Scottish Sanitary Survey Project

Sanitary Survey Report

West of Lunna

SI 380

March 2008

Report Distribution – West of Lunna

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Acknowledgements

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

Shetland Islands Council
Mr. Gilbert Clark
Mr. Erland Smith
SEPA Registry Office Dingwall
The Shetland Sea Mammal Group
Scottish Water
Dr. Alan Lilly, Macaulay Land Research Institute

1. General description

The West of Lunna: Culness site is located along the northwestern edge of the main island of Shetland approximately 3km to the east of Colla Firth. It lies in a north facing bay of between 5 and 20m depth that is open to Yell Sound. The bay is split into two halves with the relatively enclosed area of West Lunna Voe to the east and a more open bay at Culness to the west.

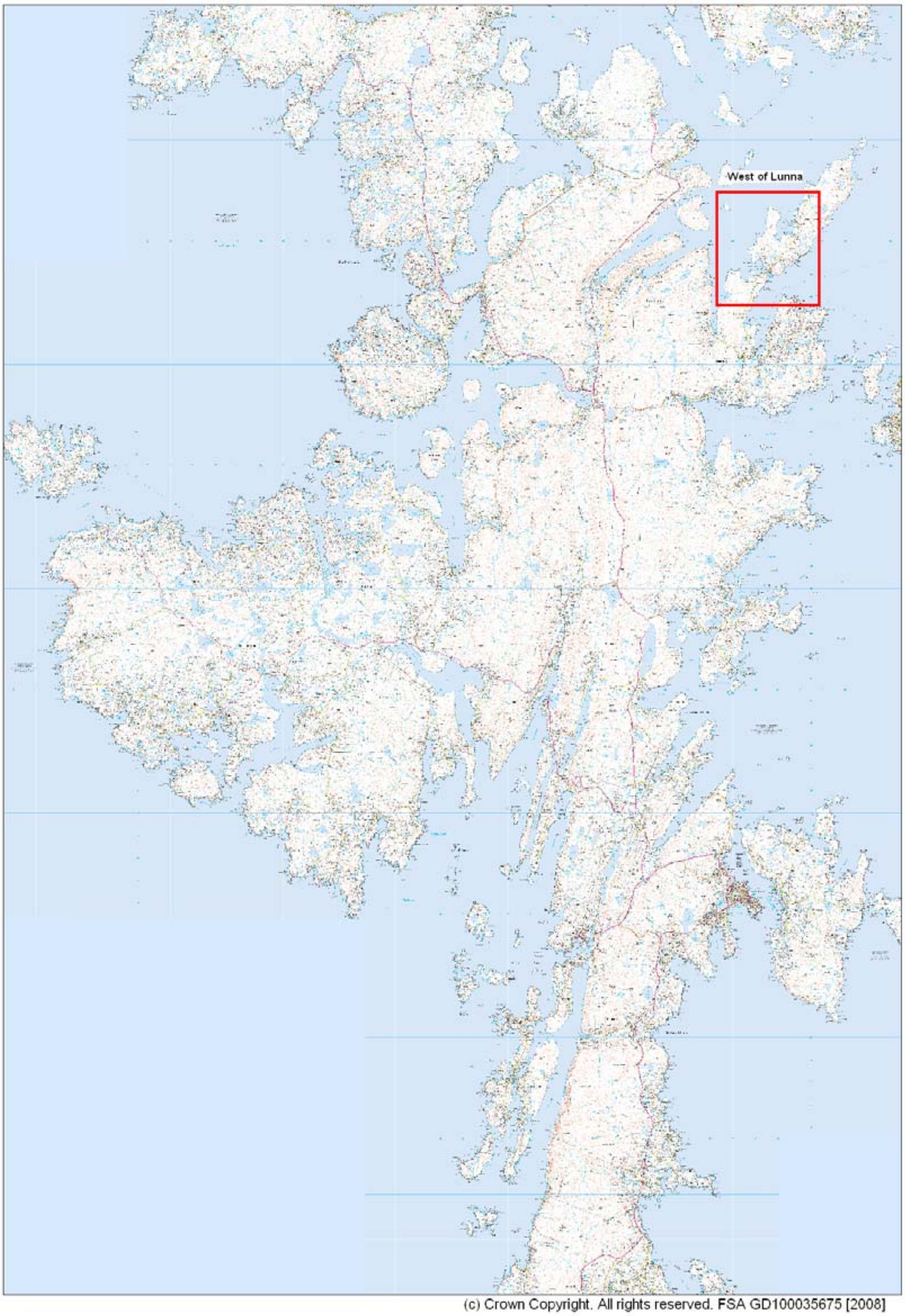


Figure 1.1 Location map for West of Lunna: Culness

2. Fishery

The fishery at West of Lunna consists of one long line mussel (*Mytilus* sp.) farm as listed below:

Table 2.1 Mussel farm at the West of Lunna

Site	SIN	Species
Culness	SI 380-770-8	Common mussels

There is no current production area or official shellfish growing water in the West of Lunna area. The shellfish farm corresponds with the Culness seabed lease area provided by the Crown Estate. Figure 2.1 shows the relative boundaries of the mussel farms and seabed lease area.

At this site, mussels are currently grown on longlines. 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 onto the droppers from the surrounding water. The spat are then left to grow for up to three years before reaching marketable size. At the time of the shoreline survey, Culness had 3 longlines on site.

Mature mussels are harvested by either stripping the lines by hand or by passing them through a system of brushes mounted to a funnel. Harvesting is to be done in rotation with different lines set out in different years to allow harvest of some stock each year.

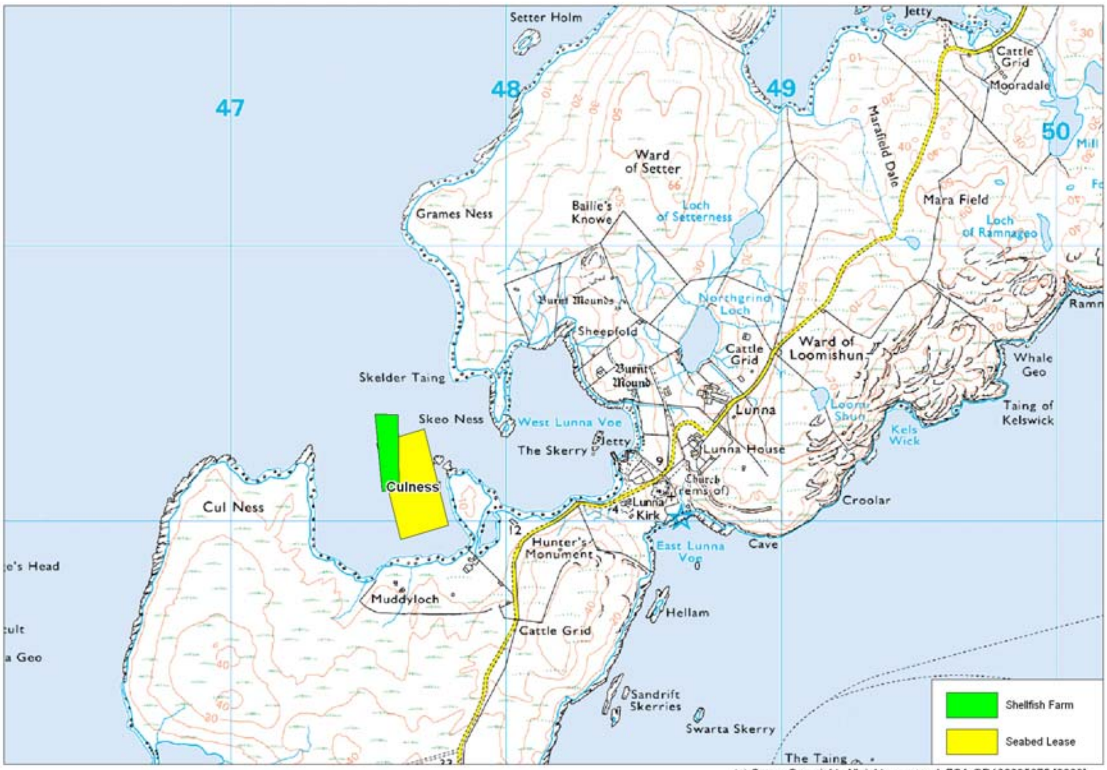
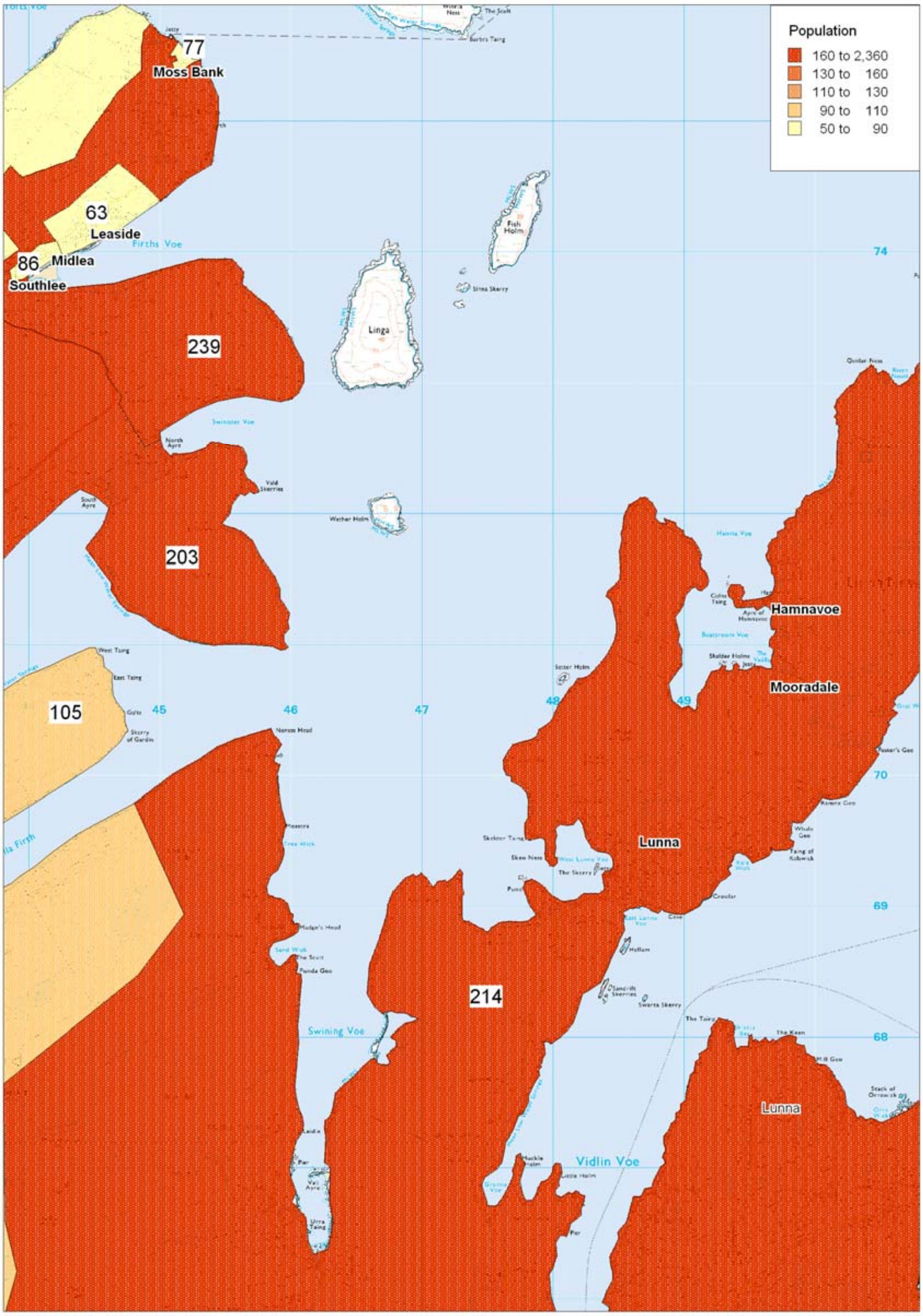


Figure 2.1 Map of West of Lunna fishery

3. Human population

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



Population data Census Data [2001] - General Register Office for Scotland

Figure 3.1 Population map for the West of Lunna

The population for the single census output area bordering immediately on the West of Lunna is:

60RD000159	214

There are also five more census output areas on the western shoreline within 6km of the West of Lunna, including:

60RD000045	203
60RD000047	105
60RD000157	239
60RD000065	63
60RD000158	86

The settlements bordering closest to the West of Lunna are Hamnavoe, Mooradale and Lunna, shown in figure 3.1. There are in addition, the settlements of Moss Bank, Leaside, Midlea and Southlee, about 4-6km away on the western coastline. It is likely that as Hamnavoe, Mooradale and Lunna are the closest settlements to the fishery that 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

There are no known sewage discharges surrounding the production area of the West of Lunna.

Six homes were observed near the fishery and it is presumed that each of these would have a private septic tank. However, no obvious discharge pipes were observed.

Soils in the area are classed as poorly draining (see section 5, figure 5.1), and any soakaway systems present may not function optimally and could result in contamination of adjacent coastal waters. Given the small number of homes in the area, this impact at West of Lunna is unlikely to be substantial.

5. Geology and soils

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

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

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

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

Peaty gleys, peaty podzols and peaty rankers contribute to a large percentage of the soil composition of 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 Scotland, non-calcareous gleys within the Arkaig association are most common and have an average surface % runoff of 48.4%, indicating that they are generally poorly draining.

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

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

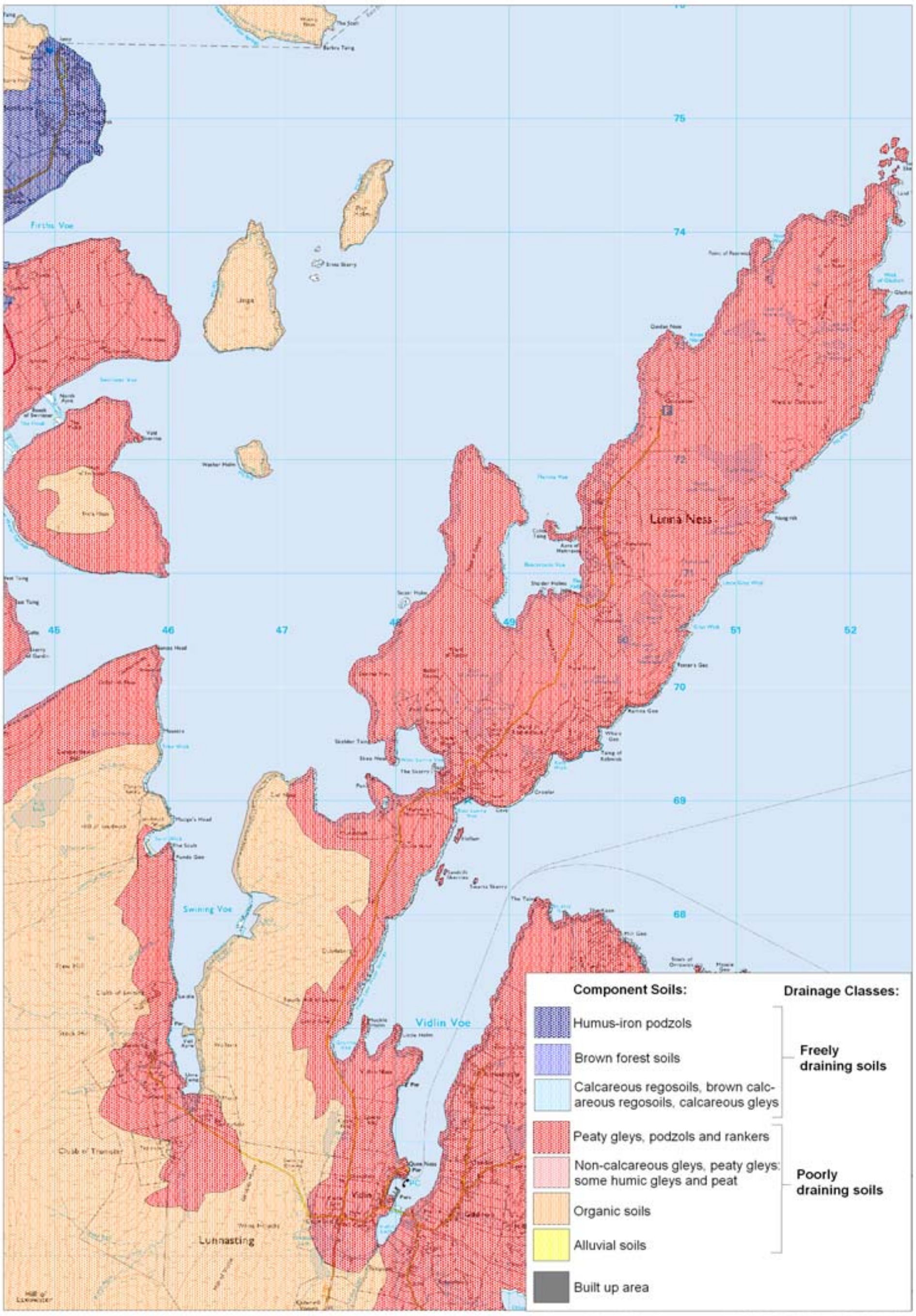


Figure 5.1 Component soils and drainage classes for the West of Lunna

The map in figure 5.1 shows component soils and their associated drainage classes for the area of the West of Lunna.

There are two component soil types visible in the immediate area of the West of Lunna. The first is composed of peaty gleys, podzols and rankers and covers the whole of the West of Lunna. The second is composed of organic soils. The peaty gleys, podzols and rankers and organic soils in this area are classed as poorly draining soils.

Understanding whether the land surrounding the West of Lunna 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 dominating the West of Lunna) surface run off is likely to be high, as peaty gleys, podzols and rankers and organic soils are often waterlogged. 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 the West of Lunna, where the soil types are poorly draining, the potential for runoff contaminated with *E. coli* from animal waste is high in all areas surrounding the shellfish farm.

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:

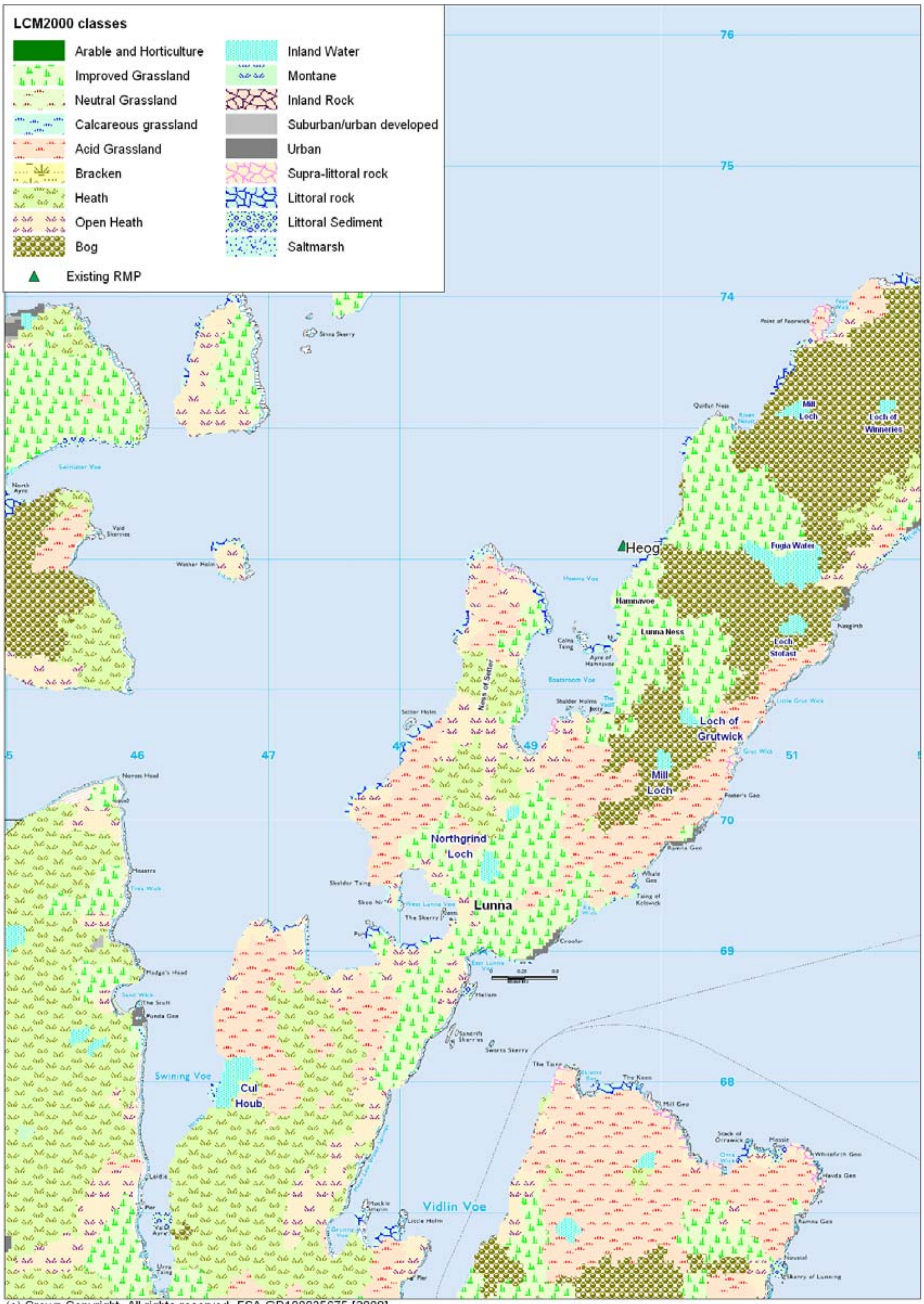


Figure 6.1 LCM2000 class data map for West of Lunna

The land cover surrounding the Culness production area is composed of four main land cover types. The coastline surrounding the shellfishery bay (to the east of Lunna) is dominated primarily by acid grassland and open heath, with improved grassland and heath further inland. On the eastern side of the production area shown in figure 6.1, improved grassland, bog and acid grassland dominate. The Ness of Setter, to the west is shown as acid grassland, open heath and improved grassland to the north and heath to the south. There are also a few areas of littoral rock and littoral sediment running along the stretch of the coastline.

In the area around Culness, the faecal coliform contribution would be expected to be highest from the improved grassland (approximately 8.3×10^8 cfu km^{-2} hr^{-1}) and lower from the other land cover types present (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 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) which only relates to the time of the site visit on 15 May, 2007.

The shoreline survey identified that sheep were grazed widely around the area. Several cattle were also identified during the shoreline survey (see figure 7.1). At the time of the shoreline survey, animals were concentrated on the areas of improved pasture around West Lunna Voe, to the east of the shellfish farm. The geographical spread of contamination at the shores of the site was likely to be more concentrated at West Lunna Voe as compared to surrounding areas. Faecal contamination washed into the voe would be washed out and across the shellfish farm on the outgoing tides.

There is no local information concerning seasonal livestock numbers available for the surrounding area the West of Lunna. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1.

Figure 7.1 Map of livestock observations at the West of Lunna

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.

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

According to the Scottish Executive, in 2001 there were approximately 119,000 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).

While there are no haulout sites recorded at West of Lunna itself, it could be expected that the area would be frequented by seals during active foraging. Seals were observed during the shoreline survey and 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.

The amount of *E. coli* and other faecal indicator bacteria contained in seal faeces has been reported as being similar to that found in raw sewage, with counts showing up to 1.21 x 10^4 CFU (colony forming units) *E. coli* per gram dry weight of faeces (Lisle et al 2004).

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 *E. coli*. There have been some sightings in and around Yell Sound, however these accounts are sparse. It is highly likely that cetaceans will be found from time to time in the sound 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.

Common terns as well as the more numerous gulls are recorded as breeding in the area. Impact of contamination from breeding birds would be limited in duration to the summer months and would be highest where large numbers of nest sites were present.

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

Observations during the shoreline survey indicated no readily apparent colonies of nesting birds in the vicinity of the mussel farm at Culness.

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. Culness is well known for its otters and otters from this area have been the filmed for a BBC wildlife program. Given the small size of the area, however, the numbers of otters frequenting the area are likely to be fewer than a dozen, hence otter populations are not sufficiently concentrated to have a predictable effect on the mussel fishery there. The bacterial composition and daily faecal output of otters are not well characterised so it is unclear how much contamination they could be contributing to the area at Culness.

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 fishery at Culness is likely to be mostly that of Eider ducks feeding on the mussel lines.

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. Whilst large cetaceans and other marine mammals have been observed in Yell Sound, their presence is not likely to be spatially or temporally predictable and so their effect will not be taken into account when establishing the sampling plan.

9. Meteorological data

The nearest weather station is Lerwick, approximately 29 km to the south 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 broadly similar to those on West of Lunna and surrounding land due to their proximity but may differ on any given day. This section aims to describe the local rain and wind patterns and how they may affect the bacterial quality of shellfish within West of Lunna.

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 wastewater treatment plant overflows (e.g. Mallin et al, 2001; Lee & Morgan, 2003).

Figures 9.1 to 9.4 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 *.

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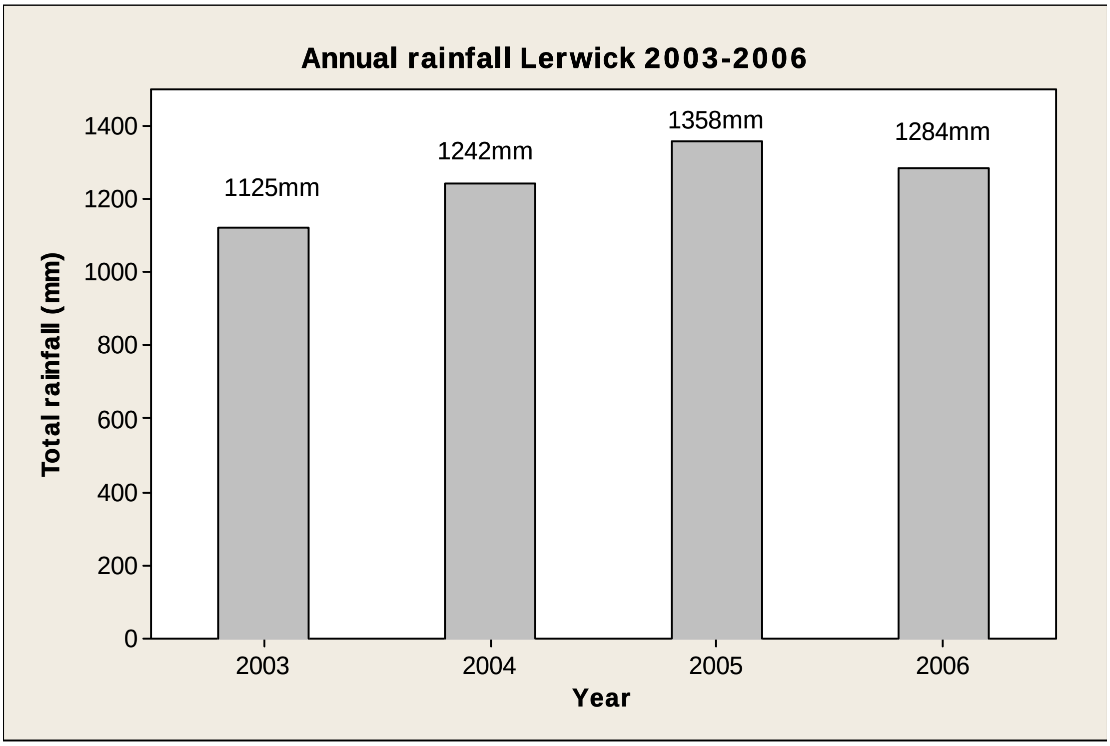


Figure 9.1 Annual rainfall at Lerwick 2003-2006

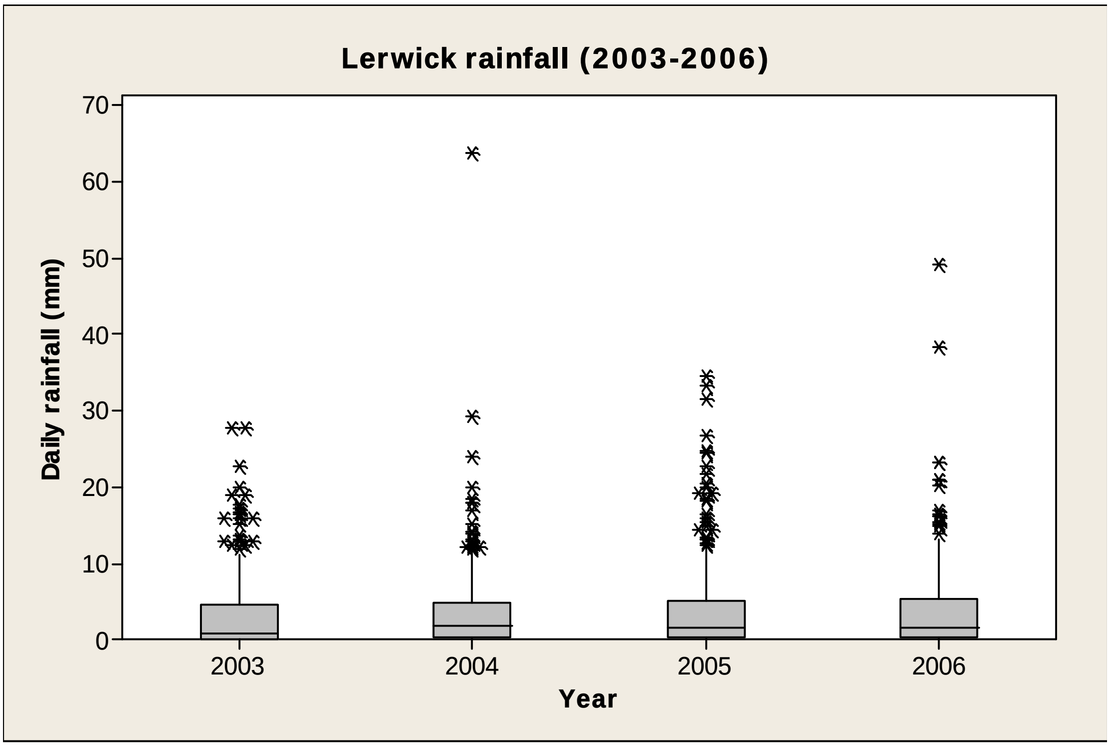


Figure 9.2 Boxplot of rainfall at Lerwick by year

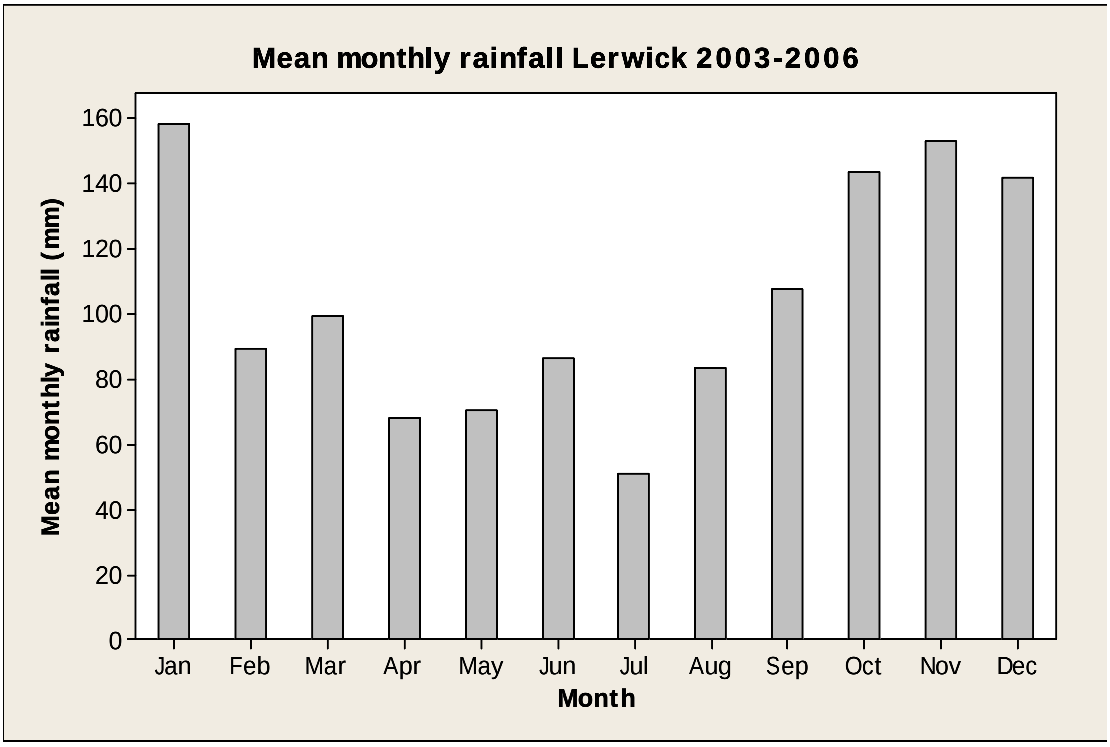


Figure 9.3 Mean monthly rainfall at Lerwick 2003-2006

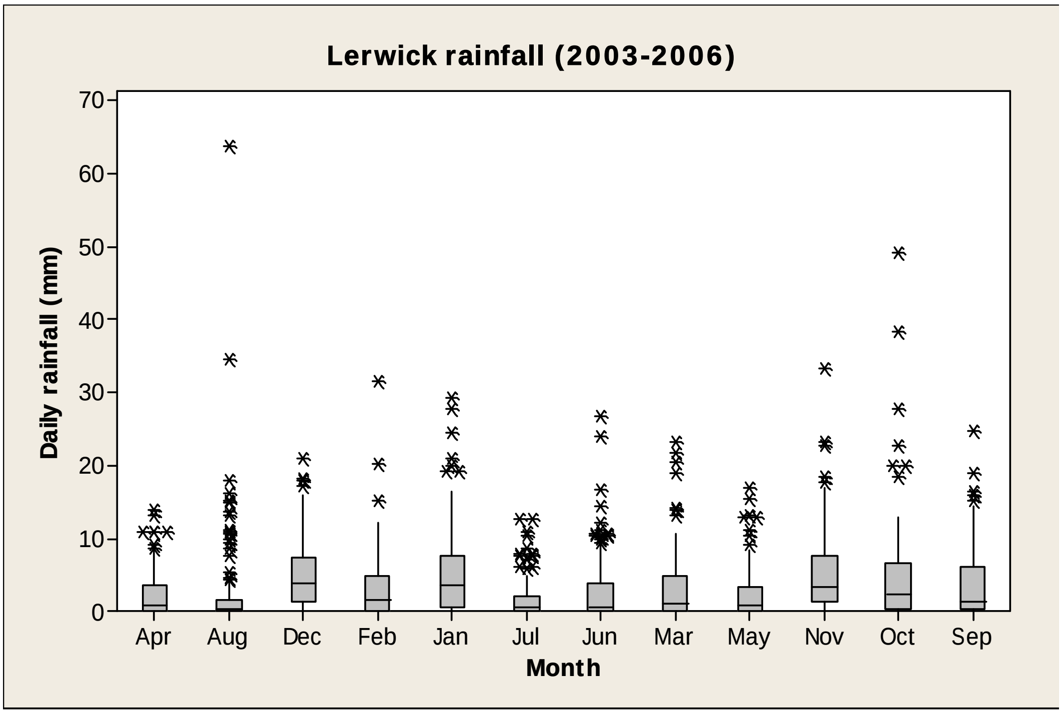


Figure 9.4 Boxplot of rainfall at Lerwick by month

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 9.1 (Data from Met office website © Crown copyright). This indicates that rainfall in Lerwick was lower than the average for the whole of Scotland for every month of the year, but there were fewer dry days in Lerwick during the autumn, winter and spring.

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

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

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

9.2 Wind

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

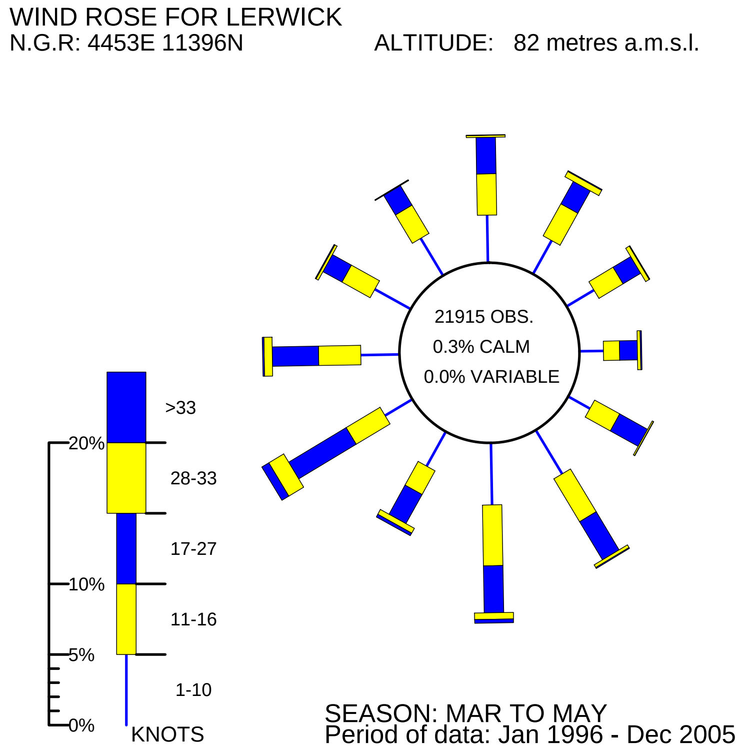


Figure 9.5 Wind rose for Lerwick (March to May)

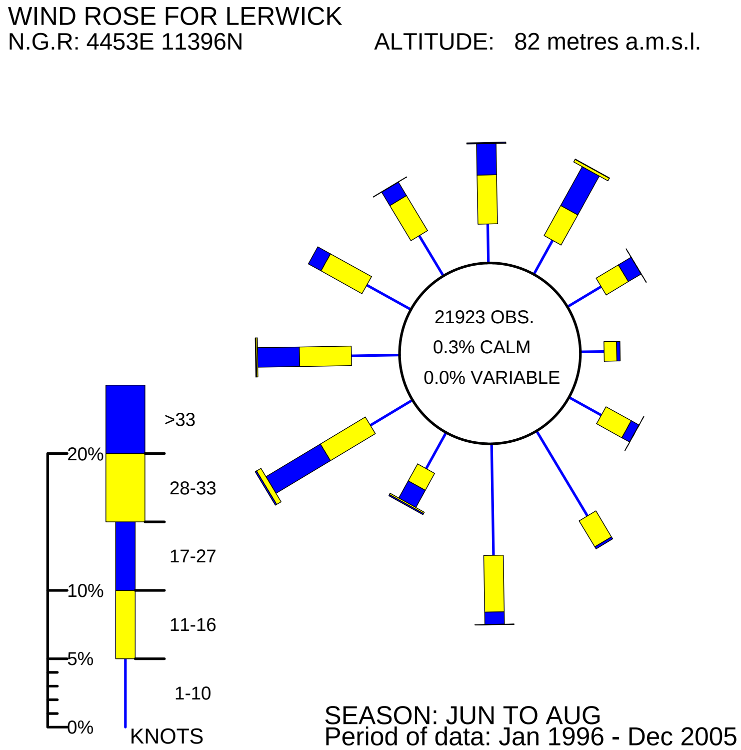


Figure 9.6 Wind rose for Lerwick (June to August)

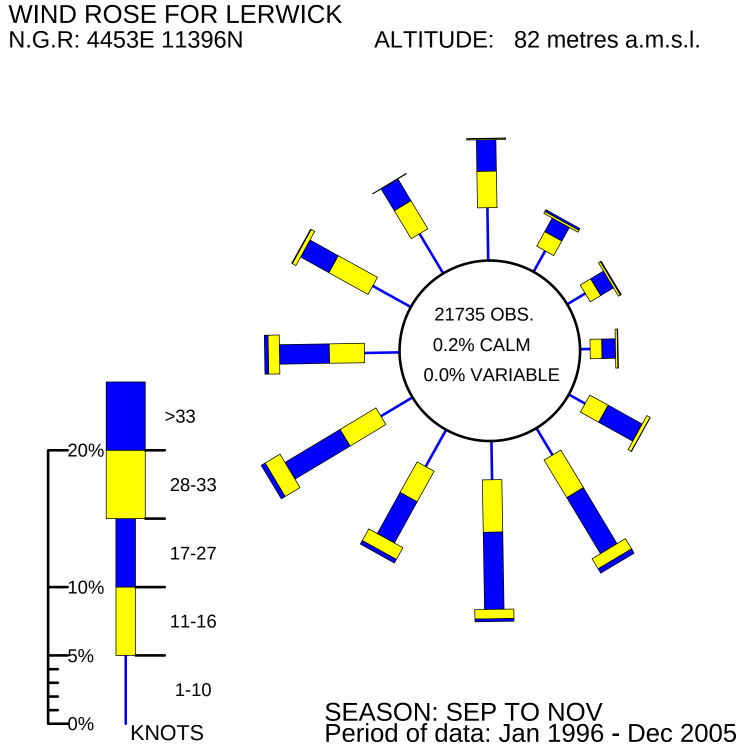


Figure 9.7 Wind rose for Lerwick (September to November)

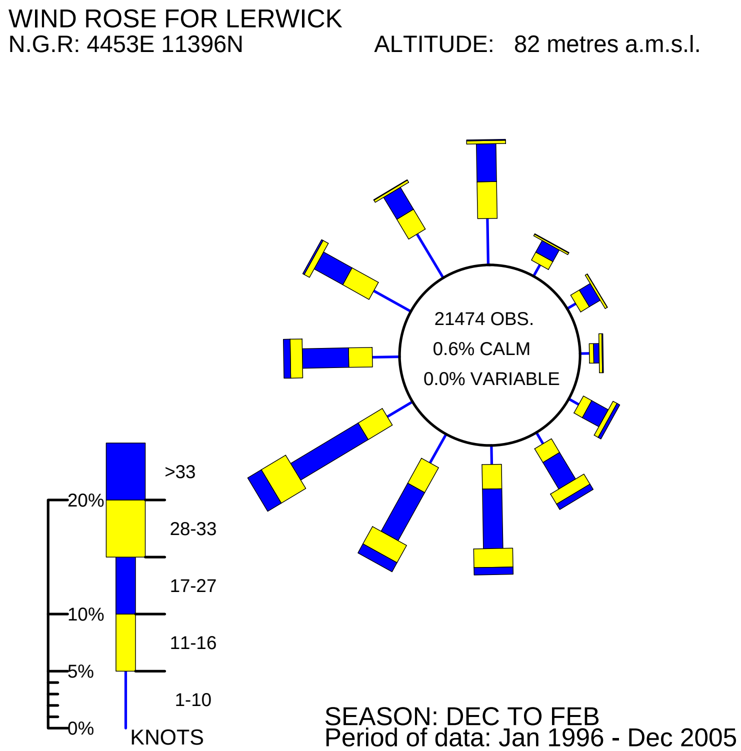


Figure 9.8 Wind rose for Lerwick (December to February)

Shetland is one of the more windy areas of Scotland with a much higher frequency of gales than the country as a whole. The wind roses show that the overall prevailing direction of the wind is from the south and west, and when it is blowing from this direction it is likely to be stronger than when blowing from other directions. Winds are generally lighter during the summer months and strongest in the winter. West of Lunna is situated in a bay exposed to northerly and northwesterly winds, but is sheltered to some extent by low hills on the surrounding land to the south.

A strong northerly 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 bay.

Wind effects are likely to cause significant changes in water circulation within the bay as tidally influenced movements of water are relatively weak (see section 12). Winds typically drive surface water at about 3% of the wind speed (Brown, 1991) so a gale force wind (34 knots or 17.2 m/s) would drive a surface water current of about 1 knot or 0.5 m/s. These surface water currents create return currents the paths of which will depend on local bathymetry. Either way, strong winter winds will increase the circulation of water and hence dilution of contamination from point sources within the bay. A strong easterly wind would have the effect of pushing any contamination originating from the small settlement of Lunna towards the production site.

10. Current and historical classification status

West of Lunna is yet to be classified.

The nearest classified production area is Lunnaness approximately 3km to the northeast. However, as it was first classified in 2007 it has limited history (Table 10.1). Both areas are displayed on the map in Figure 10.1.

Table 10.1 Classification history at Lunnaness.

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

Figure 10.1 Map of Lunnaness and West of Lunna fisheries

11. Historical *E. coli* data

11.1 Validation of historical data

All samples taken from West of Lunna up to the end of 2007 were extracted from the database and validated according to the criteria described in the standard operating procedure for validation of historical *E. coli* data. In the two instances where the result was reported as <20, it was assigned a nominal value of 10 for the purposes of statistical analysis and graphical presentation. A total of only 8 samples were taken from this production area.

Three km to the north east of this production area is another mussel production area, Lunnaness. This is also a bay with a northerly aspect into Yell sound, and so is likely to have similar water quality and respond to environmental variables in a similar manner. All samples taken from Lunnaness were extracted from the database and validated according to the criteria described in the standard operating procedure. Two samples were excluded from the analysis due to geographical discrepancies, and one sample was excluded due to an invalid test result. In the 9 instances where the result was reported as <20, it was assigned a nominal value of 10 for the purposes of statistical analysis and graphical presentation.

All *E. coli* results are reported in number of colony forming units per 100g of shellfish flesh and intervalvular fluid.

11.2 Summary of microbiological results

Common mussels were sampled from two locations from West of Lunna, and from two locations at Lunnaness. Sampling and results are summarised in Table 11.1, and sampling locations are indicated in Figure 11.1

Table 11.1 - Summary of results from West of Lunna and Lunnaness

Sampling Summary						
Production area	West of Lunna	West of Lunna	West of Lunna	Lunnaness	Lunnaness	Lunnaness
Site	Cul Ness	Cul Ness	Cul Ness	Heog	Heog	Heog
Species	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels
SIN	SI-380-770-8	SI-380-770-8	SI-380-770-8	SI-362-750-8	SI-362-750-8	SI-362-750-8
Location sampled	HU475691	HU475690	Both	HU497723	HU497721	Both
Location of RMP	None	None	None	HU497721	HU497721	HU497721
Total no of samples	4	4	8	4	9	13
No. 1999	0	0	0	0	0	0
No. 2000	0	0	0	0	0	0
No. 2001	0	0	0	0	0	0
No. 2002	0	0	0	0	0	0
No. 2003	0	0	0	0	0	0
No. 2004	0	0	0	0	0	0
No. 2005	0	0	0	0	0	0
No. 2006	0	0	0	0	5	5
No. 2007	4	4	8	4	4	8
Results summary (*E. coli* mpn/100g)						
Minimum	20	<20	<20	<20	<20	<20
Maximum	500	220	500	1100	40	1100
Median	20	25	20	15	10 (<20)	10 (<20)
Geometric mean	44.7	30.6	37	38.5	13.6	18.7
No. exceeding 230/100g	1	0	1	1	0	1
No. exceeding 1000/100g	0	0	0	1	0	1
No. exceeding 4600/100g	0	0	0	0	0	0
No. exceeding 18000/100g	0	0	0	0	0	0

No significant difference between the results obtained for these two sites was detected (T-test, T-value=-1.08, p=0.298, Appendix 4). Geometric mean results indicate low levels of contamination.

Figure 11.1 Map of sampling locations within West of Lunna and Lunnaness

11.3 Temporal pattern of results

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

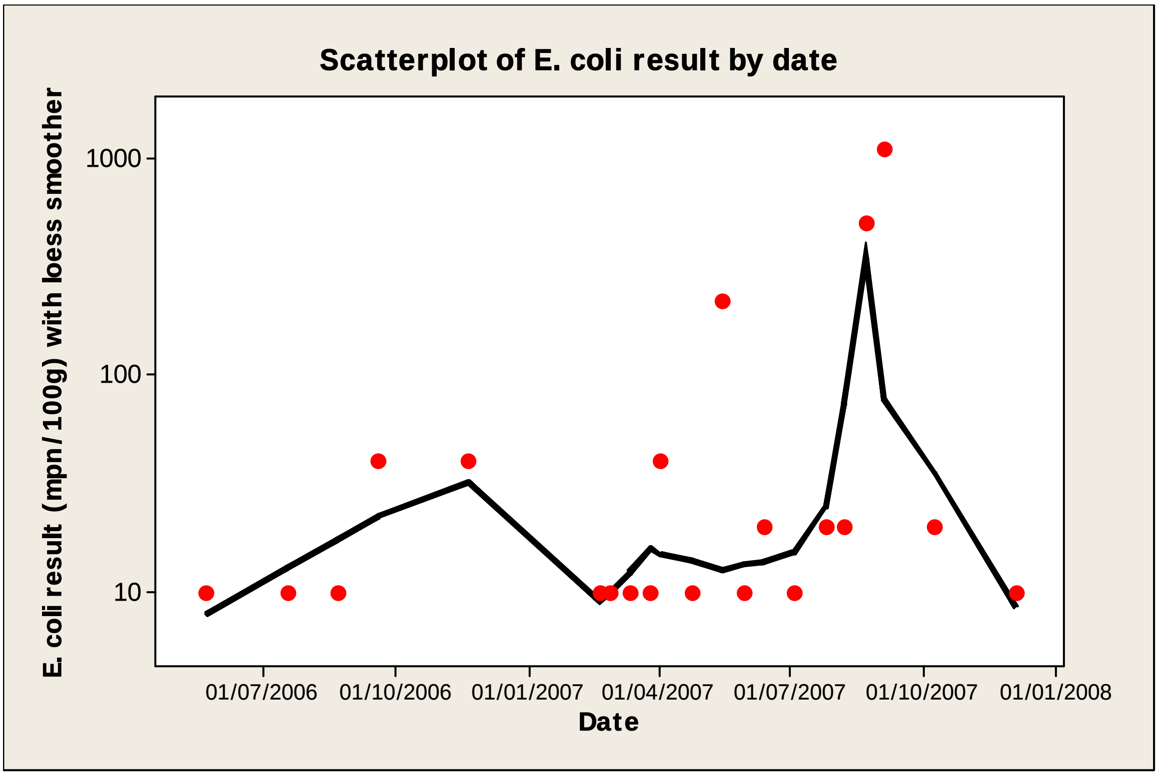


Figure 11.2 Scatterplot of results by date with loess smoother

Figure 11.2, although based on a very limited dataset, suggests a seasonal pattern of results, which are highest in the autumn and lowest in the spring.

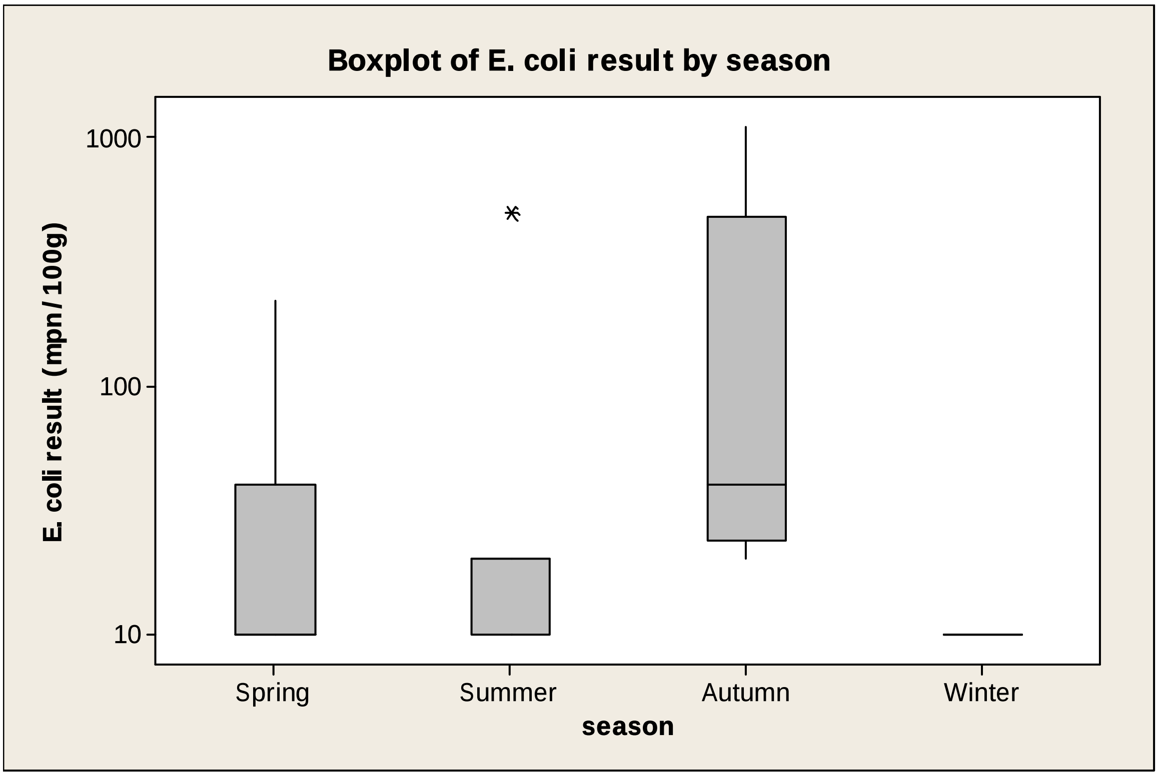


Figure 11.3 Boxplot of result by season (West of Lunna and Lunnaness)

Highest mean results occurred during the autumn, but this effect was not statistically significant (One-way ANOVA, p=0.241, Appendix 4). The sample number in this analysis is low, and it is likely that with further sampling a seasonal effect would become detectable.

11.4 Analysis of results against environmental factors

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

The general pattern observed in Shetland mussel production areas is a tendency for highest results to occur in the autumn. The early autumn is the period when livestock densities are highest, and the onset of the wetter and windier autumn/winter period so it is to be expected that contamination from livestock, the main source of contamination for this area, is at its highest. Effects of recent rainfall, wind direction and tide size tend to differ more between Shetland mussel production areas, and as a consequence are harder to predict for a new area.

12. Designated Shellfish Growing Waters Data

West of Lunna: Culness is not a designated shellfish growing water.

13. Bathymetry and Hydrodynamics

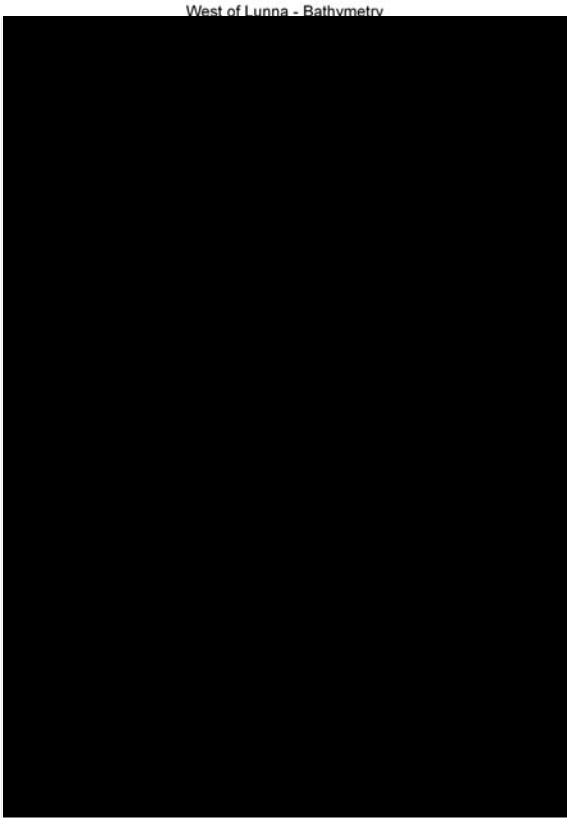


Figure 13.1 Map of West of Lunna bathymetry

Figure 13.2 OS map of West of Lunna

The chart above shows that the depth ranges from less than 2 metres along the west shore of the bay with a drying area at the tip of the spit of land on the eastern boundary of the seabed lease. The mussel lines are located just beyond the 10 metre depth curve.

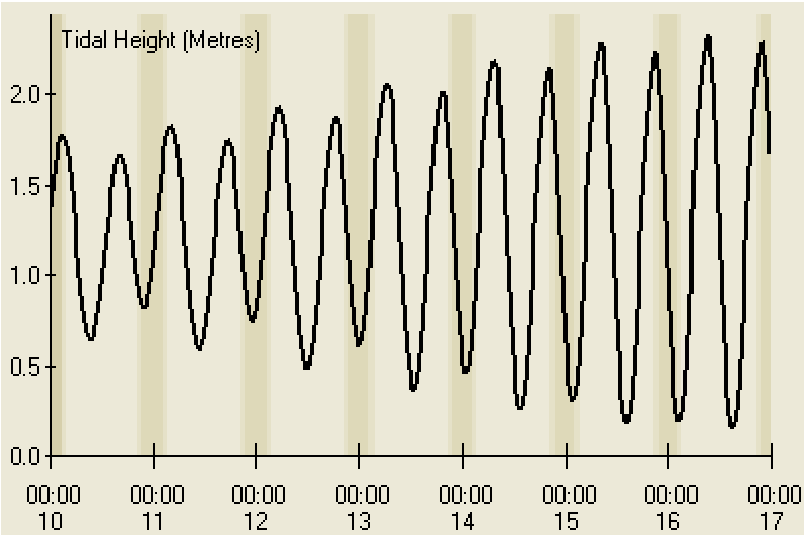
West of Lunna is located on the eastern side of the outer portion of Swining Voe. Information available for Swining Voe in the Catalog of Scottish Sea Lochs is briefly summarised below.

Length	3.4km
Max Depth	35 m
Salinity reduction	0.2 ppt
Flushing time	6 days
Watershed	13 sq.km

The production area at West of Lunna is located in small embayment that is open to Yell Sound to the west and north. It is exposed to seas and winds from the north and west. A restriction in the width of the bay is located to the southeast of the shellfish farm with a depth curve at the western side of the restriction. This would serve to increase currents through the area on tide changes and would be expected to lead to mixing of contaminants being washed out of West Lunna Voe on the outgoing tide.

13.1 Tidal Curve and Description

The two tidal curves below are for the Toft Pier, they have been output from UKHO TotalTide. The first is for seven days beginning 00.00 GMT on 10/05/07, the date of the first part of the shoreline survey. The second is for seven days beginning 00.00 GMT on 18/05/07. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle.



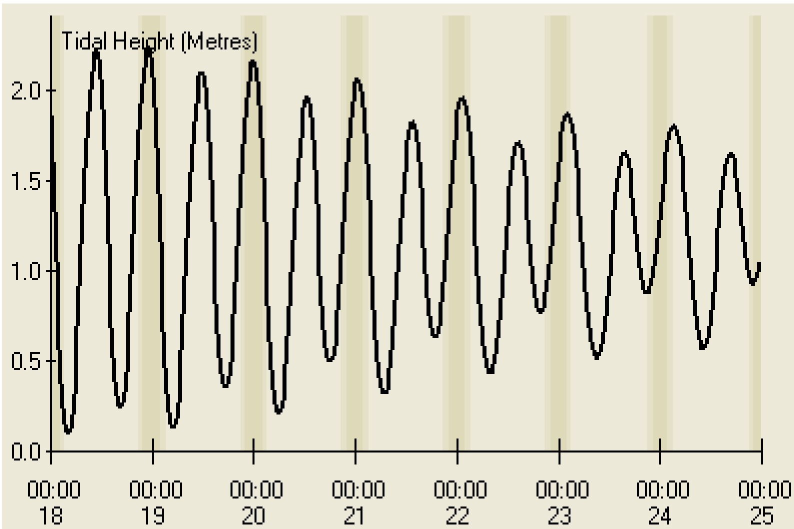


Figure 13.3 Tidal curves for Toft Pier

The following is the UKHO summary description for Toft Pier:

The tide type is Semi-Diurnal.

MHWS	2.3 m
MHWN	1.8 m
MLWN	0.8 m
MLWS	0.4 m

Predicted heights are in metres above chart datum. The tidal range at spring tide is therefore approximately 1.9 m and at neap tide 1.0 m.

13.2 Currents – Tidal Stream Software Output and Description

No tidal stream information is available for West of Lunna.

Conclusions

West of Lunna and West Lunna Voe are shallow throughout their area, providing less potential for dilution of pollutants. Flushing time reported for Swining Voe is 6 days, however due to the open aspect of West of Lunna, it may take less time to flush.

The area of West Lunna Voe is semi enclosed and contaminants would be likely to be well mixed when moved on the outgoing tide through the restriction at the entrance to the voe.

14. River Flow

There are no gauged rivers flowing into the bay at West of Lunna. The following stream was measured and sampled during the shoreline survey:

Table 14.1 Stream measurement – West of Lunna

No.	NGR	Description	Width (m)	Depth (m)	Meas. Flow (m/s)	Flow m^3/day	*E. coli* loading /day
1	HU48459 69419	Stream	0.7	0.06	0.3	1000	4×10^{10}

This small, natural stream drains Northgrind Loch as well as receiving drainage water from several fields where livestock were grazed. The loading of *E. coli*/day was calculated based on the flow and bacterial content observed on the date of shoreline survey only and this may not be representative of conditions at other times. This stream represents a significant source of faecal bacteria to the bay and the fishery when the conditions observed during the shoreline survey are present.

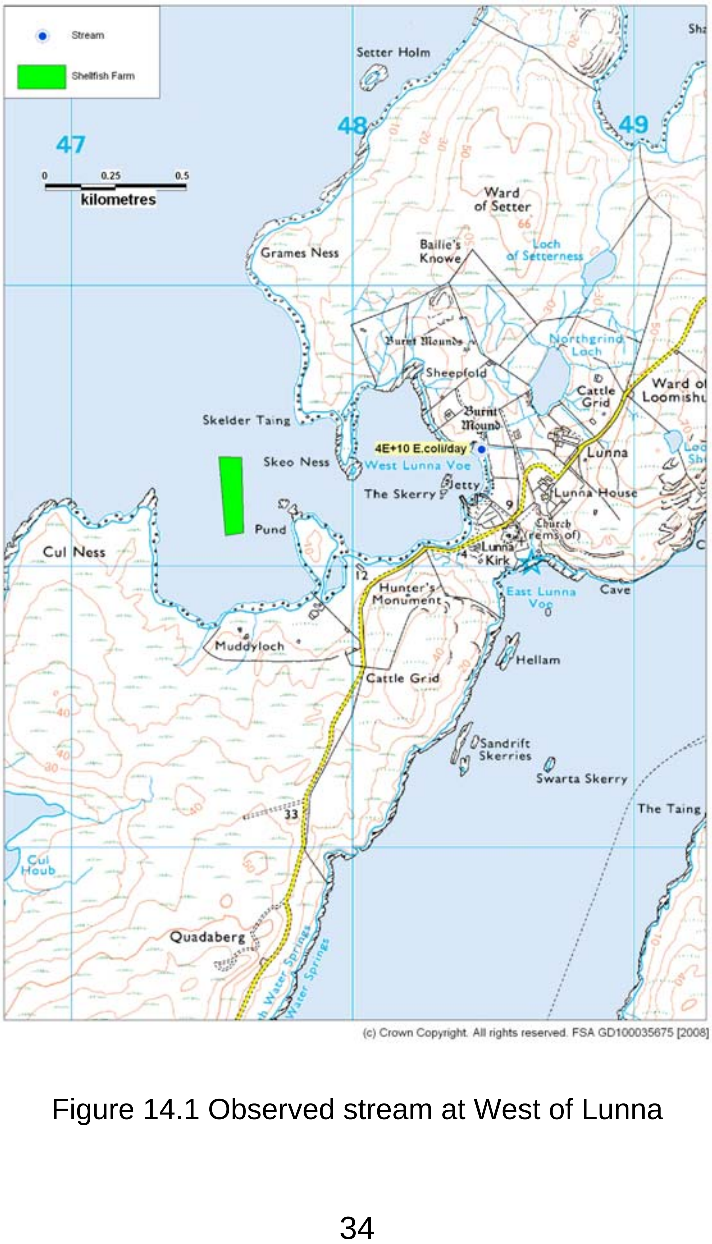


Figure 14.1 Observed stream at West of Lunna

15. Shoreline Survey Overview

The sanitary survey at West of Lunna was triggered by receipt of application for mussel production in an area not previously classified.

The shoreline survey was conducted on 15 May 2007.

There were no obvious human sewage inputs to either West Lunna Voe or the bay at Culness where the West of Lunna production area is situated. Six dwellings were observed in the vicinity and it is presumed that each has a private septic tank though no discharge pipes were seen.

Large numbers of livestock were observed in the area around West Lunna Voe and sheep were observed on the shoreline. As lambing was underway at the time of survey, it is presumed that the number of sheep counted was not necessarily representative of final numbers in the area. Over 100 sheep were directly counted.

One seal was observed on the boat trip out to conduct sampling at the fishery. Though no otters were observed during the survey, the boat skipper reported that they were common in the area.

Ships transiting Yell Sound pass within 10km of this site and one ship and one barge were observed on the day of survey. Depending upon where these vessels discharge their septic waste, there is a remote possibility that discharges could affect the area.

Both water and shellfish samples were taken on the day of survey. Shellfish were only sampled from one line on the farm as adverse conditions present on the day prevented further sampling. Mussels were collected from three depths along the line and results showed higher concentrations of bacteria at 3.5 m and 8 m depths (310 MPN *E. coli*/100 g) than near the surface (40 MPN *E. coli*/100 g).

Water samples were collected from two locations on the fishery and from along the shoreline. Results showed higher levels of faecal bacteria present in West Lunna Voe than on the western side of the bay where the shellfishery is located. This is also where the majority of livestock were observed. The highest concentration of *E. coli* (1800 cfu/100 ml) was found in a sample taken from a natural stream discharging into West Lunna Voe.

More complete information can be found in the Shoreline Survey Report found in Appendix 1.

16. Overall Assessment

Human Sewage Impacts
There is little in the way of direct human sewage impact to the fishery at West of Lunna. The six dwellings located in the vicinity are almost certainly on septic tanks, however the location of their discharges was not confirmed. If they have soakaway systems, due to the geology of the area it is likely that these will not be functioning effectively and that faecal contamination will travel to join other land runoff into the bay. These are most likely to adversely impact the eastern section of the bay (West Lunna Voe), where prevailing winds may tend to keep contamination from runoff entrained along the eastern shoreline.

Other sources of potential contamination with human sewage to the area include boats working on the fishery itself (if head is discharged into bay or if member of crew discharges directly overboard) and ships passing in Yell Sound. The impact of these is likely to be highly localised in time and location and unpredictable.

Agricultural Impacts
Impacts from livestock grazing are likely to be highly significant in this area. The area around the northeastern end of the bay is improved pasture used primarily for sheep grazing. Large numbers of sheep and some cattle were observed close to the shoreline and had access to streams and the shoreline itself.

Bacterial concentrations in water samples taken from the shoreline along West Lunna Voe showed higher levels of contamination than those taken from near the fishery and this may be the result of contamination due from livestock faeces. This area is surrounded by improved pasture which, as shown in Section 6, would contribute more faecal bacteria to stream and land runoff than would the other land cover types found around the western section of the bay.

Rivers and Streams
There is little fresh water input to this area. The one stream large enough to measure and sample provided a significant loading of *E. coli* to the bay approximately 1km to the east of the mussel farm. This would be most likely to impact the mussels on an outgoing tide.

Seasonal Variation
There is seasonal variation in livestock numbers and hence the amount of faecal material deposited by livestock on the shore. There is no appreciable impact due to tourism or seasonal occupation.

Meteorology and Movement of Contaminants
The most significant sources of contaminants to the fishery are likely to be diffuse pollution from livestock grazed in the area and faecal contamination carried to the sea via small land drains and the stream located in West Lunna Voe.

Land runoff will increase during significant rainfall. Analysis of rainfall data in section 9 shows that mean rainfall increases sharply in September and then remains elevated through January. The increased rainfall typically observed in

September would tend to flush faecal contaminants deposited during the drier months into the streams and directly into the voe.

Winds observed at Lerwick show that prevailing winds are from the southwest. Winds with a western component may tend to entrain contaminants within West Lunna Voe and against the shoreline in the vicinity of the shellfishery.

Analysis of Results

Results obtained during the shoreline survey showed higher levels of contamination at depths below 3 metres as compared to near the surface. This may be the result of mixing of contaminants in tidal and wind driven water flows through the constricted opening to West Lunna Voe.

Relatively high levels of contamination were observed near the shoreline, with the highest concentrations found to the east of the fishery within the area of West Lunna Voe. While the mussel farm at West of Lunna is located just outside this area, it is very likely that these sources impact the fishery on outgoing tides.

Comparison with results obtained at the Lunnaness production area to the north showed no significant differences in results between the sites. There appeared to be a peak in results obtained in the autumn, but this was based on a very limited number of samples. It does fall within patterns seen more generally in Shetland production areas, with higher results tending to coincide with the onset of heavier rains in autumn after a summer of livestock grazing.

It is anticipated that contamination levels will be relatively low throughout much of the year, with peak *E. coli* concentrations tending to occur between September and November.

17. Recommendations

It is recommended that the production area boundaries be established as the area bounded by lines drawn between HU 4780 6917 and HU 4783 6955 and between HU 4764 7005 and HU 4697 6922 extending to MHWS. This area is illustrated in Figure 17.1

This area specifically excludes the more contaminated waters in West Lunna Voe to the east of the shellfish farm and corresponding seabed lease.

It is recommended that the RMP be placed at HU 4759 6935 in order to reflect any contamination from West Lunna Voe that might be affecting the mussel farm.

Sampling depth is recommended to be 3-5 metres as higher levels of contamination were observed at depth during the shoreline survey and contaminants may be persisting longer at depth in this area.

As there is limited monitoring history at this site, monitoring frequency is recommended to be monthly.

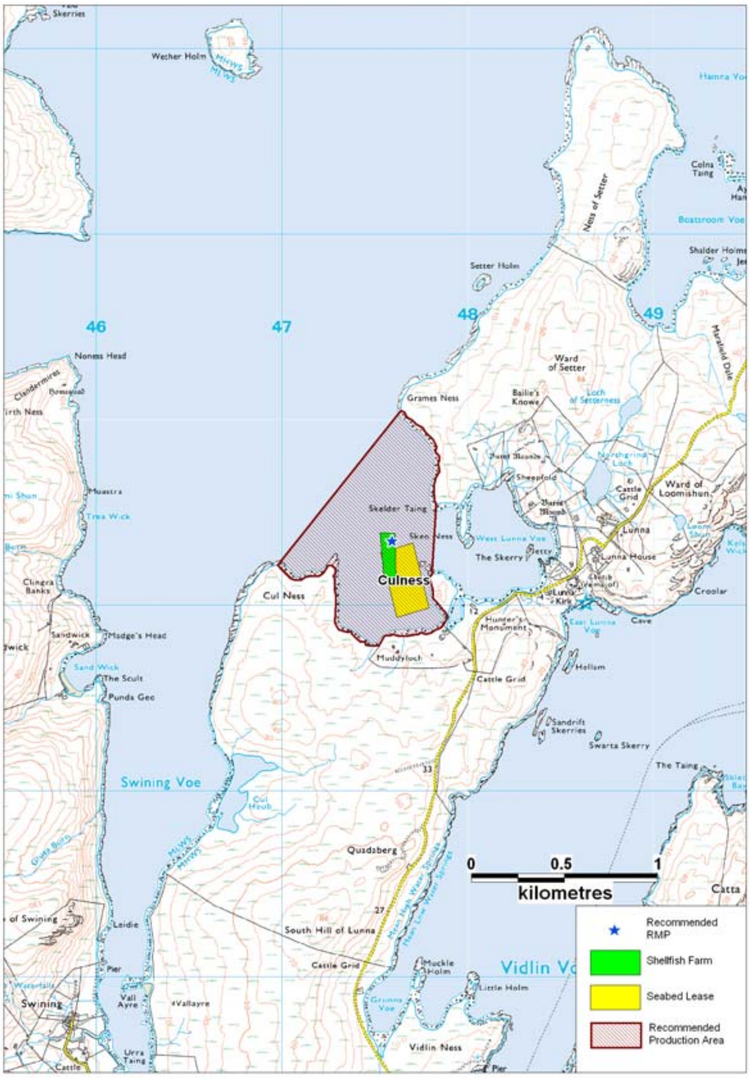


Figure 17.1 Map of recommendations for West of Lunna

18. References

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19. List of Figures and Tables

Appendices

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

Shoreline Survey Report

West of Lunna
SI 380

Scottish Sanitary Survey Project

Cefas

Shoreline Survey Report

Prod. area:	West of Lunna
Site name:	Culness (SI 380 770 08)
Species:	Common mussels
Harvester:	G. Clarke, E. Smith
Local Authority:	Shetland Islands Council
Status:	New Site
Date Surveyed:	15 May 2007
Surveyed by:	Michelle Price-Hayward and Alastair Cook
Existing RMP:	Not yet established
Area Surveyed:	See Map in Figure 1

Weather observations

Dry, partly cloudy. Rain reported over 7-8 May. Wind NNW, Force 5-6. Seas choppy.

Site Observations

Fishery

Three long lines are currently in place on site. The area has open exposure to seas from the N and NW. Stock of sufficient size and quantity was present for sampling, though conditions on the day prevented sampling from more than one point on the lines. The coastline is rocky with the eastern section of the bay more sheltered than where the mussel farm is located.

Sewage/Faecal Sources

Six homes were observed near the fishery, though no discharge pipes were directly observed (observations 47 and 49). As the area is very remote, it is most likely each home has a private septic system. Over 100 sheep were observed grazing in the area and most pastures allowed free access to the shoreline (observation 51). Some sheep were observed on the shore during the survey.

Seasonal Population

No caravans, car parks or campsites observed in the vicinity. No facilities for visiting boats.

Boats/Shipping

Ships transiting Yell Sound would pass within 10km of this site. On the day of survey, one ship was observed at anchor approximately 4km NE of the mussel lines (observation 55) and a barge was seen passing at a distance of 1-2km in the same direction (observation 54). One dinghy was seen in a bay near the fishery as well as 4 buoys (observation 49). It is not known whether these marked moorings for additional boats.

Land Use

Land use in the area is predominantly sheep grazing though 4 cattle were also observed during the survey (observation 51). The area is remote with no large or small settlements.

Wildlife/Birds

Yell Sound hosts an important population of otters and seals. While no otters were observed during the survey, the boat skipper reported that the otters are common though difficult to observe. The seals were more readily seen and one seal was noted on the boat trip out to sample the site.

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

Figure 1 Map of Shoreline Observations

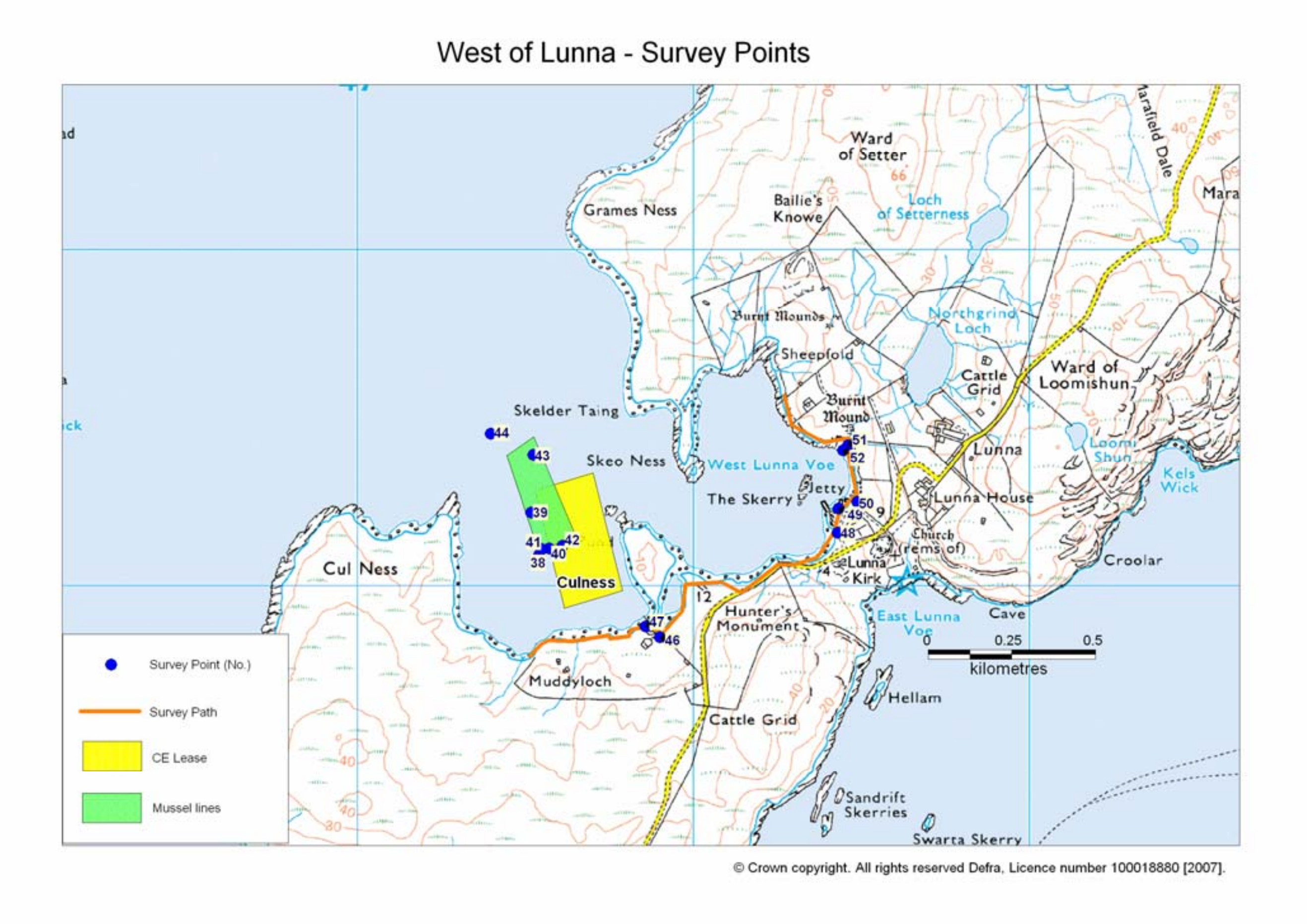


Table 1 Shoreline Observations

No.	Date	NGR	East	North	Associated photograph	Description
38	15 May 07	HU47540 69093	447540	1169093	Figure 4	Corner of ropes (3 lines)
39	15 May 07	HU47516 69219	447516	1169219	Figure 5	Mussel samples 1(top), 2(mid), 3(bottom). Water sample 1 sal 35.4, temp 9.5C
40	15 May 07	HU47570 69112	447570	1169112		Water sample 2, sal 34.9ppt, temp 9.5C
41	15 May 07	HU4754769110	447547	1169110		Corner of ropes
42	15 May 07	HU4761069120	447610	1169120	Figure 6	Corner of ropes
43	15 May 07	HU4752369391	447523	1169391		Corner of ropes
44	15 May 07	HU4739669454	447396	1169454		Trailing rope – navigational hazard
45	15 May 07	HU4548670708	445486	1170708		12 salmon cages to S of this mark
46	15 May 07	HU4789968848	447899	1168848	Figure 8	Tiny stream, sheep on beach
47	15 May 07	HU4785768880	447857	1168880	Figure 9	Broken pipes and 1 house, impossible to determine association. Water sample 3, sal 35ppt
48	15 May 07	HU4842869158	448428	1169158		Surface water pipe under road
49	15 May 07	HU4843169230	448431	1169230	Figure 10	2 jetties, 4 buoys, 1 dinghy, and 5 houses around this bay
50	15 May 07	HU4848769250	448487	1169250	Figure 11	Unknown water source, poss natural spring or dischg from house? Water sample 4.
51	15 May 07	HU4845969419	448459	1169419		Natural stream. 70cmx6cmx0.3m/s (approx) Water sample 5, 0ppt. 4 cows and 100 sheep counted from this point.
52	15 May 07	HU4844469404	448444	1169404	Figure 12	Water sample 6, 30ppt
53	15 May 07	-	-	-		Seal seen in water near salmon cages
54	15 May 07	-	-	-	Figure 7	Large barge 1-2 km NE of ropes
55	15 May 0	-	-	-		Ship anchored 4 km NE of ropes

Photos referenced in the table can be found attached as Figures 4 -15.

General Observations

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

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

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.

Agriculture is practiced within the crafting 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 infertility 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 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 pump 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. Samples were transferred to cool boxes for transport to the laboratory. All samples were analysed for *E. coli* content. Water sampled at the site was tested for salinity using a hand held refractometer. These readings are recorded in Table 1 as salinity in parts per thousand (ppt).

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

No.	Sample	E. coli (cfu/100ml)	Salinity (g/L)
1	W Lunna 1	1	30.1
2	W Lunna 2	<1	29.8
3	W Lunna 3	30	38.2
4	W Lunna 4	290	1.6
5	W Lunna 5	1.80E+03	0.5
6	W Lunna 6	310	23.5

Table 3 Shellfish Sample Results

No.	Sample	Type	E. coli (cfu/100g)	Depth
1	W Lunna 1	mussel	40	<1m
2	W Lunna 2	mussel	310	3-4m
3	W Lunna 3	mussel	310	8m

Figure 2 Water sample results map

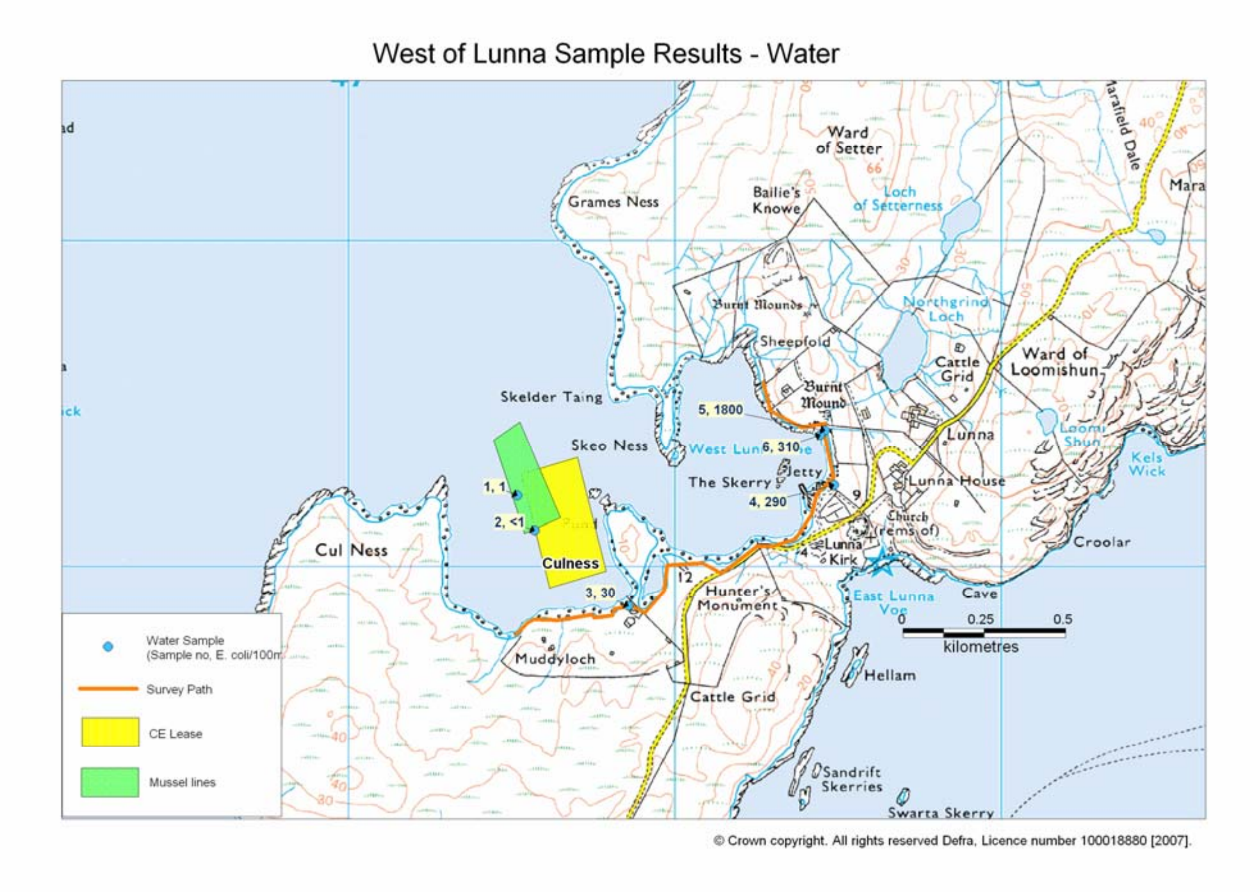
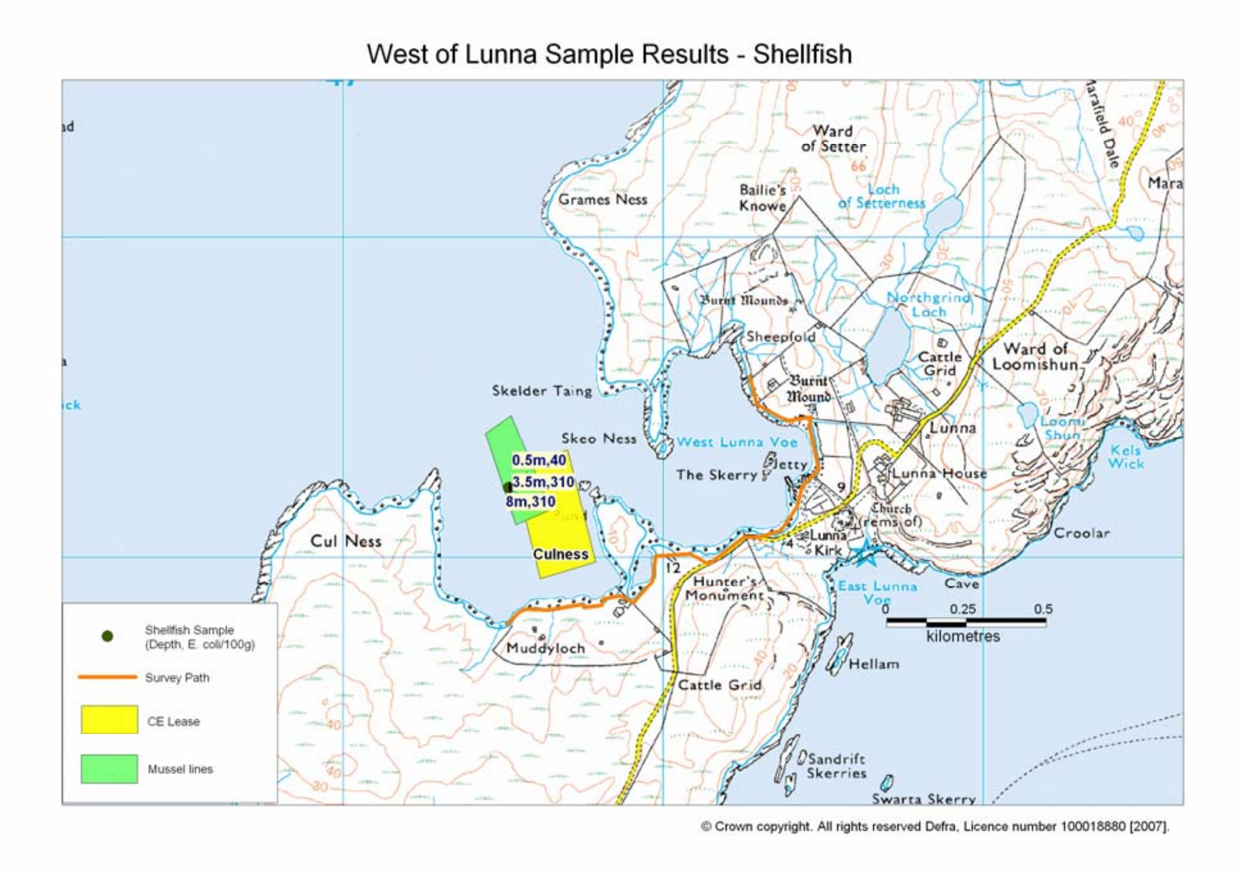


Figure 3 Shellfish sample results map



Photos

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Sampling Plan for West of Lunna

PRODUC-TION AREA	SITE NAME	SIN	SPECIES	TYPE OF FISH-ERY	NGR OF RMP	EAST	NORTH	TOLER-ANCE (M)	DEPTH (M)	METHOD OF SAMPLING	FREQ OF SAMPLING	LOCAL AUTHORITY	AUTHORISED SAMPLER(S)	LOCAL AUTHORITY LIAISON OFFICER
West of Lunna	Culness	SI 380 770 08	Mussels	Longline	HU 4759 6935	44759	116935	20	3-5	Hand	Monthly	Sheltand Islands	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.
Source: Kay, D. et al (2008) Faecal indicator organism concentrations in sewage and treated effluents. *Water Research* 42, 442-454.

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		

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

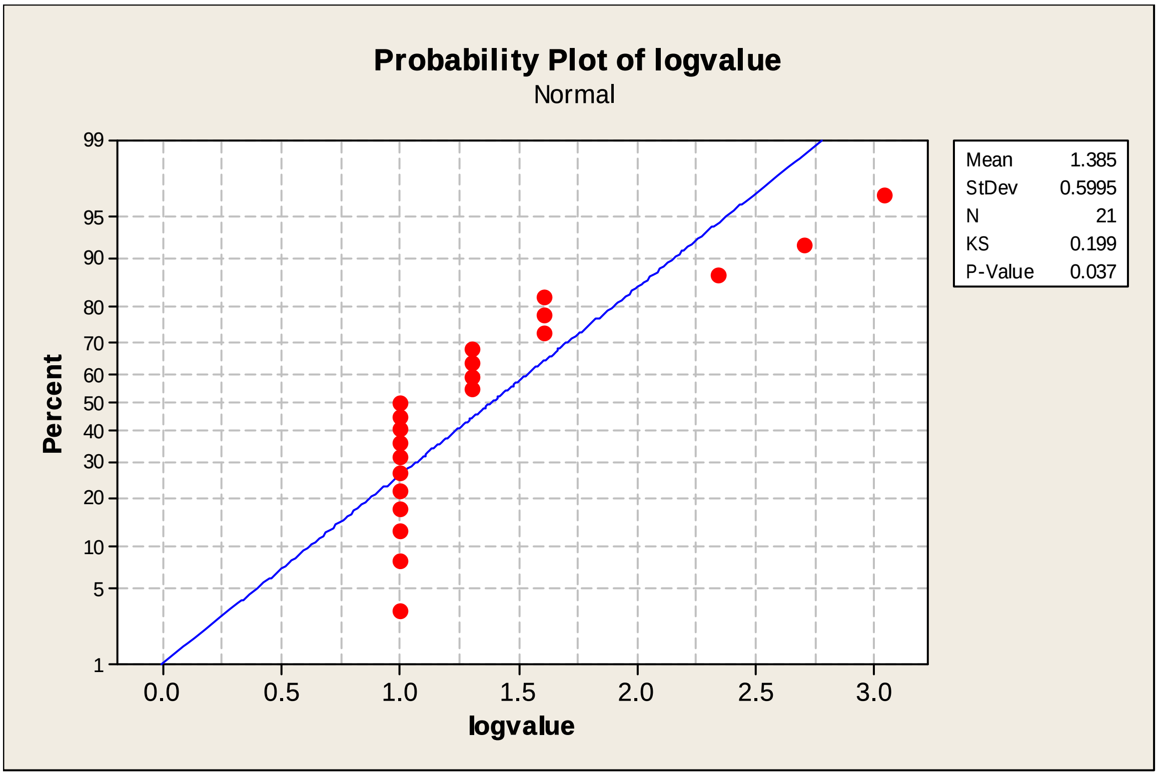
Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^8
Cow	230,000	23,600	5.4×10^9
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^8
Pig	3,300,000	2,700	8.9×10^8
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^8
Human	13,000,000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

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

Statistical Data

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

<u>Distribution of results on log scale (with Kolmogorov-Smirnov normality test results)</u>



11.1 T-test comparison of results from West of Lunna and Lunnaness

```
Two-sample T for logvalue

site         N   Mean  StDev  SE Mean
Lunnaness   13  1.273  0.578     0.16
West Lunna   8  1.568  0.626     0.22


Difference = mu (Lunnaness) - mu (West Lunna)
Estimate for difference:  -0.296
95% CI for difference:  (-0.882, 0.290)
T-Test of difference = 0 (vs not =): T-Value = -1.08  P-Value = 0.298  DF = 14
```

11.2 ANOVA comparison of results by season

```
Source  DF     SS     MS     F      P
season   3  1.533  0.511  1.54  0.241
Error   17  5.654  0.333
Total   20  7.187

S = 0.5767   R-Sq = 21.33%   R-Sq(adj) = 7.45%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -----+---------+---------+---------+----
1      7  1.2778  0.5203           (------*-------)
```

```
2       7  1.3717  0.6043            (-------*-------)
3       4  1.8866  0.7828                  (---------*----------)
4       3  1.0000  0.0000  (-----------*----------)
                           -----+---------+---------+---------+----
                              0.60      1.20      1.80      2.40

Pooled StDev = 0.5767
```

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.

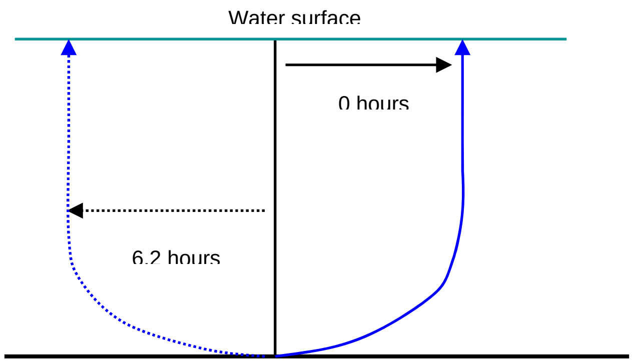
Background processes

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

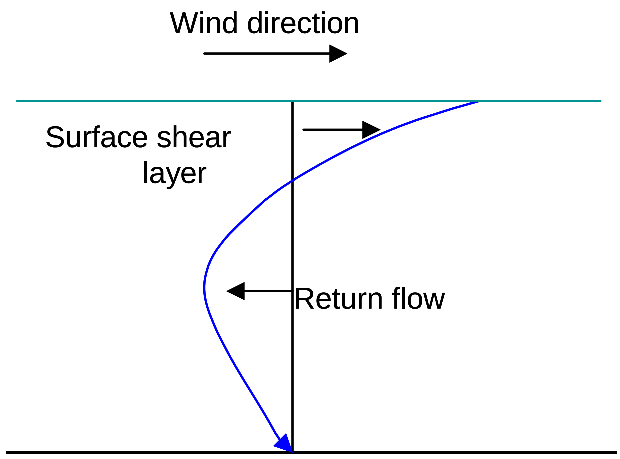
Tidal flows often dominate water movement over the short term (approximately 12 hours) and move material over the length of the *tidal excursion*. Tides move water back and forth over the tidal period often leading to only a small net movement over the 12 hours tidal cycle. This small net movement is 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)

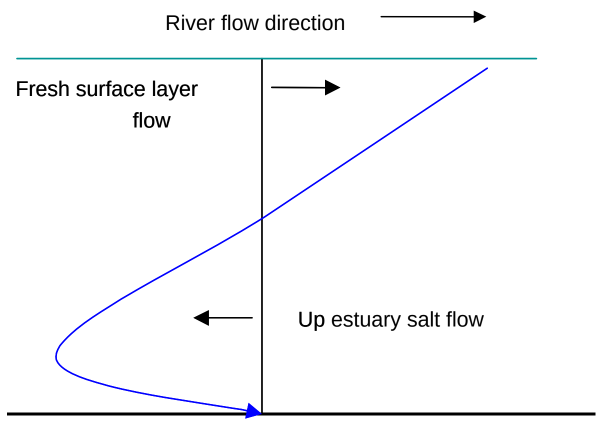


Figure 1. Typical vertical profiles for currents generated by different mechanisms. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main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

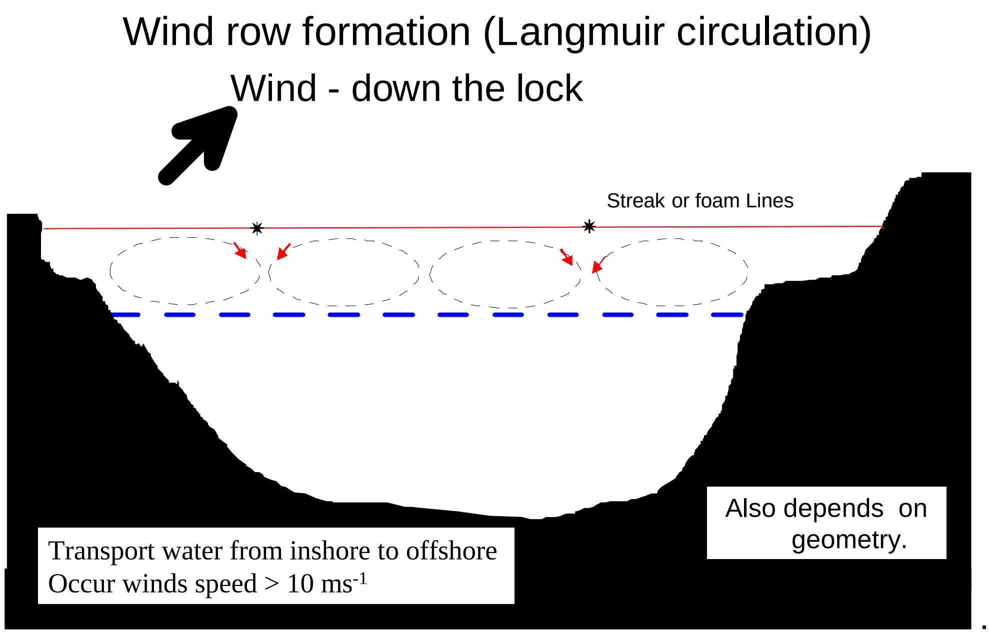


Figure 2: Schematic of wind driven 'wind row' currents. View is down the loch.The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.