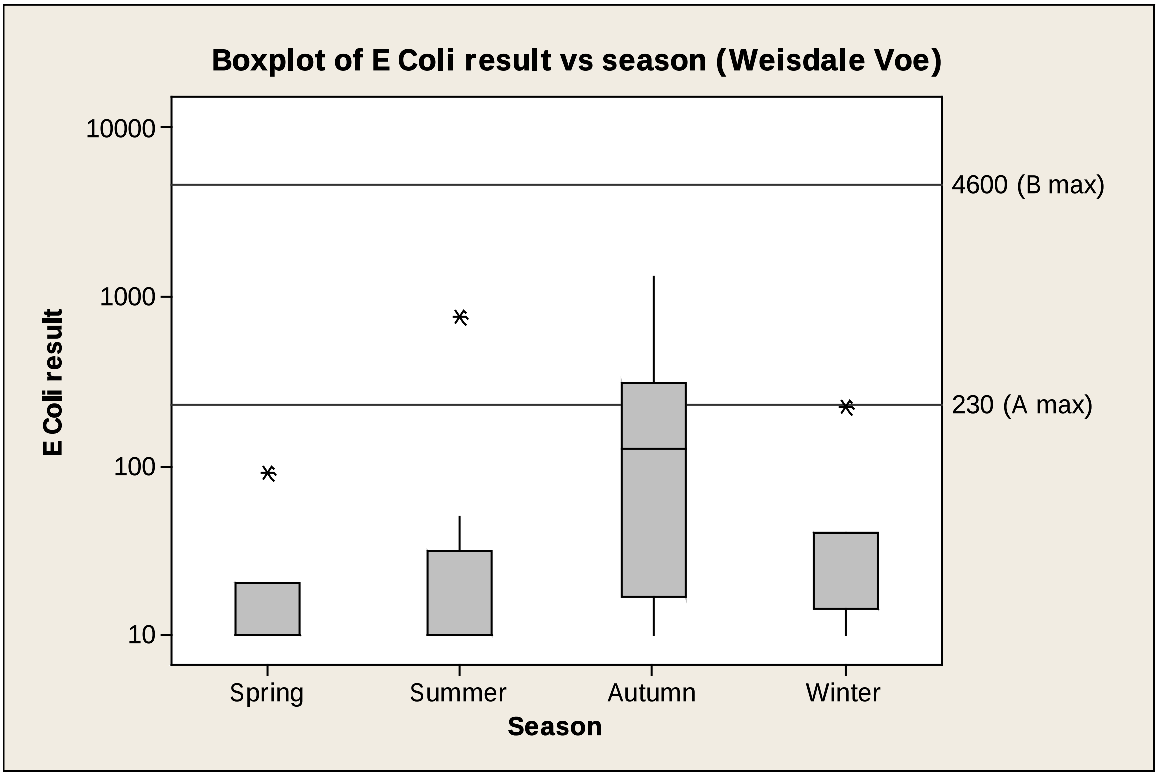


Figure 11.6

A seasonal effect was observed, with higher results in the autumn compared to all the other seasons. The seasonal effect is statistically significant (One-way ANOVA, p=0.02; Appendix 18.5). 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.

It is suggested that harvesting should take place outside of this period if possible, and this information be considered when seasonal classifications are decided upon.

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

The nearest weather station is Lerwick, approximately 9.5 km to the south east of the production area for which uninterrupted rainfall data is available for 2003-2006 inclusive.

Regression analysis was carried out to investigate the relationship between *E. coli* results and rainfall in the previous 2 days at Lerwick. Figure 11.7 presents a scatterplot of *E. coli* result and rainfall, with a best fit line derived by regression. Figure 11.8 presents a boxplot of results by rainfall quartile (quartile 1 being the lightest rainfall in the previous 2 days, and quartile 4 the heaviest).

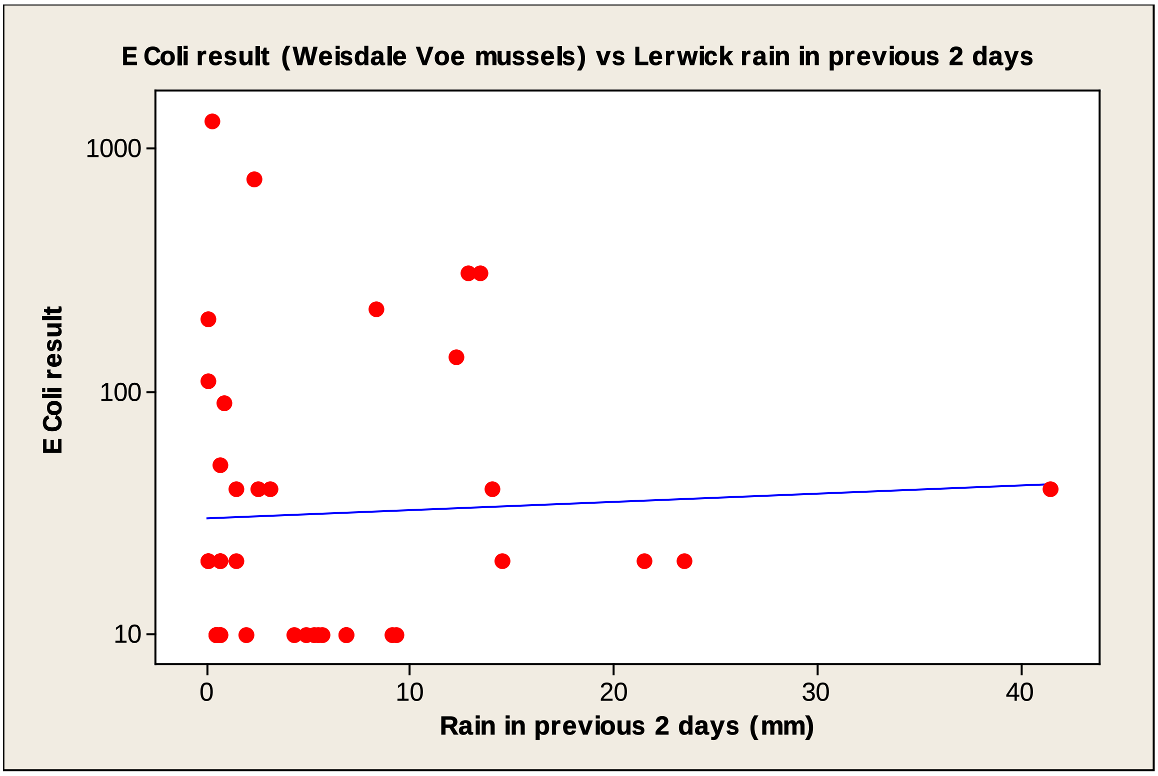


Figure 11.7

Regression analysis indicates that there is no relationship between the *E. coli* result and the rainfall in the previous two days (Adjusted R-sq=0.0%, p=0.775; Appendix 18.5).

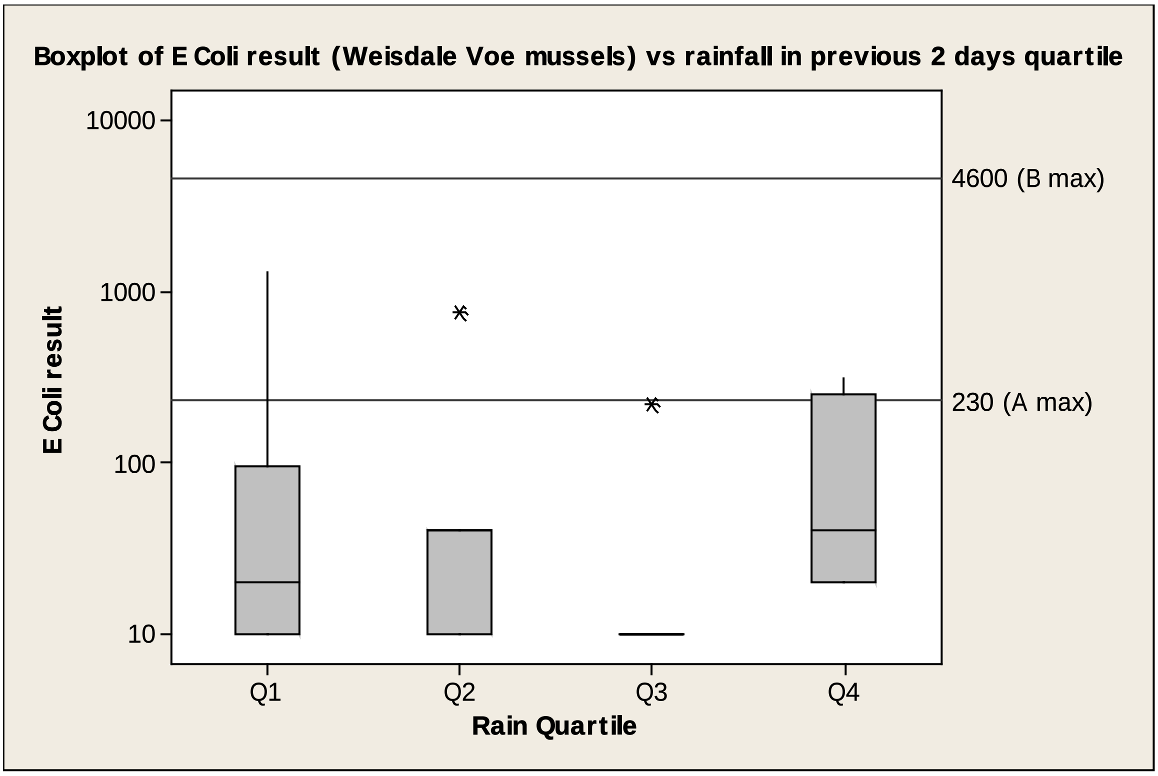


Figure 11.8
Again no relationship is apparent, and there was no statistically significant difference in result between the results for each rain quartile (One way ANOVA, p=0.164; Appendix 18.5).

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 Weisdale Voe was investigated in an identical manner to the above.

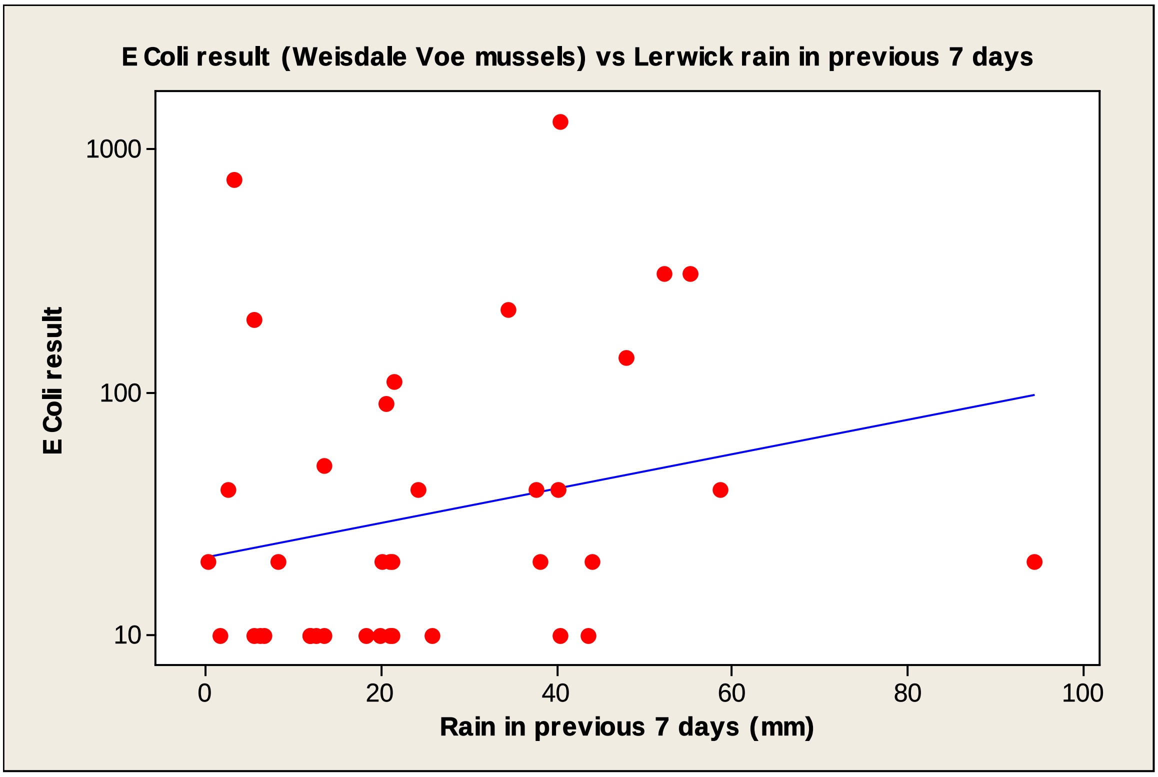


Figure 11.9

Regression analysis indicates that there is no statistically significant relationship between the *E. coli* result and the rainfall in the previous 7 days (Adjusted R-sq=3.1%, p=0.147; Appendix 18.5), but a weak positive relationship between the two can be seen in Figure 11.9.

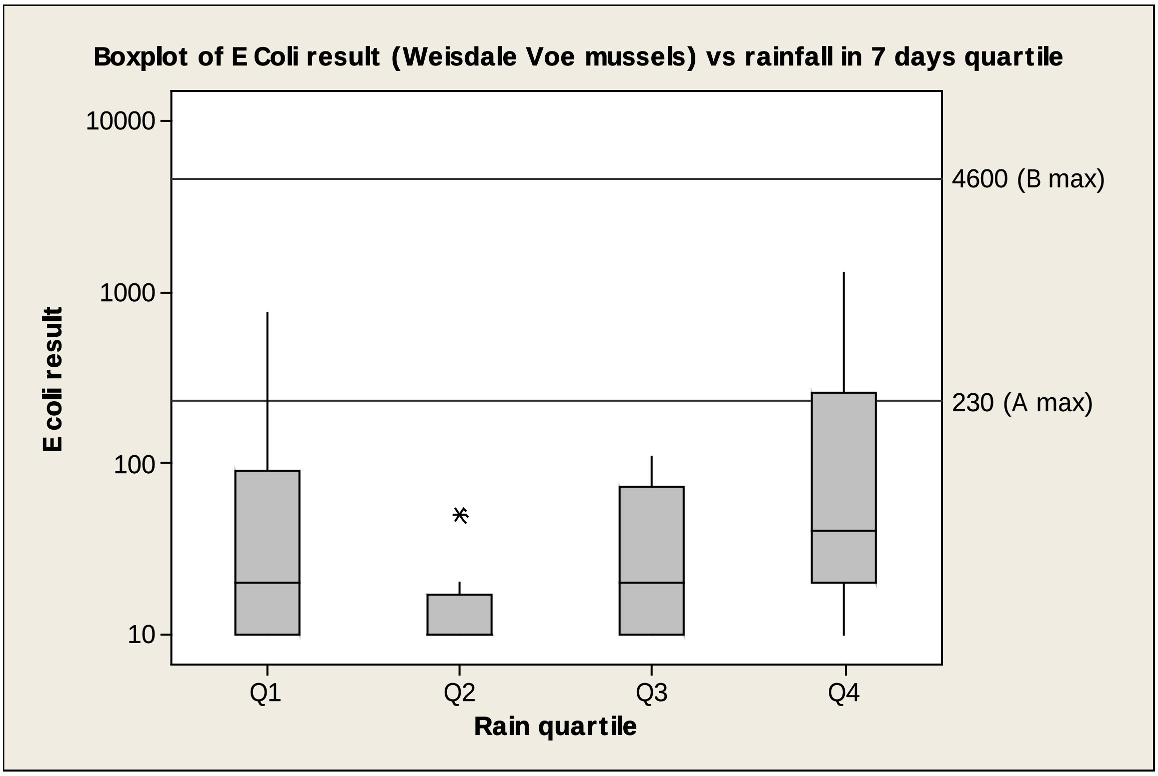


Figure 11.10

Again, there was no statistically significant difference between results for each quartile (One way ANOVA, p=0.078; Appendix 18.5). What figure 11.10 does show is that for quartiles 2-4 there is a positive relationship between rainfall and results, and that high results have also occurred in quartile 1 (lowest rainfall). Therefore although rainfall is clearly not the only factor causing high results, but highest rainfalls (quartile 4) may be associated with increased levels of contamination.

Overall, recent rainfall has only a very a slight effect of increasing the *E. coli* result when rain in the previous 7 days is considered, and no effect when rain in the previous 2 days is considered. The poor relationship may be due in part to differences in rainfall received in the Weisdale Voe catchment and at the weather station in Lerwick. Any rainfall related effects might be expected in the autumn and winter months when rainfall is at its' highest (see section 9).

<u>11.4.3 Analysis of results against lunar state</u>

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, ranging from 0.7 to 1.1m. Figure 11.11 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 11.11.

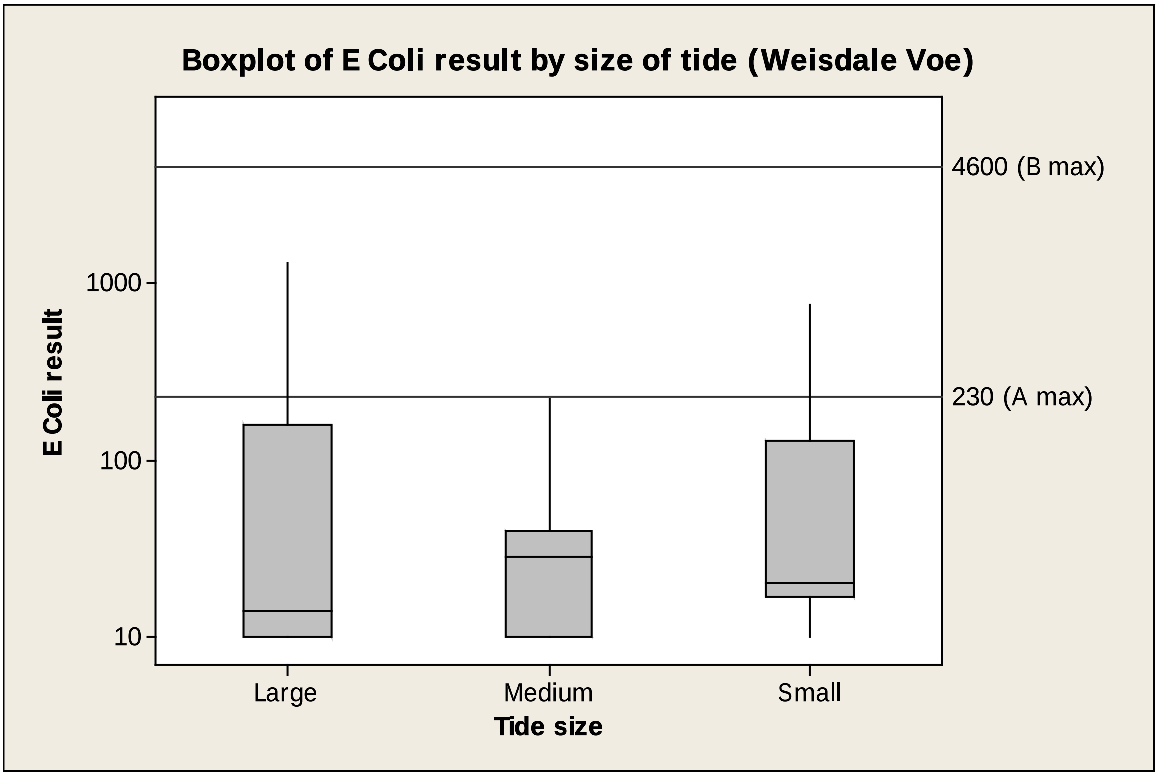


Figure 11.11

There was no statistically significant influence of tide size detected by this analysis (One way ANOVA, p=0.635; Appendix 18.5). This may be expected, as the tidal range is small and the voe is large and deep.

11.4.4 Water temperature

Water temperature is likely to affect the survival time of bacteria in seawater (Burkhardt *et al*, 2000) and presumably 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.

11.4.5 Wind direction

As discussed in section 9, wind speed and direction is likely to significantly change water circulation patterns in Weisdale 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 mean wind direction in the previous 7 days is plotted in Figure 11.12. Wind direction data was available for 32 of the 38 samples.

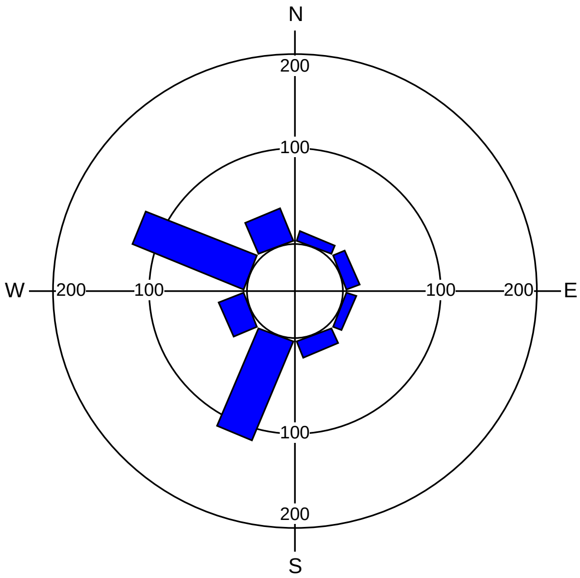


Figure 11.12 Circular histogram of mean *E. coli* result by wind direction

A significant correlation between wind direction and *E. coli* result was found (circular-linear correlation, r=0.39, p=0.012; Appendix 18.5). Results were higher when the wind was blowing from the west, suggesting that westerly winds may result in increased transport of faecal contamination into the production sites.

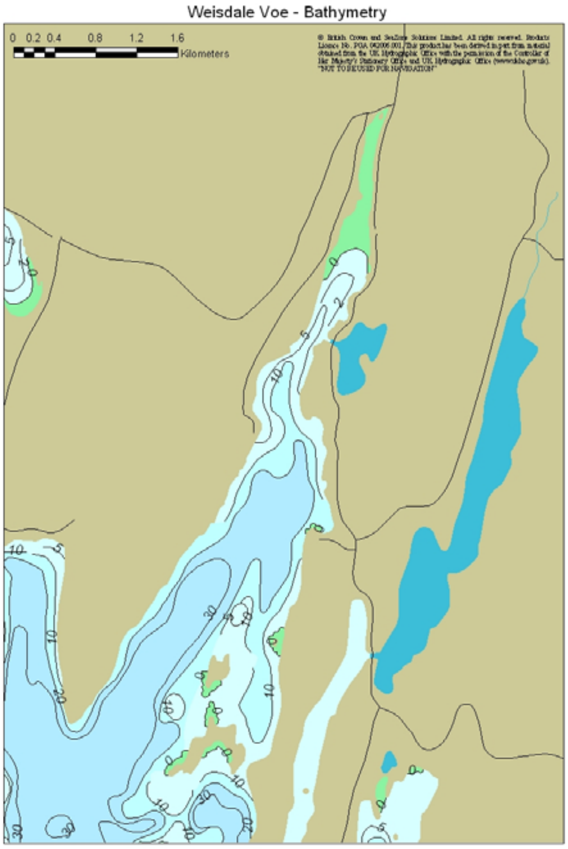
<u>11.4.6 Discussion of environmental effects</u>

All analyses presented in this section should be treated with caution due to the low number of samples considered (38). A strong seasonal effect was found, with results in the autumn being significantly higher than in other seasons. Very weak rainfall effects were also observed but not detected statistically. No influence of tide size was apparent. Westerly winds are associated with increased contamination, possibly due to increased circulation of contamination to the growing sites. 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.

12. Designated Shellfish Growing Waters Data

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

13. Bathymetry and Hydrodynamics



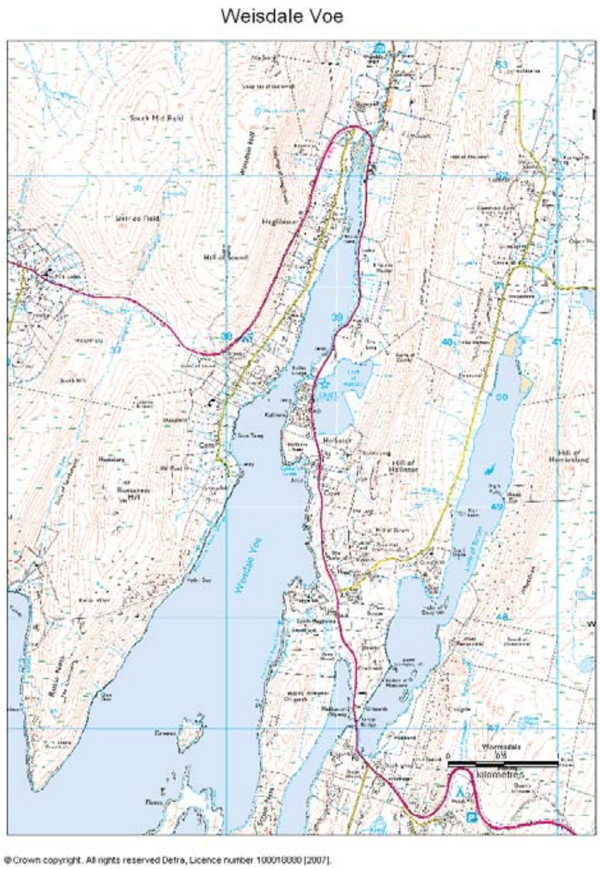


Figure 13.1

Figure 13.2

The chart (figure 13.1) above shows that the depth at datum in the middle of the voe ranges from less than 5 metres at the head to more than 30 metres in the vicinity of the most southerly extent of the Voe (see below) with the bottom shelving steeply at the edges away from the head. There is a significant length of drying area (approximately 300 m) at the head of the voe.

The following is the information from Edwards and Sharples (1986, as amended 1991).

Table 13.1 Weisdale Voe

O S Reference	HU360460
Chart number	3057
Chart scale	50000
Loch length (km)	6.7
Tidal range (m)	1.1
Maximum depth (m)	48.0
HW area (sq km)	5.0
LW area (sq km)	4.6
2m area (sq km)	3.9
5m area (sq km)	3.4
10m area (sq km)	2.9
LW Vol (million m3)	79.2
Watershed (sq km)	26
Annual rainfall (mm)	1200
Runoff (mm3/year)	24.4
K.E. Supply (Kw)	**
Mean depth at LW (m)	17.2
Fresh/tide, per thousand	9.4
Run off/width (m2/day)	93
Sill Data	There are no basins in this loch

The ratio of length to width (aspect) is given as 9.
The flushing time is given as 11 days – this is the 4th longest flushing time for Scottish lochs and voes given by the authors. Transport of material along the voe is therefore likely to be limited.

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 12/05/07, the date of the first part of the shoreline survey. The second is for seven days beginning 00.00 GMT on 19/05/07. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle.

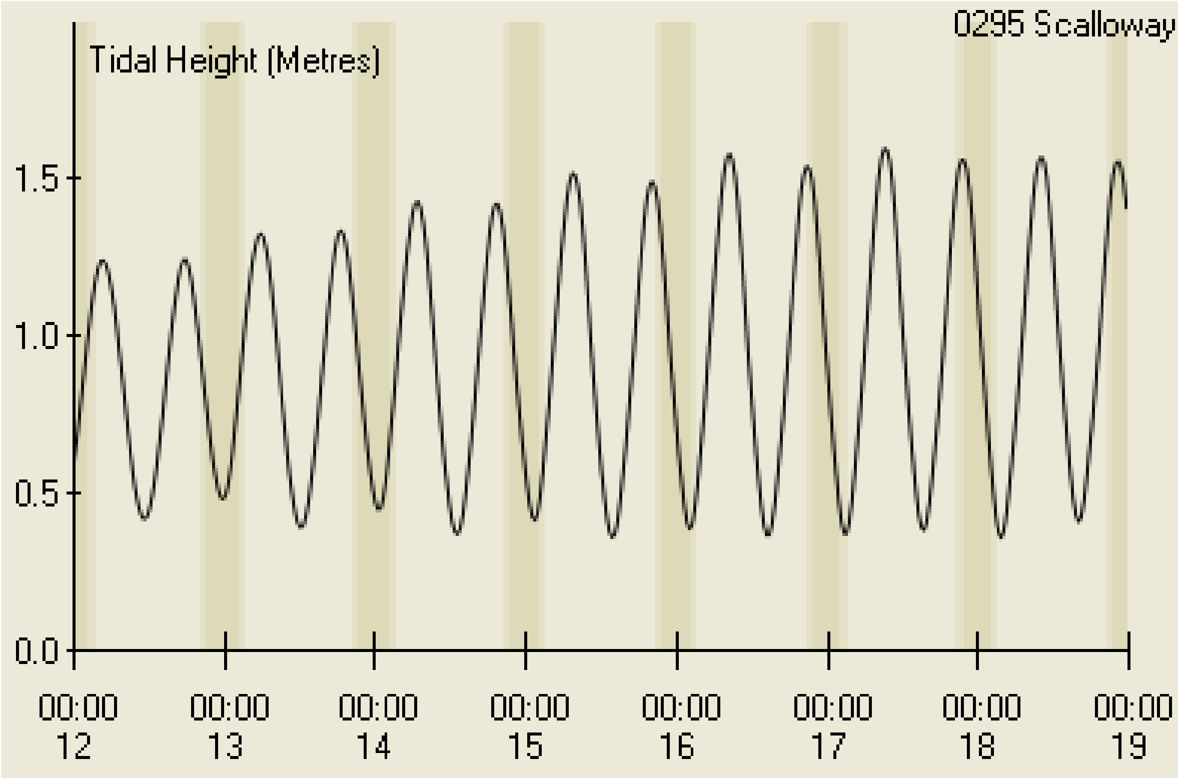


Figure 13.3

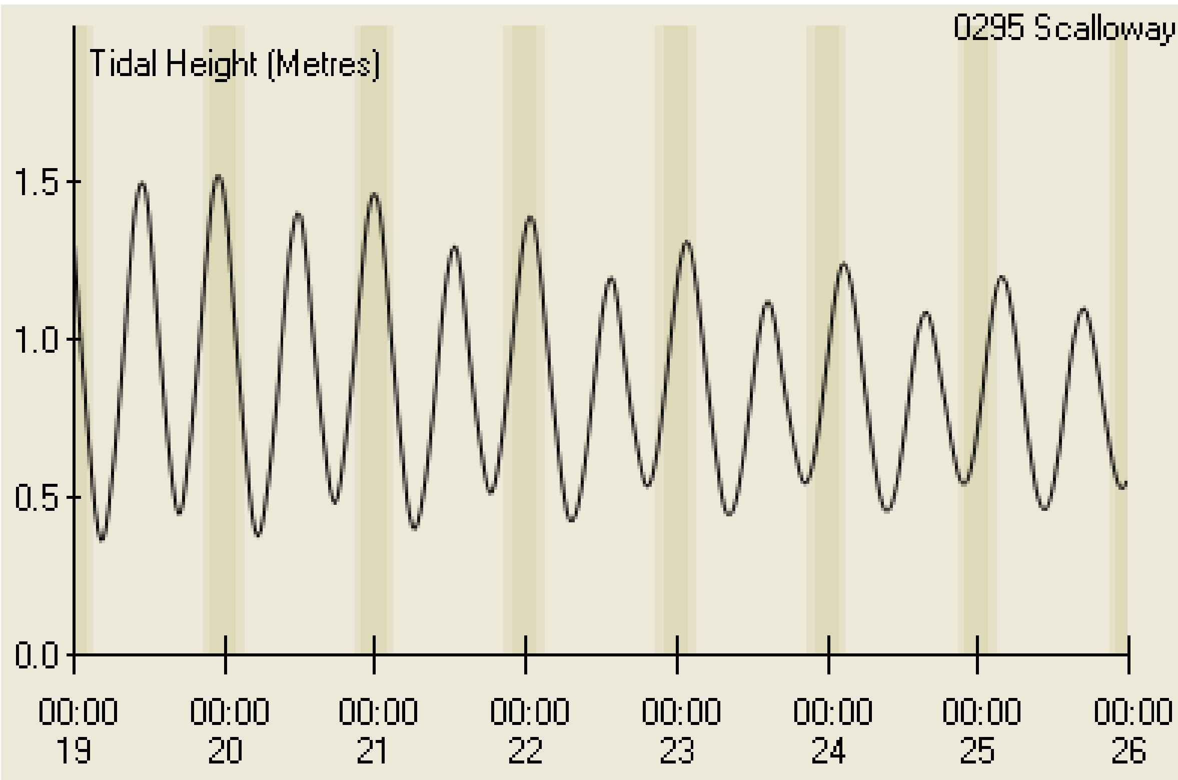


Figure 13.4

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 Weisdale Voe. Tidal currents are expected to be weak in the vicinity of the shellfish sites, as indicated by the extended flushing time (see above). Wind effects will therefore be significant. Currents in the vicinity of Greena and Flotta will be complex due to the effects of the islands.

Given the expected weak tidal currents in the area, small local sources of faecal contamination will be expected to have a significant effect compared to more remote sources. Also significant impact of faecal contamination arising from the upper Loch would be expected to be limited to the Vedri Geo site. The generally southerly to southwesterly winds would tend to keep any such contamination in the upper lays of the loch away from the shellfish sites.

14. River Flow Data

A gauging station was installed on the Burn of Weisdale at Weisdale Mill and recorded flow data is available from January 2005.

The Burn of Weisdale drains a catchment area of 12.6 km2 and empties into the head of Weisdale Voe 2.5km northeast of the Vedri Geo mussel site. Mean flows for the period by month are summarised in Table 14.1.

Table 14.1 Mean flow (m^3/s)

Month	**2005**	**2006**	**2007**
Jan	1.279	.757	1.97
Feb	.915	.517	1.43
Mar	.932	1.069	.639
Apr	.360	.515	.322
May	.187	.151	.163
Jun	.540	.112	.052
Jul	.231	.090	.033
Aug	.825	.377	
Sep	1.27	.362	
Oct	1.312	1.933	
Nov	1.135	1.531	
Dec	.754	1.148	

Recorded flow data show that the highest river flows occur in autumn and winter, with a substantial increase occurring between July and August. However, there are only two and a half years recorded data at this station, which is not sufficient history from which to draw firm conclusions.

15. Overall Assessment

Weisdale 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 the highest 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 Weisdale Voe, it is possible that local rainfall conditions were not accurately reflected in the Lerwick data.

<u>Human Sewage Impacts</u>
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. During the shoreline survey conducted at Weisdale Voe, one private septic tank was observed to have overflown with solid waste in evidence on the ground around the tank. 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 Weisdale 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. This coincides with the known and observed septic tank discharges in the area as can be seen in Figure 4.1. Soils on this side of the voe are classed as freely draining (Figure 5.1) though a review of landcover shows that this area also has the highest concentration of developed land and hardstanding which would contribute higher loadings of faecal bacteria in rain runoff. Effluent from properly functioning septic tanks would be unlikely to wash into the voe with surface runoff.

Though there is little in the way of tourist accommodation and facilities around the voe, there is a gallery and café at Weisdale Mill that would be expected to draw visitors during the summer season.

<u>Agricultural Impacts</u>
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 the northwestern shore of the voe. Land cover here (Figure 6.1) is predominantly improved grassland, which has been shown to provide a moderate contribution to faecal coliform loadings in runoff. The soils along this side of the voe are poorly

draining, indicating a greater likelihood of surface runoff and this 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. SEERAD have 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 whales, 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 areas, these are not considered to be a significant contributor to contamination levels. Seabirds may be contributors, with northern fulmar colonies located at the head of the loch, as well as on Greena and Flotta islands. Any affect from these would be most acute at the Greena and Flotta sites. All sites are likely to receive faecal inputs from birds such as cormorants, gulls, and arctic terns that roost 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 occurs in the upper reaches, and during prevailing southwesterly winds this would tend to be entrained toward the head of the voe and away from the mussel production areas. During a northerly wind, however, contamination may drift further out into the voe and would affect the Vedri Geo site first.

The Weisdale Voe Upper site is likely to see slightly higher levels of faecal contamination than the sites in the Weisdale Voe production area as it lies in closer proximity to the septic tanks and communities at the head of the voe.

The Vedri Geo site lies just to the south of the main populated areas of the voe and slightly north and west of the southernmost community septic discharge. Due to its location, it is likely to be impacted by these discharges. The Greena and North Flotta sites lie well to the south and would be less likely to be affected by contamination from these sources.

No significant difference was seen in historical *E. coli* results between samples taken from the Greena and Flotta sites. They are subject to the similar influences from shore-based contamination, however the Flotta site is more likely to be impacted as contaminants could tend to become entrained in the area under some weather conditions.

Faecal contamination due to runoff from land used to graze sheep is highly likely to impact the Vedri Geo site due to its proximity to the crofts. The Greena and North

Flotta sites, while impacted, would be expected to see less contamination due to distance from the areas where livestock will be most concentrated. These sites would receive contamination from livestock grazing on the shores to either side of the production area, but this covers a more limited area.

During the shoreline survey, it was noted that there was little stock on the Vedri Geo site for sampling and that harvest would not be possible in the coming year. For this reason, a bacteriological survey will be conducted using bagged shellfish during spring 2008 to assess whether a provisionally assigned RMP is best reflecting the sources of contamination at the site.

It was not possible to compare samples taken at different depths during the shoreline survey due to insufficient stock on the lines. However, results indicated low levels of bacterial contamination in all samples on this occasion.

The highest levels of *E. coli* contamination found in water samples taken during the shoreline survey came from samples taken at or near private septic tank discharges on the eastern shore of the voe. These are small in volume and likely to have a highly localised effect. One of these lies just under one kilometre to the northeast of the Vedri Geo production area. Due to prevailing wind conditions and postulated hydrodynamics within the voe, in most cases this contamination would be expected to travel to the northeast, avoiding the production areas.

Seasonal Variation

There is a strong seasonal component to the monitoring results, showing higher levels of contamination in August and September. This tends to coincide with three events: an increase in historical average rainfall beginning in August, peak numbers of sheep on grazing as lambs have not yet been sent to market, and peak tourist season.

The harvesters in Weisdale Voe have historically not harvested during August and September. Often, these months coincide with biotoxins closures and so the risk to human health due to higher *E. coli* levels at this time is limited.

The classification history of the existing production area shows that the classifications have been substantially adjusted, with the area currently classified B during August and September.

Meteorology and Movement of Contaminants

Analysis of wind and rainfall indicated a positive 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 and freshwater input from the Burn of Weisdale at the head of the voe may ride over the denser salt layer in certain conditions. 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.

16. Recommendations

Based on analysis in the sections above, it is recommended that two production areas be retained with the Weisdale Voe Upper area containing the Vedri Geo site. A provisional RMP is recommended for the Weisdale Voe Upper production area at HU 37960 48710. Best practice would be to place bagged shellfish at a depth of 1metre within a 10m radius of this grid reference as this will provide for a consistent sampling location. The location of the sampling point lies to the northern end of the existing mussel lines and would allow for detection of contamination moving down the voe from the main sources further to the north and east as well as detecting contamination coming from land runoff to the northwest. See Figure 15.1.

A production area boundary is recommended as illustrated in the figure to abut the existing Weisdale Voe area and to extend just past the northern edge of the Vedri Geo site. It is recommended that the existing RMP at Flotta be retained, but specified to 10m accuracy. A more accurate grid reference has been proposed that lies on the fishery.

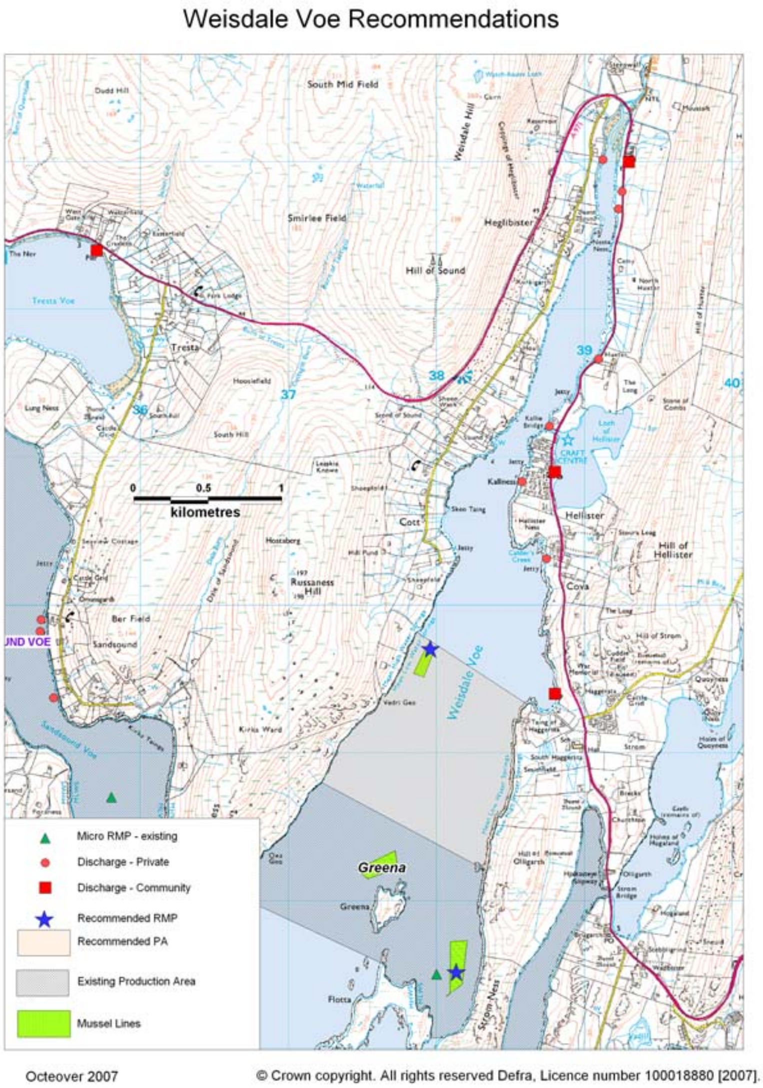


Figure 16.1

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Appendices

18.1 Shoreline Survey Report
18.2 Sampling Plan
18.3 Data Tables
18.4 List of Tables and Figures

18.1 Shoreline Survey Report

Weisdale Voe and Weisdale Voe Upper
SI 378 and SI 297

Scottish Sanitary Survey Project

Prod. area:	Weisdale Voe, Weisdale Voe Upper
Site name:	Vedri Geo (SI 378 768), Greena (SI 297 468), Flotta (SI 297 469)
Species:	Common mussels
Harvester:	Demlane; S. Hawkins
Local Authority:	Shetland Islands Council
Status:	Weisdale Voe Upper – New Application

Date Surveyed:	12-14, 16 May
Surveyed by:	Michelle Price-Hayward and Alastair Cook
Existing RMPs:	North Flotta HU380465
Area Surveyed:	See map in Figure 1

Weather
Partly cloudy with intermittent showers over period. Winds W-NW force 2-5

Site Observations

Fishery

This survey was triggered by the application for harvesting at the Vedri Geo site. This is located further up the Voe than the existing sites at Greena and Flotta. There were four long lines on site at the time of survey, however, the lines appeared to have been stripped and had a heavy covering of algae and few mussels of appreciable size. The harvester indicated the site had been scheduled for harvest next year but that it would not be possible with the growth observed.

The Greena and Flotta sites were both located further down the voe. A flock of 80-100 eider ducks were observed feeding on the Greena site during sampling on 13 May. The lines at Greena had also been stripped and samples were taken from the top 1m only.

The Flotta site had recently been harvested, though the harvester and the OC Sampling officer provided samples from the site on 16 May. It was not possible to arrange sampling earlier due to technical difficulties with the harvester's equipment.

Sewage/Faecal Sources

The Burn of Weisdale empties into the head of Weisdale Voe. Above where it meets the voe, there is a weir and SEPA gauging station. A fish hatchery is located across from Weisdale Mill. A sample was taken from the burn on the day of survey.

Two permitted discharges from septic tanks were reported to discharge directly into Weisdale Voe: one at Swedish Houses Weisdale (HU 39305200) and the other at Clach-na-Strom Whiteness (HU 388484). A third septic tank at Kalliness West Weisdale (HU 38804990) discharges into the Loch of Hellister, which connects to Weisdale Voe 1.7km north east of the Vedri Geo site. These discharges were not directly observed.

A number of individual homes with private septic tanks were observed around the voe. Evidence of raw sewage overflow was observed next to one of these septic systems (Table 18.1, 57). This was reported to both the local authority and to SEPA for follow up.

Sheep droppings were observed around the voe and also on the shoreline.

Seasonal Population

There is little in the way of seasonal accommodation in the area and no campsites or caravan parks were seen during the survey. There is a gallery and café at Weisdale Mill and a shop and tourist centre at Kalliness both of which would draw tourists in summer.

Boats/Shipping

Aside from boats used to work the mussel farms, there was little not other boating observed within the voe. The Clyde Cruising Guide mentions an achorage at the head of the voe, however no boats were observed to be anchored in the area on the day of the survey.

Land Use

The land around Weisdale Voe is used primarily for grazing sheep. There are a number of crofts located around the voe, most of which have sheep on them. Sheep numbers were recorded in the observations table and 219 were counted from the shoreline but due to the hilly nature of the landscape, it is probable that there were many more sheep outside of the range of view.

Wildlife/Birds

A seal was observed during the boat survey of the Voe. A large flock of Eider Ducks (75 birds) were observed feeding near the mussel farm at Greena.

A few cormorants and other birds were seen, but not in appreciable numbers.

Specific observations taken on site are mapped in Figures 18.1 and 18.2 and listed in Table 18.1.

Figure 18.1

Weisdale Voe Survey Points

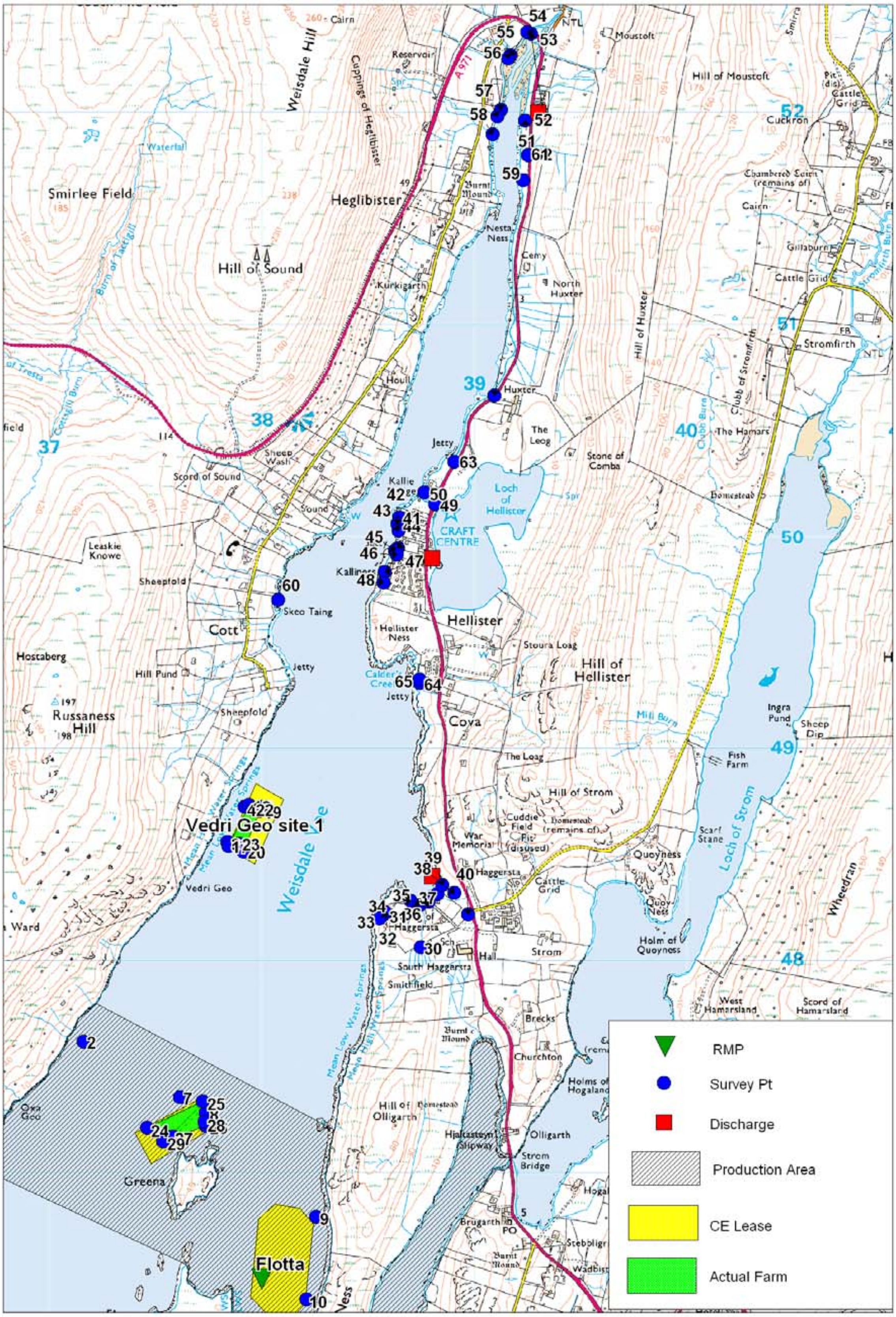

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Table 18.1 Shoreline Observations

No.	Date	NGR	Photograph	Notes
1	12/05/2007	HU 36314 46337		Northeast of headland at Russa Ness. 15 sheep, 17 ducks, 2 cormorants
2	12/05/2007	HU 37160 47619		10 sheep
3	12/05/2007	HU 37838 48559	Figure 18.4	mussel floats start 1 cormorant
4	12/05/2007	HU 37919 48725		mussel floats end
5	12/05/2007	HU 37990 48727		cormorant
6	12/05/2007	HU 37990 48726		75 eider ducks, 3 mussel ropes, 6 cormorants
7	12/05/2007	HU 37613 47355		corner of ropes (3)
8	12/05/2007	HU 37734 47284		corner of ropes (3)
9	12/05/2007	HU 38255 46792		corner of ropes (7)
10	12/05/2007	HU 38210 46404		corner of ropes (7). 20 sheep on little island
11	12/05/2007	HU 37748 45540		8 salmon cages and barge
12	12/05/2007	HU 36132 47065		41 sheep 2 ducks
13	12/05/2007	HU 35409 48373		overflow pipe to shore from houses
14	12/05/2007	HU 35320 48823		overflow pipe to shore from houses
15	12/05/2007	HU 35326 48903		overflow pipe to shore from houses, 50 sheep
16	12/05/2007	HU 35413 49400		rest of shoreline from here was covered on foot
17	13/05/2007	HU 37843 48540		Corner of Vedri Geo ropes (4 in total)
18	13/05/2007	HU 37938 48734		Corner of Vedri Geo ropes
19	13/05/2007	HU 37989 48708		Corner of Vedri Geo ropes
20	13/05/2007	HU 37914 48514		Corner of Vedri Geo ropes
21	13/05/2007	HU 37889 48551		Vedri Geo water sample 1 (35ppt, 9.0C)
22	13/05/2007	HU 37954 48719		Vedri Geo water sample 2 (35ppt, 9.0C). Vedri Geo mussel sample 1 taken from all depths (0-8m) as very few mussels on rope and of these not many were big enough
23	13/05/2007	HU 37889 48551		Vedri Geo mussel sample 2 taken from all depths (0-8m)as few mussels on ropes
24	13/05/2007	HU 37458 47211		North West Greena corner
25	13/05/2007	HU 37720 47336		North West Greena corner
26	13/05/2007	HU 37735 47221		North West Greena corner
27	13/05/2007	HU 37579 47169		North West greena water sample 1 (9.1C, 34.9ppt) and mussel sample 1 (1m depth). Ropes had been stripped by ducks and remaining mussels in top 1m of water only
28	13/05/2007	HU 37730 47241		North West greena water sample 2 (9.1C, 34.9ppt) and mussel sample 2 (1m depth). Ropes had been stripped by ducks and remaining mussels in top 1m of water only
29	13/05/2007	HU 37535 47147		North West Greena corner
30	14/05/2007	HU 38748 48063		40 sheep

31	14/05/2007	HU 38578 48221	Figure 18.8	Pile of straw from stable dumped on clifftop
32	14/05/2007	HU 38579 48231		surface water drain pipe from concrete yard and stock shed not flowing at the time
33	14/05/2007	HU 38554 48198		Weisdale water sample 1 35ppt
34	14/05/2007	HU 38700 48284		small jetty, 3 moorings, 1 small boat
35	14/05/2007	HU 38742 48261		12" concrete pipe from field drain flowing very slightly. Water sample Weisdale 2 (34.5ppt)
36	14/05/2007	HU 38784 48279	Figure 18.9	Small surface water input from 4" plastic pipe run under road from field. Water sample weisdale 3 (fresh)
37	14/05/2007	HU 38827 48314		Small freshwater stream
38	14/05/2007	HU 38904 48321		Water mains box ignore
39	14/05/2007	HU 38848 48358		Septic tank overflow pipe to beach, not flowing
40	14/05/2007	HU 38969 48218		Septic tank cover? Concrete
41	14/05/2007	HU 38647 50090		4" orange plastic pipe to shoreline dripping. Possibly septic overflow.
42	14/05/2007	HU 38636 50061		4" orange plastic pipe to shoreline dripping. Possibly septic overflow
43	14/05/2007	HU 38643 50029		Very small freshwater stream, not sampled or measured
44	14/05/2007	HU 38640 49948		Some small surface water pipes. Not flowing, appear to provide drainage from private patio
45	14/05/2007	HU 38626 49935		Weisdale water sample 4, salinity 33 ppt
46	14/05/2007	HU 38634 49915		Very small freshwater stream through pipe
47	14/05/2007	HU 38577 49835		Possible septic overflow from orange pipe flowing about 10ml per second. Weisdale water sample 5, fresh water.
48	14/05/2007	HU 38572 49783		3" black pipe surface water drain. There are about 100 houses in this settlement.
49	14/05/2007	HU 38815 50153		Weisdale water sample 6 from water body on other side of road, salinity 20ppt. This must be inundated with salt water at high tide, but at the time of sampling a stream was flowing under the road from it to Weisdale Voe.
50	14/05/2007	HU 38764 50208	Figure 18.10, 18.11	2 septic tank overflows direct into sea either side of the stream. One leaking raw sewage including solids onto shore around base of tank. Weisdale water sample 7 taken from bay, salinity 24ppt.
51	14/05/2007	HU 39237 51963		Small stream – measured 30cmx5cm flowing at 0.3 m/s. Weisdale water sample 8 fresh. 8 houses on shoreline. About 60 sheep in area including 3 on shoreline
52	14/05/2007	HU 39267 52372		River – measured 7.5mx5cm flowing at 0.4m/s. Weisdale water sample 9 fresh.
53	14/05/2007	HU 39250 52381		Small amount of old sanitary debris (cotton buds) in highest tideline deposit.
54	14/05/2007	HU 39171 52271		Stream - measured 0.6mx7cm flowing at 0.5m/s. Weisdale water sample 10, fresh
55	14/05/2007	HU 39160 52256		3 sheep and 3 ducks on beach as well as fresh sheep droppings
56	14/05/2007	HU 39125 52014		Septic tank discharge pipe not running possibly serving 8 houses. Water sample weisdale 11 20ppt
57	14/05/2007	HU 39107 51982		Small stream, not measured or sampled

58	14/05/2007	HU 39086 51899		Small stream, not measured or sampled
59	14/05/2007	HU 39229 51682	Figure 18.16	Septic tank to 6" metal pipe discharging to low tide mark. Weisdale water sample 12(30ppt) tanke next to pipe.
60	14/05/2007	HU 38075 49702		Weisdale water sample13, salinity 35ppt. Additional 23 houses dotted along this shore all are some disatance (200m plus) from shore, all probably on individual septic tanks. At least 61 sheep also and one sheep pen on roadside
61	14/05/2007	HU 39253 51799		Roadside layby next to septic tank (looked like a scottish water one, but no labels)
62	14/05/2007	HU 39095 50666	Figure 18.14	Septic overflow pipe from farmhouse, trickling into voe. Weisdale water sample14, salinity 30ppt taken next to pipe.
63	14/05/2007	HU 38906 50353		2 sheds, 1 jetty and 2 small boats.
64	14/05/2007	HU 38742 49311		Settlement of about 29 houses with one septic outfall flowing about 1 l/min. Weisdale water sample 15, salinity 32ppt taken next to pipe.
65	14/05/2007	HU 38742 49328		Small stream, not sampled or measured.

Photos referenced in the table can be found attached as Figures 18.4-18.17.

General Observations Relevant to Site

Sheep droppings were widely distributed in the area. A discussion with the local agricultural office confirmed that sheep are generally allowed to roam fairly freely with access to the shoreline. Some farmers in the area graze their sheep on seaweed at the shoreline as this produces meat with a distinctive flavour that can be sold as a specialty product. During the winter, sheep will naturally tend to feed on seaweed at the shoreline as grazing becomes scarce on the crofts.

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 Shetland due to soil conditions and climate so most of the crofts graze sheep or, more rarely, cattle. With changes occurring in the system of paying subsidies on sheep, the agriculture office anticipates a continued decline in the number of sheep grazed on Shetland during the next few years.

Homes in the area are widely distributed and do not appear to be on any 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 pumpout service, for which it has recently begun to charge a fee.

Water and shellfish samples were collected at sites marked on the map. Bacteriology results follow in Tables 18.2 and 18.3.

Table 18.2 Water Sample Results

No.	**Sample**	***E. coli* (cfu/ 100ml)**	**Salinity (g/L)**
1	Weisdale 1	3	28.6
2	Weisdale 2	100	27.6
3	Weisdale 3	15	0.5
4	Weisdale 4	1	25.3
5	Weisdale 5	10	1.3
6	Weisdale 6	6	16.1
7	Weisdale 7	30	19.4
8	Weisdale 8	8	1.3
9	Weisdale 9	90	0.8
10	Weisdale 10	20	0.2
11	Weisdale 11	70	17.3
12	Weisdale 12	$> 3 X 10^5$	25.4
13	Weisdale 13	<1	29.2
14	Weisdale 14	<1	25.5
15	Weisdale 15	$> 3 X 10^5$	27.5
16	Greena 1	<1	29.1
17	Greena 2	<1	29.6
18	Vedri Geo 1	<1	29.8
19	Vedri Geo 2	<1	28.4

Table 18.3 Shellfish Sample Results

No.	Sample	Type	*E. coli* (cfu/100 g)	Depth
1	Greena 1	Mussel	<20	<1m
2	Greena 2	Mussel	<20	<1m
3	Vedri Geo 1	Mussel	<20	0-8m
4	Vedri Geo 2	Mussel	<20	0-8m
5	Flotta	Mussel	<20	3m

Figure 18.2

Weisdale Voe Water Samples

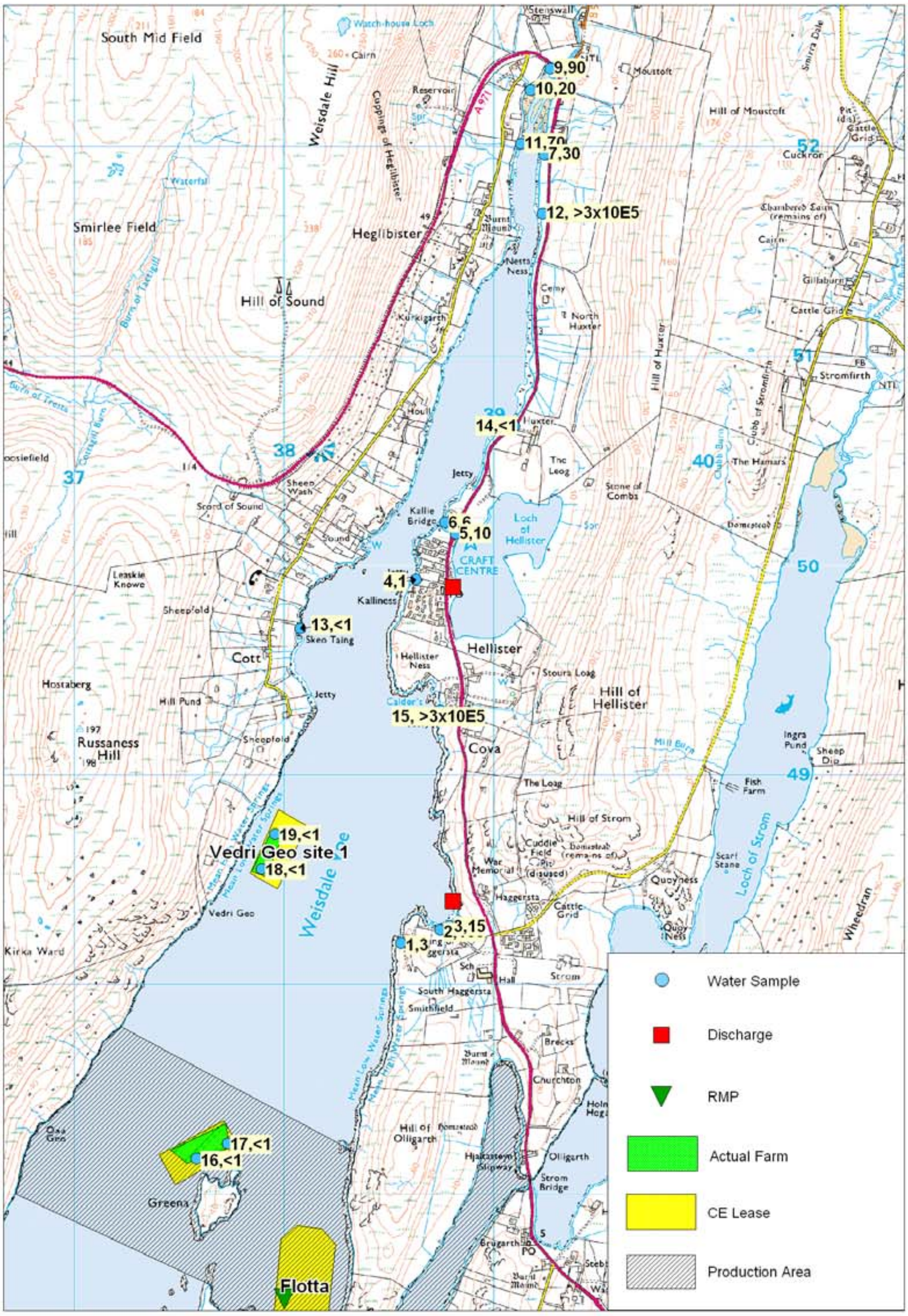

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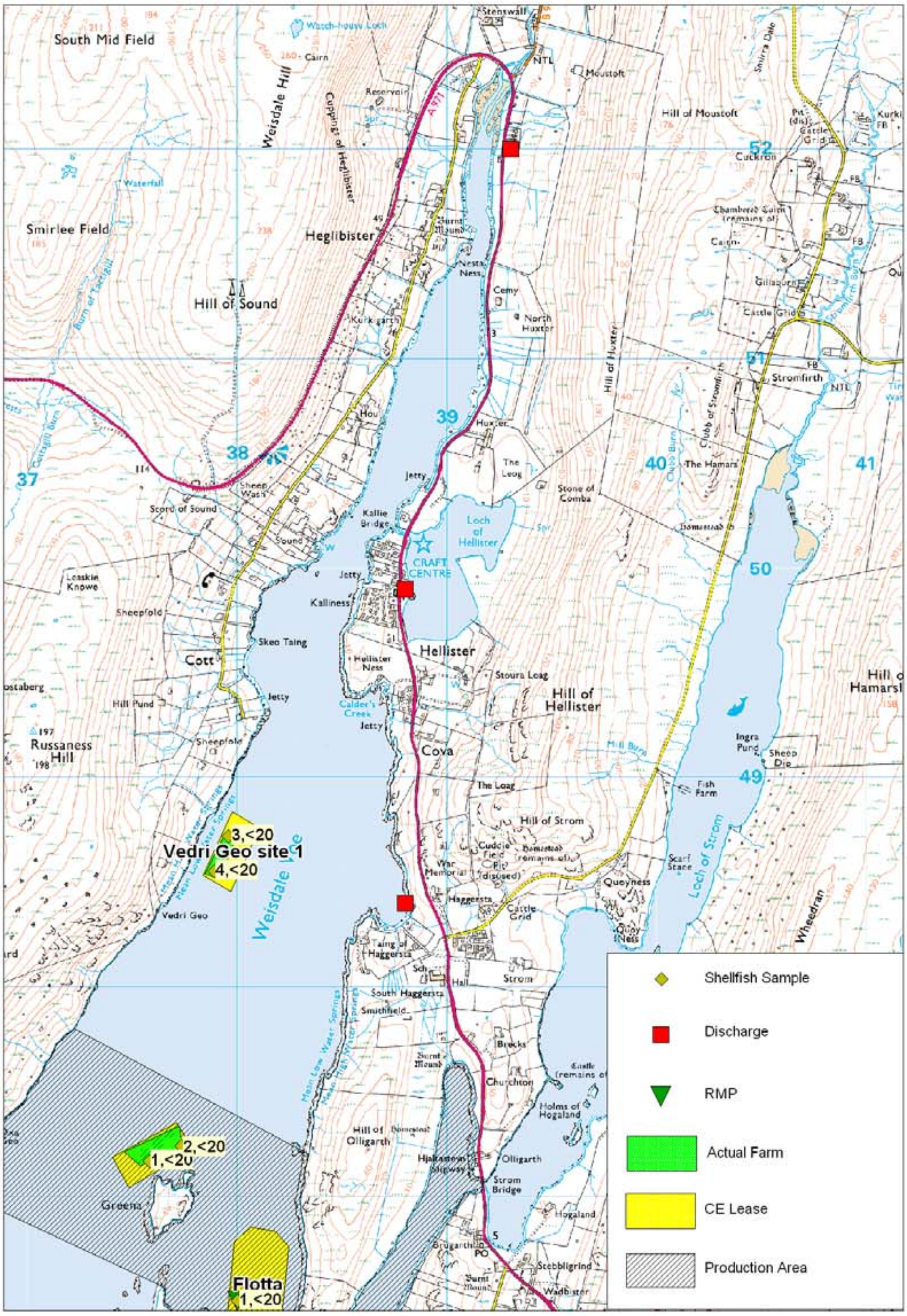
Figure 18.3

Weisdale Voe Shellfish Samples



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Photos

Figure 18.4

Figure 18.5

Figure 18.6

Figure 18.7

Figure 18.8

Figure 18.9

Figure 18.10

Figure 18.11

Figure 18.12

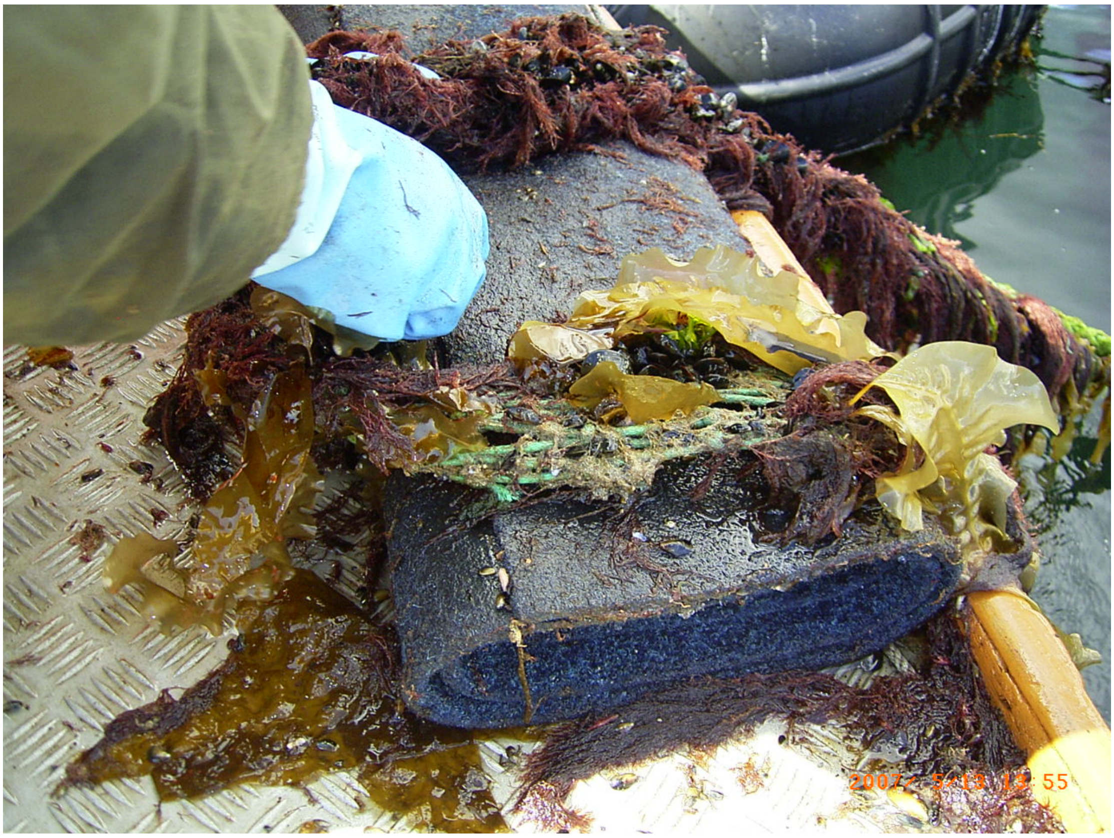
Figure 18.13

Figure 18.14

Figure 18.15

Figure 18.16

Figure 18.17



18.2 Sampling Plans for Weisdale Voe

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
Weisdale Voe Upper	Vedri Geo	SI378768	Common mussels	Long line	HU 37960 48710	437960	1148710	10	1	Hand	Monthly	Shetland Islands Council	Sean Williamson George Williamson Kathryn Winter Marion Slater	Dawn Manson	
Weisdale Voe	Flotta	SI297469	Common mussels	Long line	HU 38150 46530	438150	1146530	10	1	Hand	Monthly	Shetland Islands Council	Sean Williamson George Williamson Kathryn Winter Marion Slater	Dawn Manson	

18.3 Data Tables

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		

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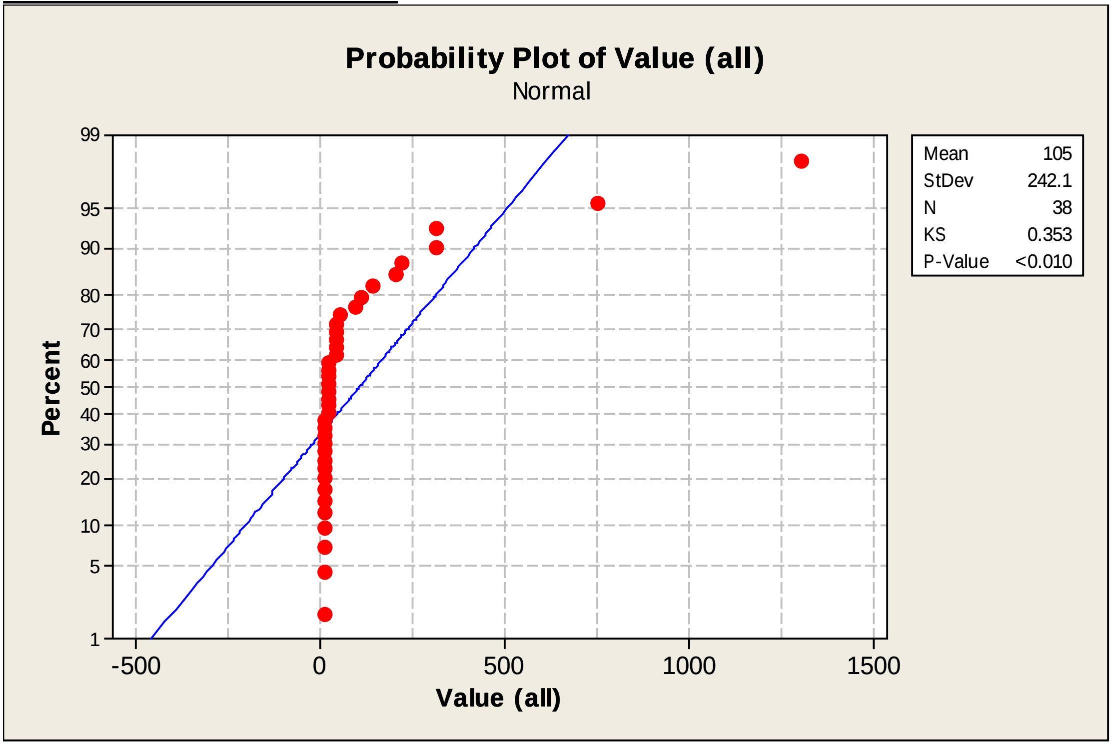
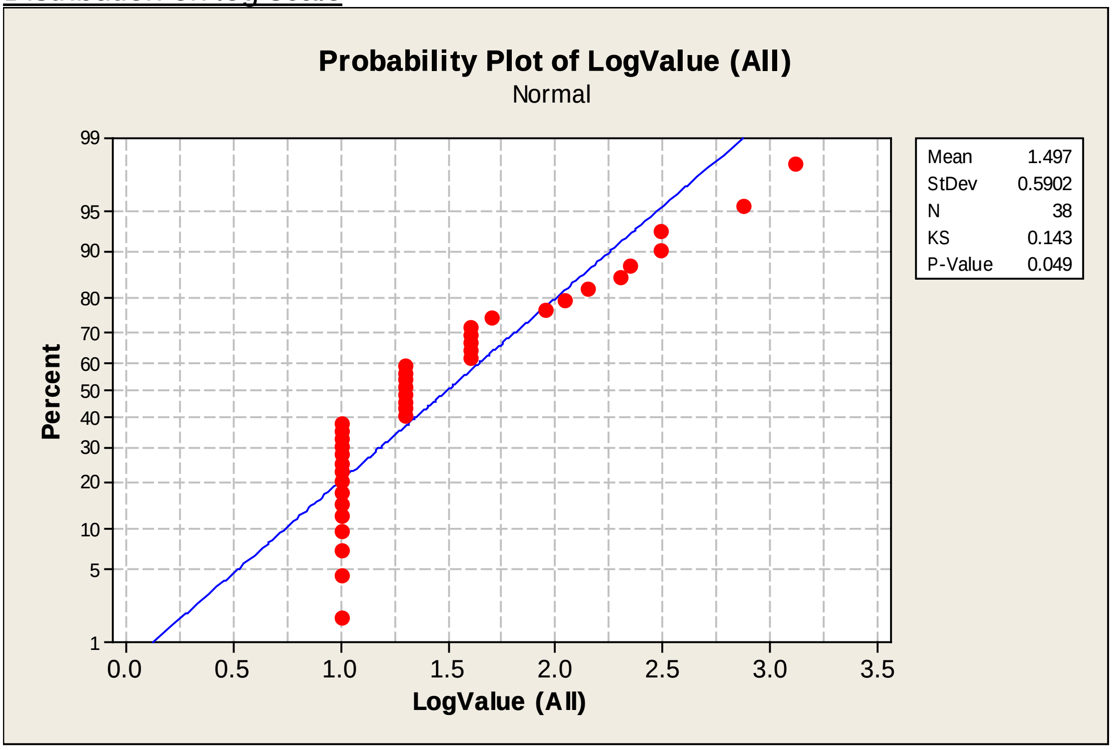
18.5 Statistical Data

All analyses were done using log transformed micro results (aside from circular linear correlation) as this gives a much more normal distribution.

Distribution on normal scale



Distribution on log scale



Section 11.2 T-Test Comparison of Greena & Flotta results

Two-Sample T-Test and CI: North Flotta, Greena

Two-sample T for North Flotta vs Greena

	N	Mean	StDev	SE Mean
North Flotta	25	1.406	0.585	0.12
Greena	13	1.671	0.582	0.16

Difference = mu (North Flotta) - mu (Greena)
Estimate for difference: -0.266
95% CI for difference: (-0.677, 0.146)
T-Test of difference = 0 (vs not =): T-Value = -1.33 P-Value = 0.195 DF = 24

Section 11.4.1 ANOVA comparison of results by season

One-way ANOVA: LogValue (All) versus Season (all results)

Source	DF	SS	MS	F	P
Season (all results)	3	3.199	1.066	3.74	0.020
Error	34	9.689	0.285		
Total	37	12.887			

S = 0.5338 R-Sq = 24.82% R-Sq(adj) = 18.19%

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
1      10  1.1857  0.3050  (--------*-------)
2       9  1.3529  0.6190      (--------*--------)
3      10  1.9488  0.7038                     (--------*-------)
4       9  1.4836  0.4074         (--------*--------)
                           ---------+---------+---------+---------+
                                 1.20      1.60      2.00      2.40
```

Pooled StDev = 0.5338

Section 11.4.2 Regression analysis vs rain

Regression Analysis: Result (prev 2 days rain versus Rain in prev 2 days

The regression equation is
Result (prev 2 days rain = 1.48 + 0.0033 Rain in prev 2 days

Predictor	Coef	SE Coef	T	P
Constant	1.4760	0.1208	12.21	0.000
Rain in prev 2 days	0.00335	0.01164	0.29	0.775

S = 0.597632 R-Sq = 0.2% R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.0295	0.0295	0.08	0.775
Residual Error	36	12.8579	0.3572		
Total	37	12.8874			

Unusual Observations

```
     Rain in     Result
      prev 2    (prev 2
```

```
Obs     days  days rain     Fit  SE Fit  Residual  St Resid
 11     41.4     1.6021  1.6145  0.4209   -0.0124     -0.03 X
 24      2.2     2.8751  1.4833  0.1075    1.3917      2.37R
 25      0.2     3.1139  1.4766  0.1195    1.6373      2.80R

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 by rain quartile (previous 2 days)

One-way ANOVA: LogValue (All) versus Q prev 2 days rain

```
Source             DF      SS     MS     F      P
Q prev 2 days rain   3   1.773  0.591  1.81  0.164
Error              34  11.115  0.327
Total              37  12.887

S = 0.5718   R-Sq = 13.75%   R-Sq(adj) = 6.15%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -+---------+---------+---------+--------
Q1     14  1.5224  0.6317             (-------*-------)
Q2      7  1.5689  0.6362           (----------*----------)
Q3      9  1.1492  0.4475   (---------*--------)
Q4      8  1.7795  0.5207                 (---------*----------)
                           -+---------+---------+---------+--------
                           0.80      1.20      1.60      2.00

Pooled StDev = 0.5718
```

Section 11.4.2 Regression analysis vs rain in previous 7 days

Regression Analysis: Result prev 7 days rain versus Rain in prev 7 days

```
The regression equation is
Result prev 7 days rain = 1.32 + 0.00707 Rain in prev 7 days


Predictor                Coef   SE Coef     T      P
Constant               1.3185    0.1528  8.63  0.000
Rain in prev 7 days  0.007069  0.004770  1.48  0.147


S = 0.580865   R-Sq = 5.7%   R-Sq(adj) = 3.1%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   0.7409  0.7409  2.20  0.147
Residual Error  36  12.1465  0.3374
Total           37  12.8874


Unusual Observations

     Rain in
      prev 7  Result prev
Obs     days  7 days rain     Fit  SE Fit  Residual  St Resid
  9     94.4       1.3010  1.9857  0.3432   -0.6847     -1.46 X
 24      3.0       2.8751  1.3397  0.1418    1.5354      2.73R
 25     40.2       3.1139  1.6026  0.1183    1.5113      2.66R

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 by rain quartile (previous 7 days)

One-way ANOVA: LogValue (All) versus Q prev 7 days rain

```
Source             DF      SS     MS     F      P
Q prev 7 days rain  3   2.314  0.771  2.48  0.078
Error              34  10.574  0.311
Total              37  12.887

S = 0.5577   R-Sq = 17.95%   R-Sq(adj) = 10.71%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
Q1      9  1.4867  0.6727            (---------*----------)
Q2      8  1.1250  0.2547  (----------*-----------)
Q3      8  1.4000  0.4241          (----------*----------)
Q4     13  1.7919  0.6608                     (--------*--------)
                           ---------+---------+---------+---------+
                                 1.05      1.40      1.75      2.10

Pooled StDev = 0.5577
```

Section 11.4.3 ANOVA comparison by tide size

One-way ANOVA: LogValue (All) versus Tide size

```
Source     DF      SS     MS     F      P
Tide size   2   0.330  0.165  0.46  0.635
Error      35  12.558  0.359
Total      37  12.887

S = 0.5990   R-Sq = 2.56%   R-Sq(adj) = 0.00%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  ------+---------+---------+---------+---
Large   12  1.5000  0.7501    (-------------*-------------)
Medium  16  1.4062  0.4372  (-----------*-----------)
Small   10  1.6376  0.6237        (---------------*--------------)
                            ------+---------+---------+---------+---
                                1.25      1.50      1.75      2.00

Pooled StDev = 0.5990
```

Section 11.4.5 Circular linear correlation results and wind direction

CIRCULAR-LINEAR CORRELATION
Data file - C:\Documents and Settings\acc00\Desktop\weasel.ori
Analysis begun: 03 December 2007 17:47:52

Variables (& observations)	r	p
Wind bearing & E Coli result (32)	0.39	0.012

18.6 Hydrography 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.

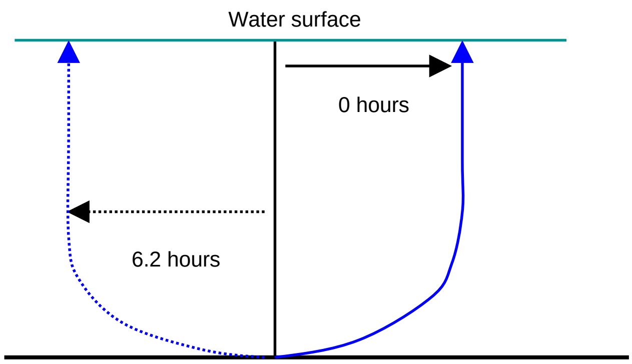
Background processes

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)



b)

c)

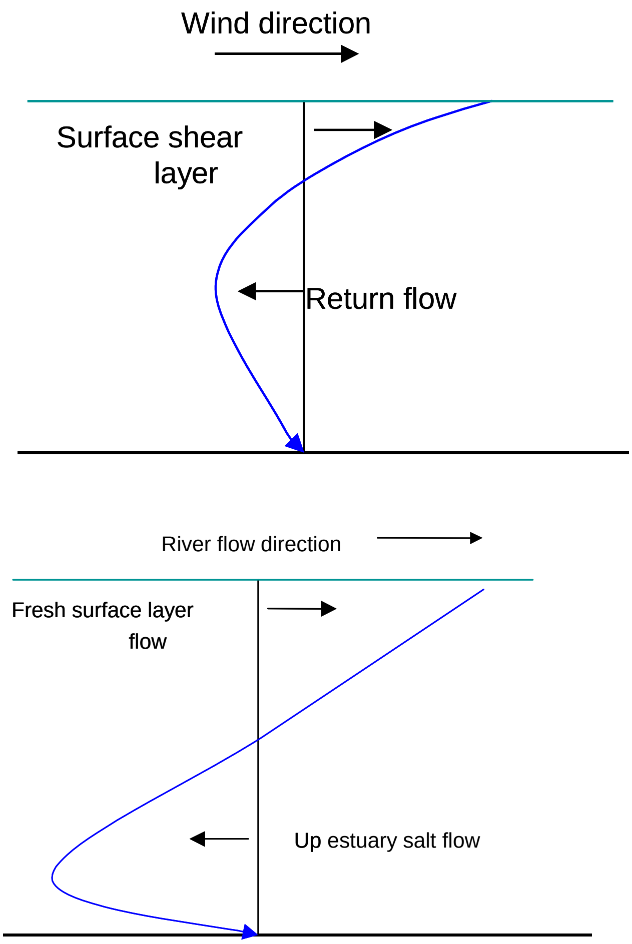


Figure 1. Typical vertical profiles for currents generated by different mechanisms. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main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

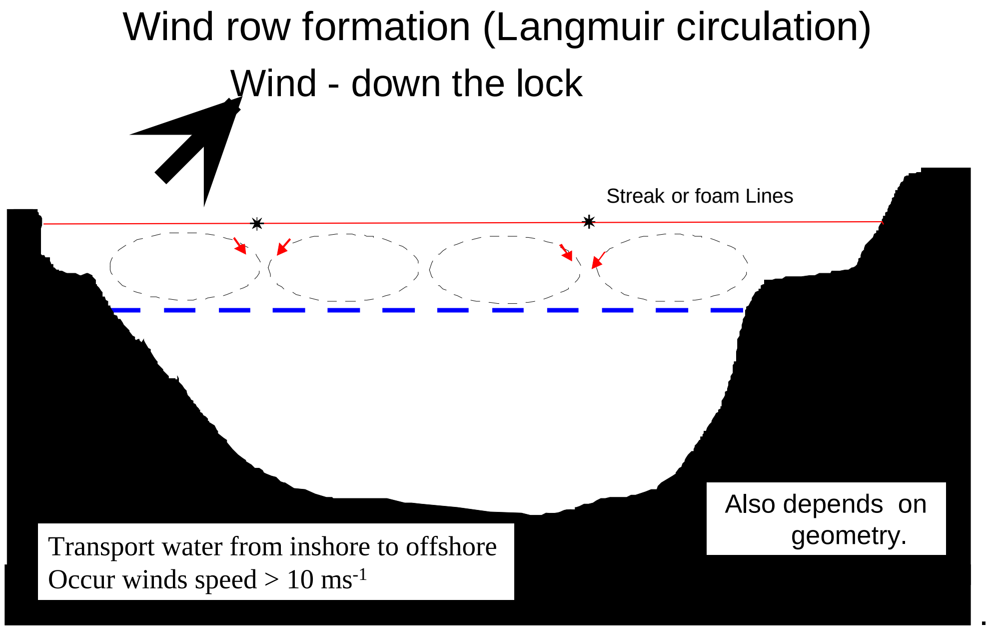


Figure 2: Schematic of wind driven 'wind row' currents. View is down the loch.The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.