Scottish Sanitary Survey Project

Sanitary Survey Report
Ronas Voe
SI 239
June 2008

Final Report Distribution – Ronas Voe

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

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

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Dr. Alan Lilly, Macaulay Land Research Institute

1. General description

Ronas Voe is located on the northwest side of the main island of Shetland. It is a long, narrow voe approximately 9 km in length and about 0.5 km wide in the production area. It has a maximum depth of 42 m at LAT, and contains two sills, one at 15 m depth and one at 9 m.

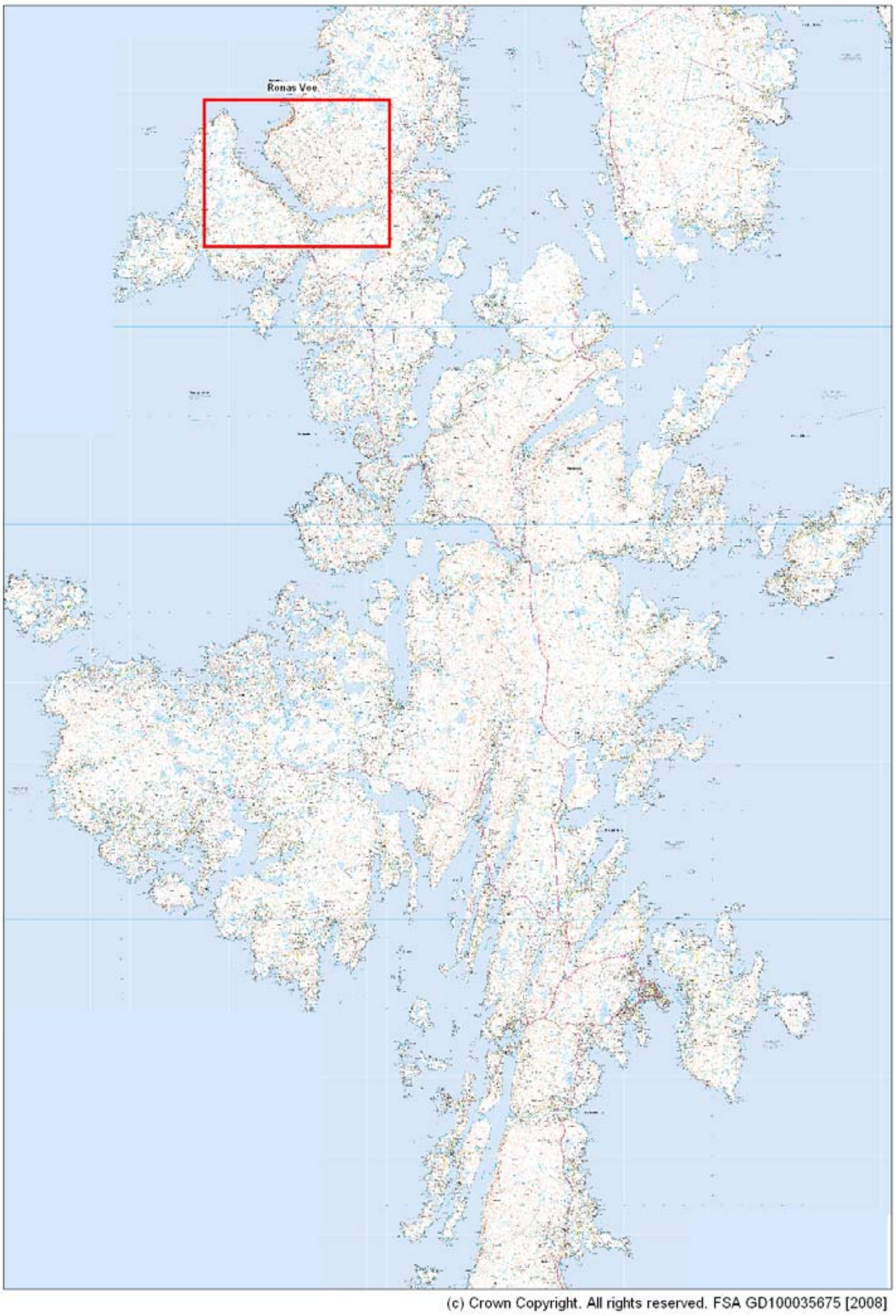

Figure 1.1 Location map of Ronas Voe

The sanitary survey was triggered by the score Ronas Voe received in the risk matrix. This site scored highly on the risk analysis due to a change in classification and unexpected results from monitoring.

2. Fishery

The fishery at Ronas Voe is comprised of one sheet farm and two long line mussel (*Mytilus* sp.) farms as listed in Table 1 below:

Table 1. Ronas Voe shellfish farms

Site	SIN	Species
South of Ayre of Teogs	SI 239 442 08	Common mussels
Ronas Voe	SI 239 441 08	Common mussels
Ronas Voe	SI 239 441 08	Common mussels

Current production area boundaries are given as the area east of the line drawn between HU 2916 8113 to HU 2940 8157 extending to MHWS.

The identified RMP for the production area does not lie within any of the three leases. The actual grid reference used for collecting RMP samples at this site is HU 32734 80905, which lies within the southern rope mussel farm at the Ronas Voe site.

At the South of Ayre of Teogs site at the western end of the production area, mussels are grown in four lines of sheets using the SMART system. The sheets are only two metres deep. The other two leases, designated Ronas Voe are conventional mussel lines at the upper end of the voe. These are both under the same ownership and site ID number. There are 3 sets of lines in each of these leases. 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. Harvesting is done in rotation with different lines set out in different years to allow harvesting of some stock every year. The harvester at Ronas Voe will harvest year round when possible in order to satisfy customer demand.

Spawning occurs in May, during which the meat yield declines substantially. Blooms of toxic algae typically occur during the summer, resulting in fishery closures during the summer months. These are unpredictable and sporadic, usually clearing up by September or October.

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

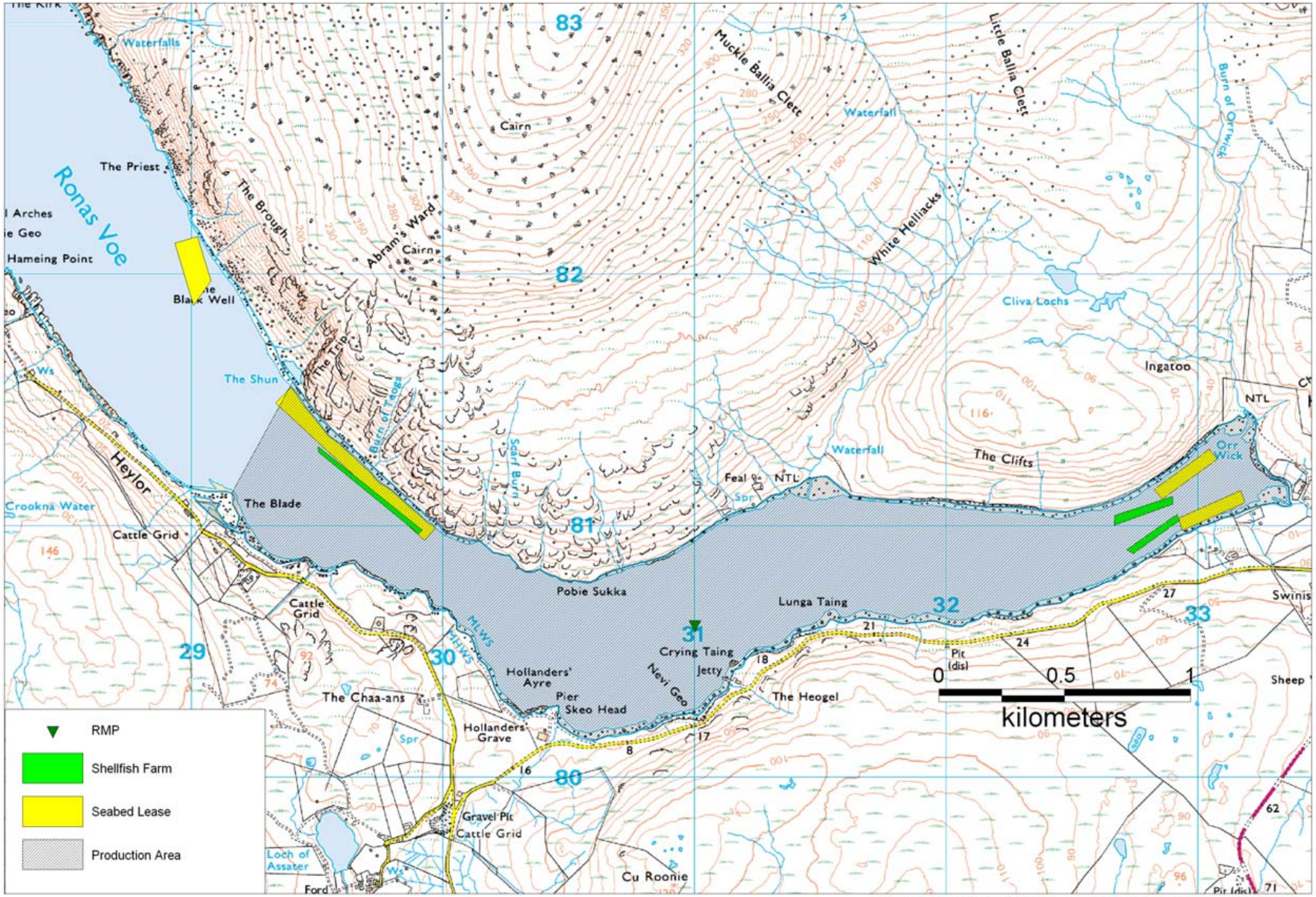

Figure 2.1 Ronas Voe Fishery

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 Ronas Voe.

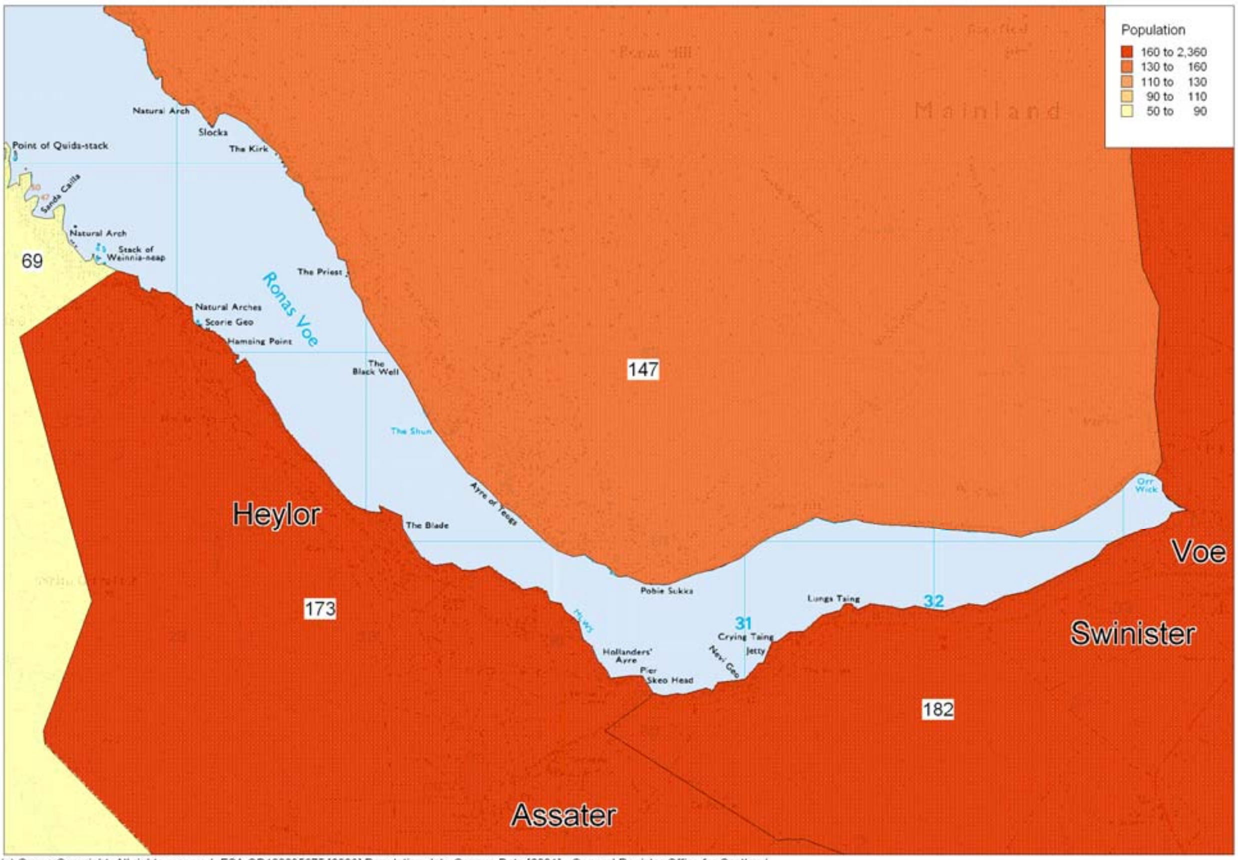

Figure 3.1 Population map for Ronas Voe

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

60RD000041	69
60RD000042	147
60RD000039	173
60RD000043	182

There are no settlements on the northern shore bordering immediately on the voe. On the southern side of the voe are the settlements of Heylor, Swinister, Assater and Voe. Most of the population is concentrated towards the eastern end of the shore and any associated faecal pollution from human sources will be concentrated within 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.

Overall, the voe is large and the population on its shores is sparse.

4. Sewage Discharges

According to Scottish Water and SEPA there are no known permitted sewage discharges into Ronas Voe at the time of writing this report. It is therefore assumed that all of the dwellings will be on private septic tanks.

During the shoreline survey however, a few sewage discharge pipes were observed. The observation are listed in Table 4.1 and their locations have been mapped in Figure 4.1.

Table 4.1 Sewage pipes observed during the shoreline survey

No	NGR	Description
1	HU 30457 80263 - 181	Sewage pipe
2	HU 30390 80237 - 182	15cm plastic sewage pipe
3	HU 29231 80956 - 188	30cm pipe
4	HU 29185 80949 - 189	Sewage pipe
5	HU 29238 80884 - 190	50cm sewage pipe

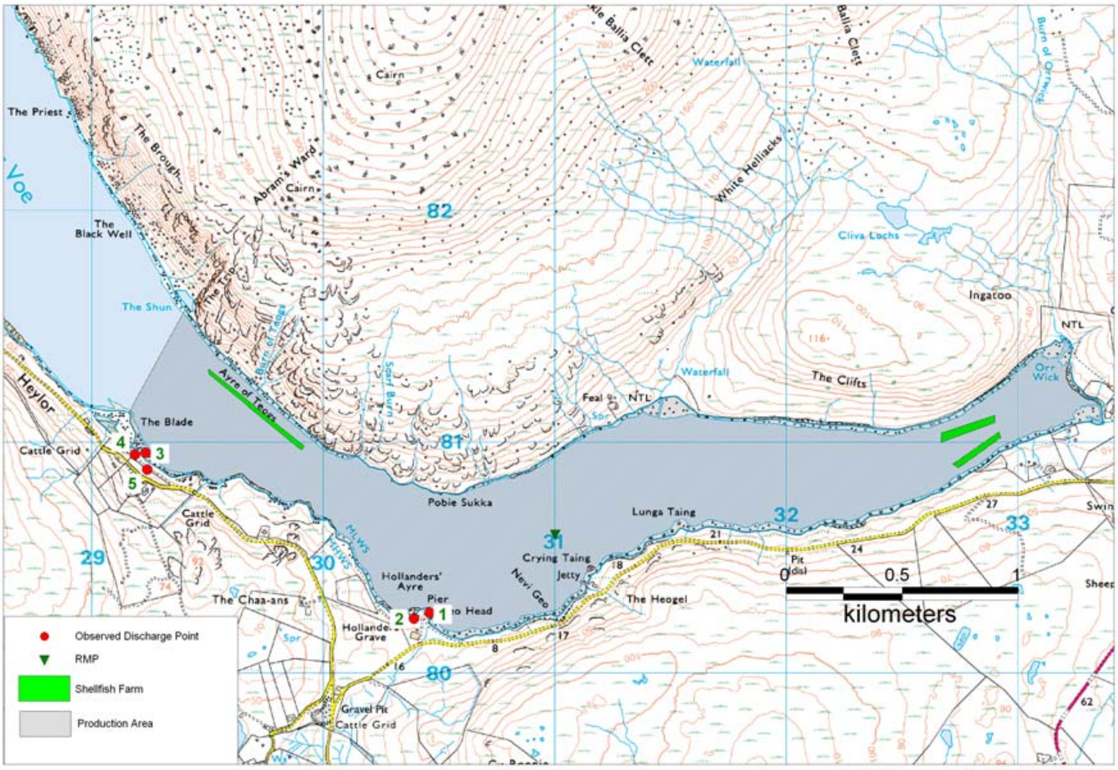

Figure 4.1 Map of discharge observations at Ronas Voe

Septic tank discharges 3,4, and 5 may adversely impact water quality around the Ayre of Teogs shellfish farm, though they are likely to be single dwelling discharges and are on the opposite side of the voe. As the voe is deep, it is likely that these discharges will be highly diluted. Discharges 1 and 2 are sufficiently distant that they are unlikely to adversely impact either of the farms. Additionally, the several dwellings on the south shore at the head of the voe may impact on the southern set of lines at the Ronas Voe site, although no explicit sewage inputs were seen here during the shoreline survey.

5. Geology and soils

Component soils and their associations were identified using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute. The relevant 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 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.

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

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

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

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

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

Maps were produced using these seven soil type groups and whether they are characteristically freely or poorly draining. The map of component soils and their associated drainage classes for the area surrounding Ronas Voe is provided in Figure 5.1.

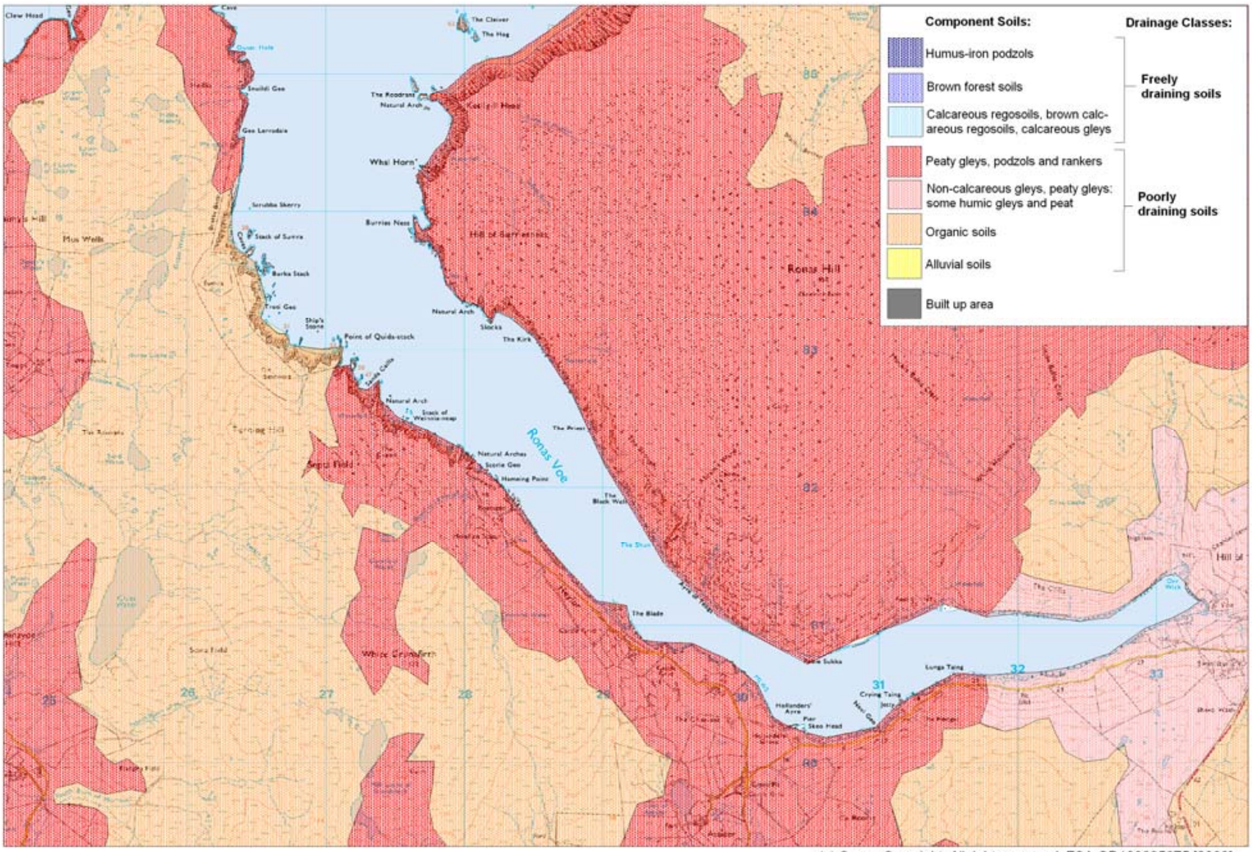

Figure 5.1 Component soils and drainage classes

There are three main types of component soils visible in this area. The most dominant is composed primarily of peaty gleys, (peaty) podzols and (peaty) rankers. This soil type dominates much of the eastern coast of Ronas Voe and some of the western stretch of coastline also. The second dominant component soil is organic soil. This covers a small stretch of coastline at the northwest tip of the voe and much of the inland on the western coastline and southeastern end. Surrounding the coastline at the bottom of the voe is the third component soil type, which is non-calcareous gleys, peaty gleys: some humic gleys and peat.

All these three are poorly draining soils so surface run off is likely to be high, as these component soils are often waterlogged. Thus the potential for runoff contaminated with *E. coli* from animal waste is high on both sides of the voe.

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:

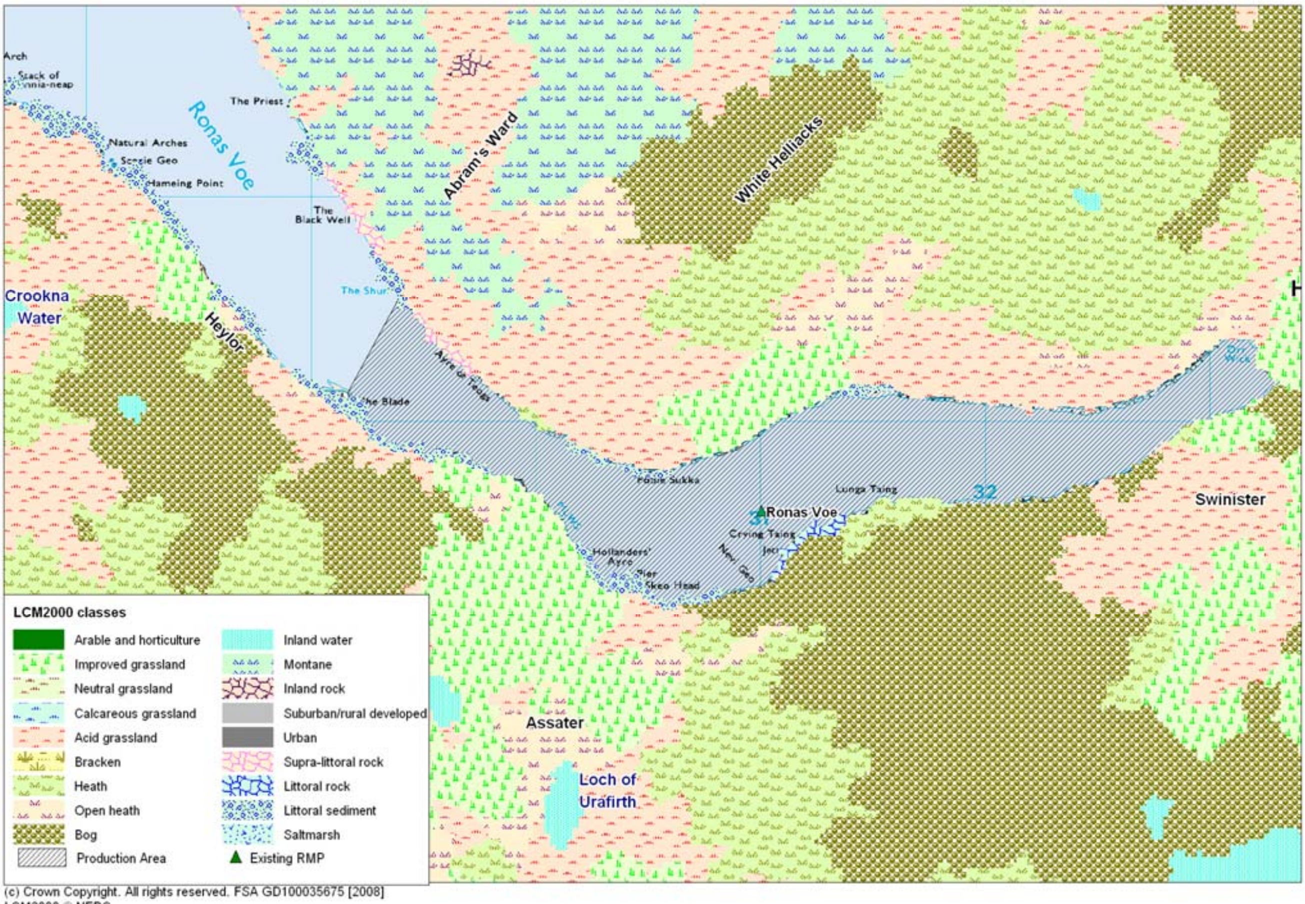

Figure 6.1 LCM2000 class data map for Ronas Voe

Five main types of land cover surround Ronas Voe, including improved grassland, acid grassland, bog, heath and open heath. On the southern coastline of the voe improved grassland, bog and acid grassland dominate the coastline. On the northern coastline of the voe, acid grassland and improved grassland cover much of the coast, with heath, bog and montane further inland. Along much of the coastline of Ronas Voe there are areas of littoral sediment and littoral rock.

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.

Although most of the land surrounding Ronas Voe falls into the category giving the lowest contribution, there are significant areas of improved grassland located close to the shellfish farms from which more heavily contaminated runoff might be expected.

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 21st – 22nd September and 5th December 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. Cattle however, are farmed near the eastern head of the voe. The cattle here are constrained in the area that they can graze but were seen directly around the stream in the vicinity and on the foreshore (see Figure 7.1). The geographical spread of contamination at the shores is likely to be concentrated to this area and therefore needs to be assumed that this factor should be taken into account when identifying the location of a routine monitoring point (RMP).

Local information is not available for the seasonal numbers of livestock in the area surrounding Ronas Voe, although it is likely that numbers of livestock increase significantly following lambing in the spring, and decrease in the autumn when lambs are sent to market. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1.

Of relevance to the sampling plan, the most significant concentration of livestock was the cattle at the head of the voe, which may have localised effects on water quality here. Sheep are present at fairly consistent densities on the surrounding land, and while they will affect the water quality in the voe, this will apply evenly to all areas.

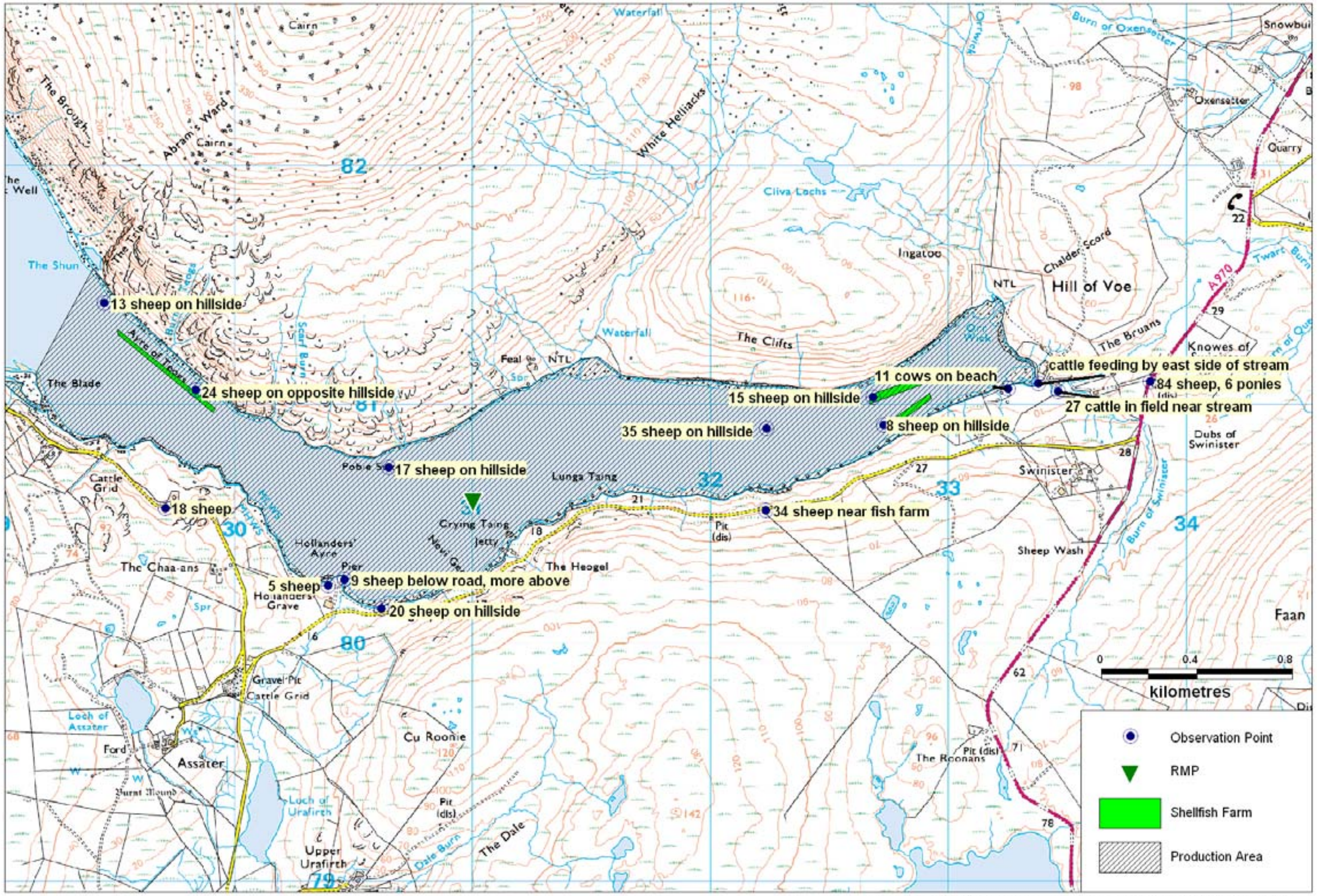

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Figure 7.1 Map of livestock observations at Ronas Voe

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 *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).

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

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

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

Both bacterial and viral pathogens affecting humans and livestock have been found in wild and captive seals. *Salmonella* and *Campylobacter* spp., some of which were antibiotic-resistant, were isolated from juvenile Northern elephant seals (*Mirounga angustirostris*) with *Salmonella* found in 36.9% of animals stranded on the California coast (Stoddard et al 2005). *Salmonella* and *Campylobacter* are both enteric pathogens that can cause acute illness in humans and it is postulated that the elephant seals were picking up resistant bacteria from exposure to human sewage waste.

One of the *Salmonella* species isolated from the elephant seals, *Salmonella typhimurium*, is carried by a number of animal species and has been isolated from cattle, pigs, sheep, poultry, ducks, geese and game birds in England and Wales.

Serovar DT104, also associated with a wide variety of animal species, can cause severe disease in humans and is multi-drug resistant (Poppe et al 1998).

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

8.2 Cetaceans

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

Table 8.1 Cetacean sightings, Shetland 2001-2002

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

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

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

Due to the relatively shallow sills, and distance from open sea, Ronas Voe is unlikely to host whales or larger cetacean species. It is likely that dolphins may be found from time to time in outer reaches of the voe and the impact of their presence is, as with pinnipeds, likely to be fleeting and unpredictable.

8.3 Birds

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

Table 8.2 Breeding seabirds, Shetland 2000

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

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

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

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 were over 3000 apparently occupied sites or nests around the area of Ronas Voe noted during a sea based survey undertaken in June 2000, mainly towards the mouth of the voe. This will equate to roughly 6000-9000 individuals.

An arctic tern colony is reportedly located at a gravel pit near The Blade, which is on the opposite shore to the Ayre of Teogs site. Given water depths and distance, it is unlikely that this will significantly impact water quality at the shellfish farm.

Gulls were seen during the shoreline survey in the vicinity of the mussel farms but not in great numbers.

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 close to the runoff.

Waterfowl (ducks and geese) are present in Shetland at various times of the year. Eider ducks feed on the mussel lines and are present, sometimes in groups of 100 or more, throughout the year, although none were noted during the shoreline survey. A flock of approximately 100 geese were disturbed from near the head of the loch by survey staff during the second shoreline visit in December 2007, although it is uncertain whether these were passing through or overwintering here.

The locations and numbers of these birds are likely to vary and be relatively unpredictable in specific location and duration so their impact on the fishery will not be considered in determining the sampling plan.

8.4 Other

A large number of rabbits and rabbit droppings were seen during the course of the shoreline survey. These were spread out around the voe, and so although constituting a source of diffuse pollution, their presence will not materially affect the sampling plan.

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

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

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

8.5 Summary

Wildlife impact generally to the fisheries is likely to be relatively minor compared to the impact of diffuse pollution due to livestock. Any impact is likely to be limited in area and unpredictable in time and as a consequence, will not materially affect the sampling plan for Ronas Voe.

9. Meteorological data

The nearest weather station is located at Baltasound, approximately 41 km to the north east of the production area. Uninterrupted rainfall data is available for Baltasound from 1/1/2003 to 31/10/2006 inclusive. It is likely that rainfall patterns at Baltasound are broadly similar to those on Ronas Voe and surrounding land, but may differ slightly on any given day due to the distance between the two. The nearest weather station for which wind data is available is located at Lerwick, approximately 43 km to the south east of the production area. It is expected that wind patterns in Ronas Voe are broadly similar to those experienced at Lerwick, but it is possible the differences in local topography affect wind patterns and that the distance between the weather station and the production area may result in differences 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 Ronas 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 summarise the pattern of rainfall recorded at Baltasound. The box and whisker plots summarize the distribution of individual daily rainfall values (observations) by year (Figure 9.2) or by month (Figure 9.4). The grey box represents the middle 50% of the observations, with the median at the midline. The whiskers extend to the largest or smallest observations up to 1.5 times the box height above or below the box. Individual observations falling outside the box and whiskers are represented by the symbol *.

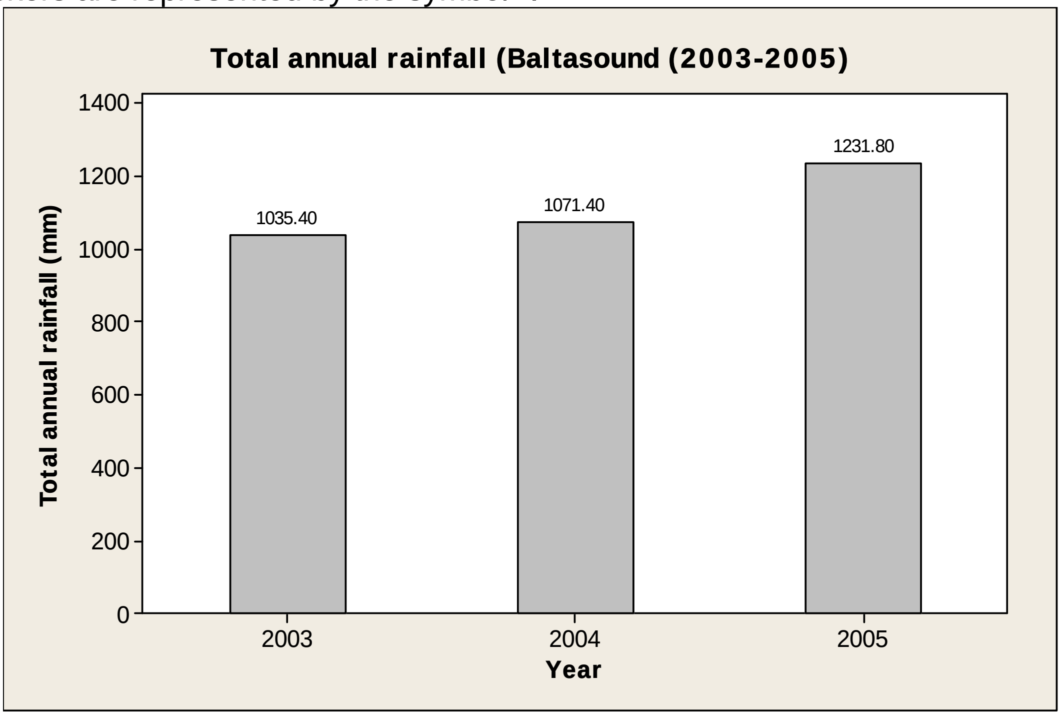

Figure 9.1 Annual rainfall at Baltasound 2003-2005

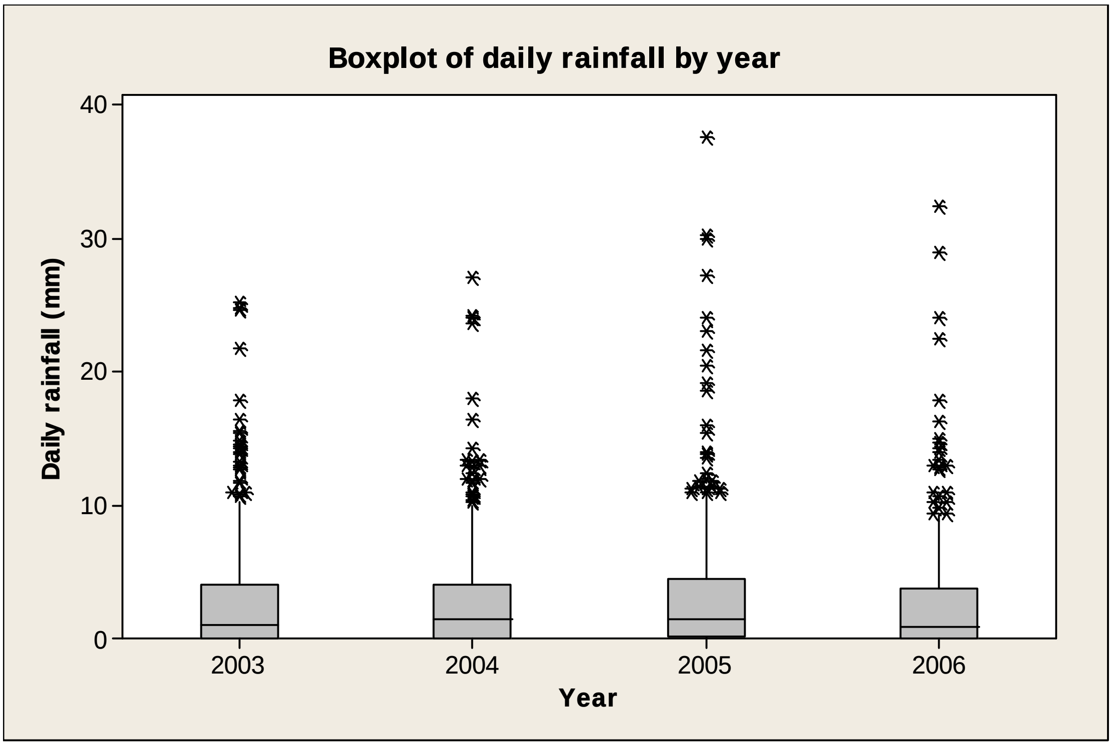

Figure 9.2 Boxplot of daily rainfall at Baltasound by year (no data for November and December 2006)

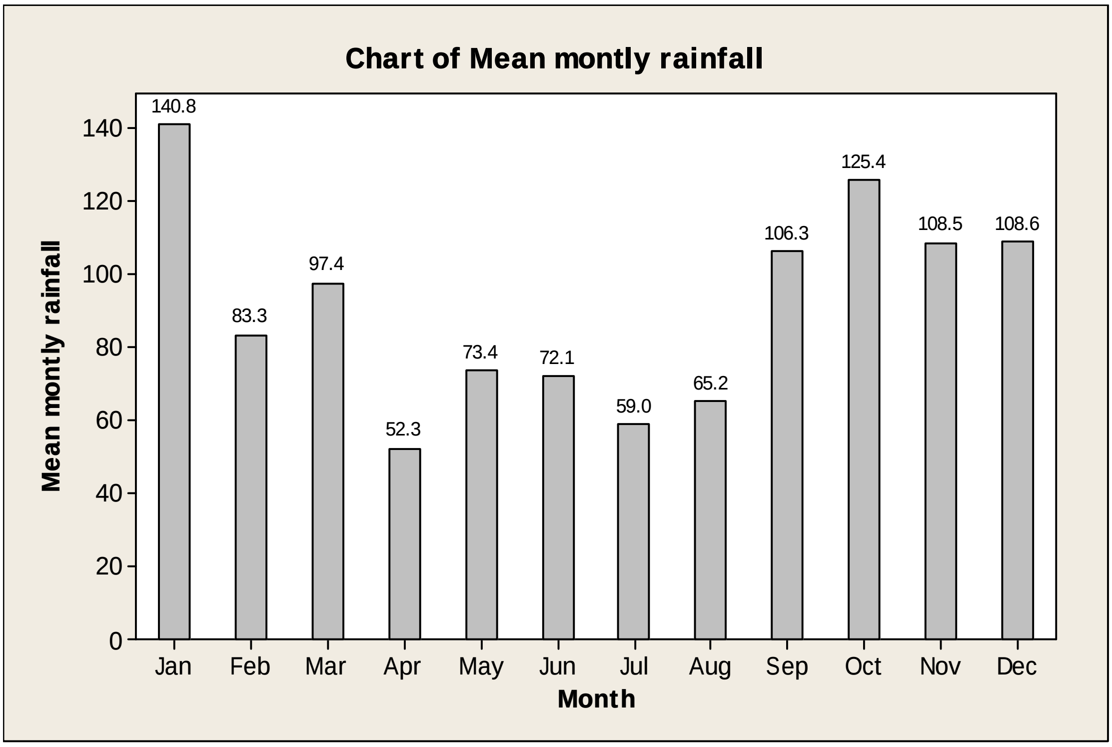

Figure 9.3 Mean monthly rainfall at Baltasound 2003-2006 (no data for November and December 2006)

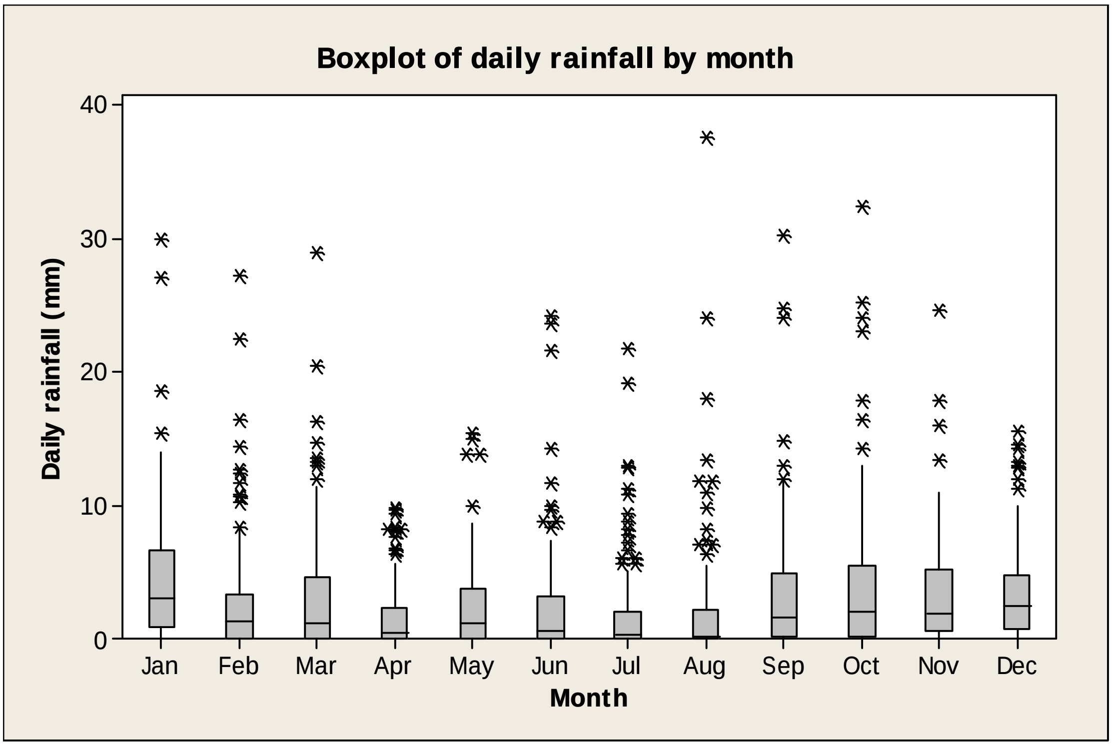

Figure 9.4 Boxplot of daily rainfall values at Baltasound by month (no data for November and December 2006)

2005 was a wetter year than either 2003 or 2004. The wettest months were September through to January. For the period considered here (1/1/2003-31/10/2006), only 27.0% of days experienced no rainfall. 45.6% of days experienced rainfall of 1mm or less.

It was not possible to draw a meaningful comparison between rainfall at Baltasound and that of Scotland as a whole with the data available. 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.

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

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

9.2 Wind

Wind data collected at the Lerwick weather station is summarised by season and presented in figures 9.5 to 9.9.

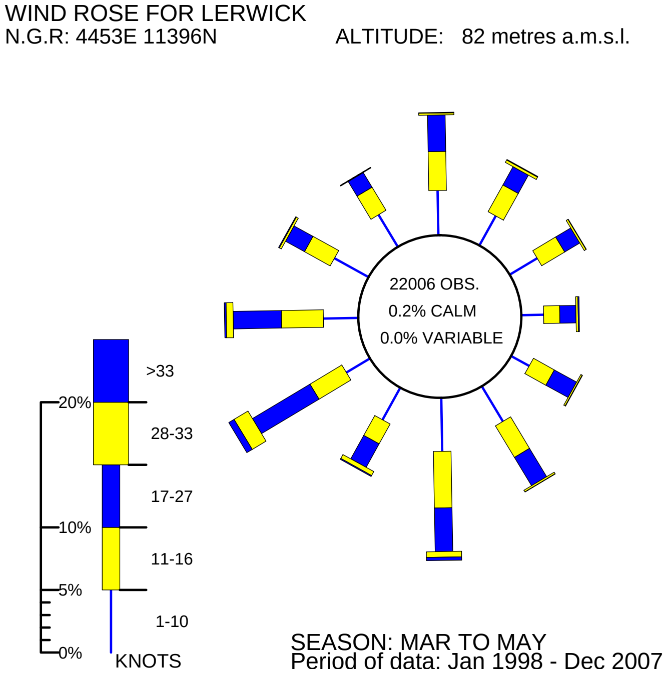

Figure 9.5 Wind rose for Lerwick (March to May)

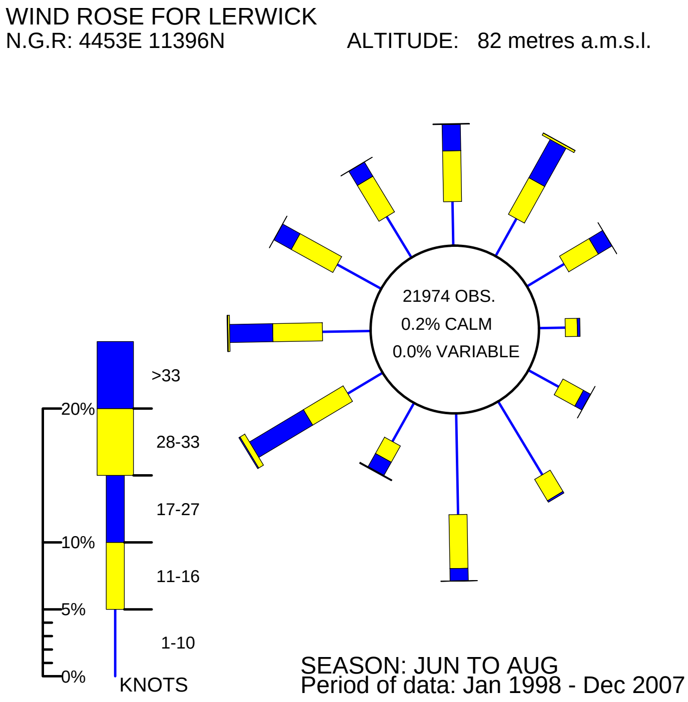

Figure 9.6 Wind rose for Lerwick (June to August)

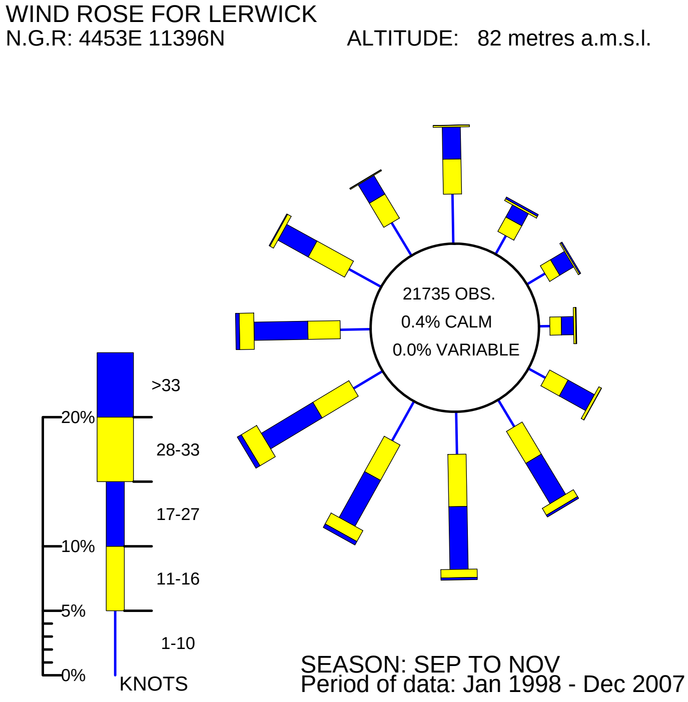

Figure 9.7 Wind rose for Lerwick (September to November)

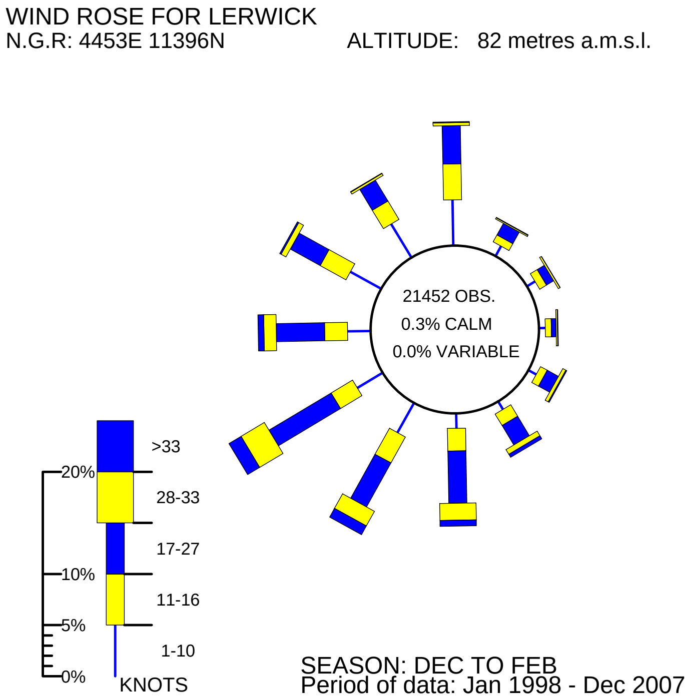

Figure 9.8 Wind rose for Lerwick (December to February)

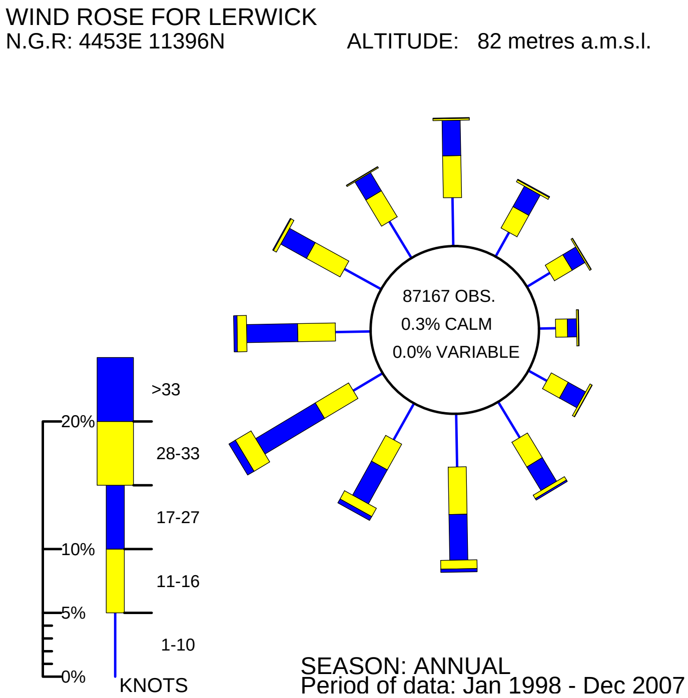

Figure 9.9 Wind rose for Lerwick (Annual)

Shetland is one of the more windy areas of Scotland with a much higher frequency of gales than the country as a whole. The wind roses show that the overall prevailing direction of the wind is from the south and west, and when it is blowing from this direction it is likely to be stronger than when blowing from other directions. Winds are generally lighter during the summer months and strongest in the winter. The mouth of Ronas Voe faces north bending round to an east west aspect at its head. It is long and narrow, and surrounded by high ground which whilst providing shelter for the inner reaches where the mussel farms are located, will also funnel winds up or down the voe.

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

Wind effects are likely to cause significant changes in water circulation within the voe as tidally influenced movements of water are relatively weak. 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 path of which will depend on wind direction and local bathymetry. Strong winter winds will increase the circulation of water and hence dilution of contamination from point sources within the voe. Winds from certain directions may create currents which carry contamination from point sources to the shellfish farms. No major point sources within the voe have been identified, with sources of contamination limited to a few private septic tanks in small settlements located to the south shore, as well as a number of small watercourses draining pasture land at various points around the voe. Strong westerly winds may either have the effect of entraining fresh water from the small rivers near the head of the voe, which will likely affect the Ronas Voe site, or conversely, may increase their movement seaward via countercurrents.

10. Current and historical classification status

The area has been classified for production since 2001. The classification history is presented in Table 10.1. Currently, the area is classified as seasonal A/B. The area contains two active sites over three crown estates leases all growing mussels. A map of the current production area is presented in Figure 10.1.

Table 10.1 Classification history

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	A	A	A	A	A	A	B	B	B	B	B	B
2002	A	A	A	A	A	A	A	A	A	A	A	A
2003	A	A	A	A	A	A	B	B	B	B	A	A
2004	A	A	A	A	A	B	B	B	B	A	A	A
2005	A	A	A	A	A	A	B	B	A	A	A	A
2006	A	A	A	A	A	A	A	A	A	A	A	A
2007	A	A	A	A	A	B	B	B	B	B	B	B

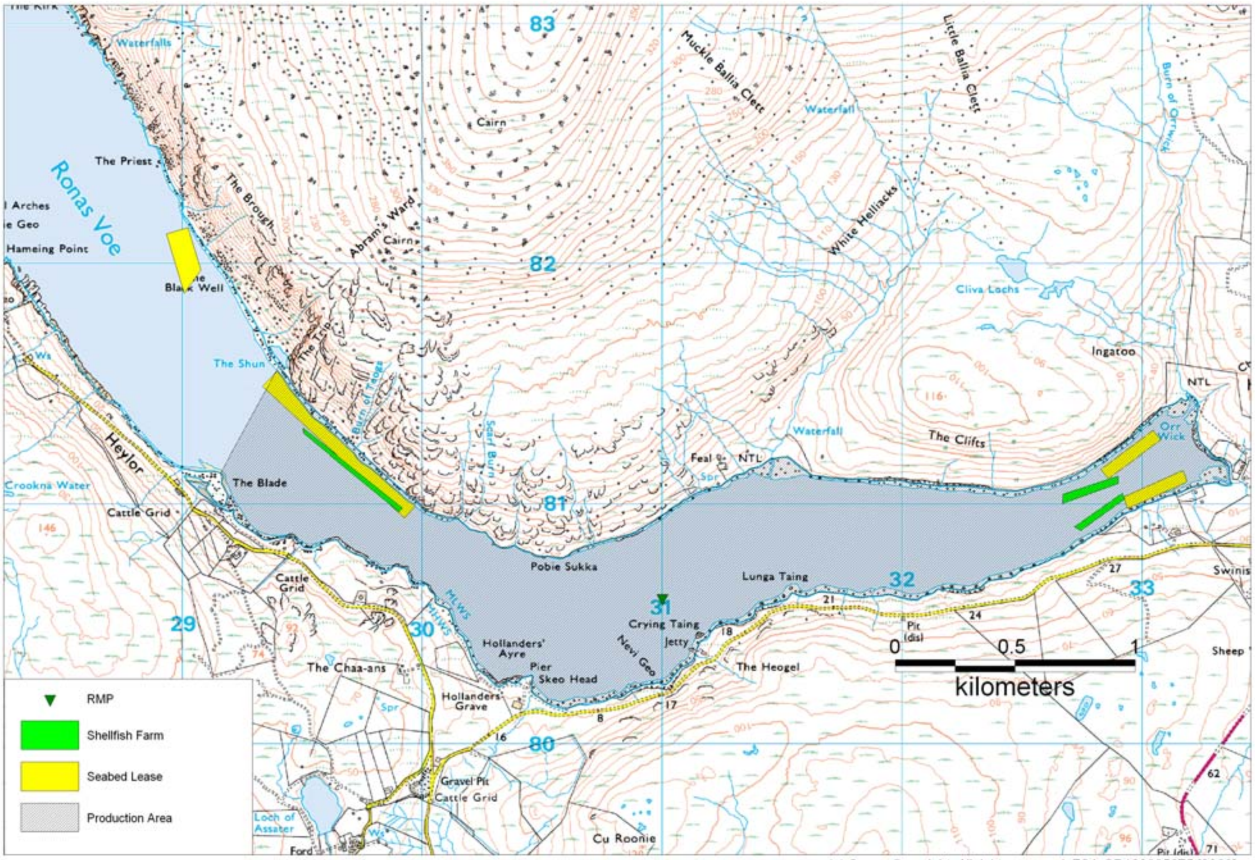

Figure 10.1 Map of current Ronas Voe production area

11. Historical *E. coli* data

11.1 Validation of historical data

All mussel samples taken from Ronas Voe 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. No samples were rejected on the basis of major geographical discrepancies. In the 25 instances where the result was reported as <20, it was assigned a nominal value of 10 for the purposes of graphical presentation and analysis. In the one instance where the result was reported as >18000, it was assigned a nominal value of 36000 for the purposes of graphical presentation and analysis. All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intervalvular fluid.

11.2 Summary of microbiological results by sites

Common mussels were sampled from two sites within the production area as shown on Figure 11.1 and in Table 11.1.

Table 11.1 Summary of results from Ronas Voe

Sampling summary			
Production area	Ronas Voe	Ronas Voe	Ronas Voe
Site	Ronas Voe	South of Ayre of Teogs	Both sites combined
Species	Common mussels	Common mussels	Common mussels
SIN	SI 239 441 08	SI 239 442 08	SI 239
Location	HU310806	HU298811	HU310806 and HU298811
Location of RMP	HU310806	none	HU310806
Total no of samples	74	43	117
No. 1999	6	0	6
No. 2000	4	0	4
No. 2001	11	0	11
No. 2002	9	0	9
No. 2003	10	7	17
No. 2004	10	12	22
No. 2005	12	12	24
No. 2006	12	12	24
Results Summary			
Minimum	<20	<20	<20
Maximum	>18000	1300	>18000
Median	45	20	40
Geometric mean	68.9	37.0	54.8
90 percentile	500	192	500
95 percentile	750	472	710
No. exceeding 230/100g	17 (23%)	3 (7%)	20 (17%)
No. exceeding 1000/100g	3 (4%)	1 (2%)	4 (3%)
No. exceeding 4600/100g	1 (1%)	0 (0%)	1 (1%)
No. exceeding 18000/100g	1 (1%)	0 (0%)	1 (1%)

The RMP should lie within one of the two mussel farms in the Ronas Voe site but is reported to lie approximately 1.7 km to the west of these. As there are no shellfish located at that point, the samples reported from the Ronas Voe mussel site have been assigned to a point on the actual mussel farm. Geometric mean *E. coli* result by site and by year are presented in Figure 11.1.

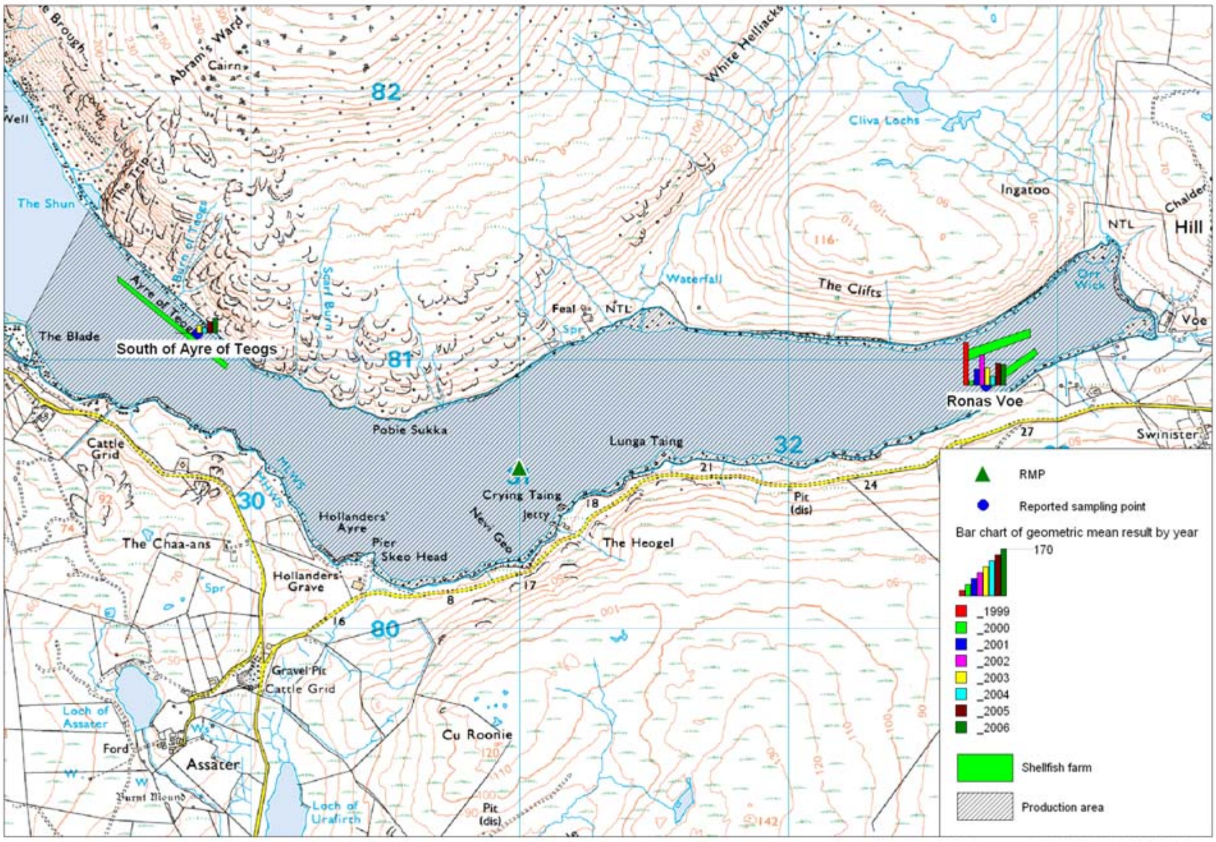

Figure 11.1 Map of geometric mean *E. coli* result (mpn/100g) by year by site

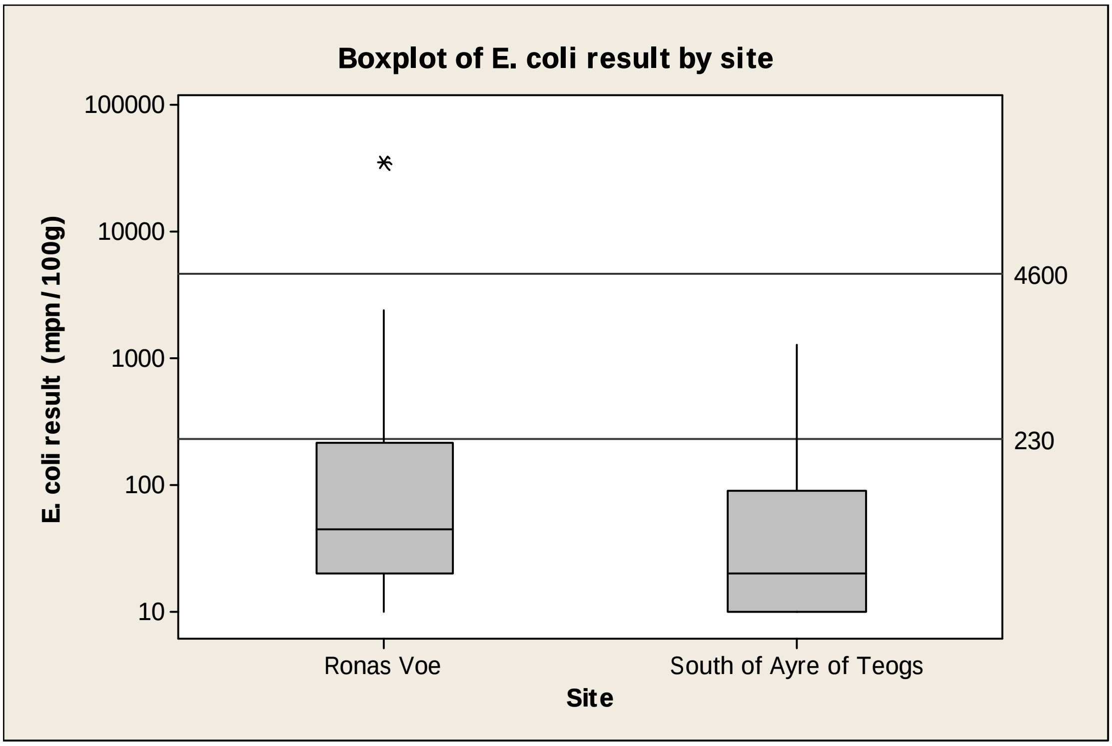

Figure 11.2 Boxplot of *E. coli* result by site

A comparison of all results reveals that results obtained for South of Ayre of Teogs are lower than those obtained for Ronas Voe (T-test, T=2.31, p=0.023, Appendix 4). On 19 occasions both sites were sampled on the same day and hence under the same environmental conditions, thereby providing the opportunity for a more robust comparison. A comparison of these results also revealed that results for South of Ayre of Teogs were lower than those obtained for Ronas Voe (paired T-test, T=2.45, p=0.0234, Appendix 4).

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 Ronas Voe. Both are fitted with trend 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. Similar plots, with data for each site shown separately are presented in Figures 11.5 to 11.8. Figure 11.9 presents the geometric mean of results by month (+ 2 times the standard error).

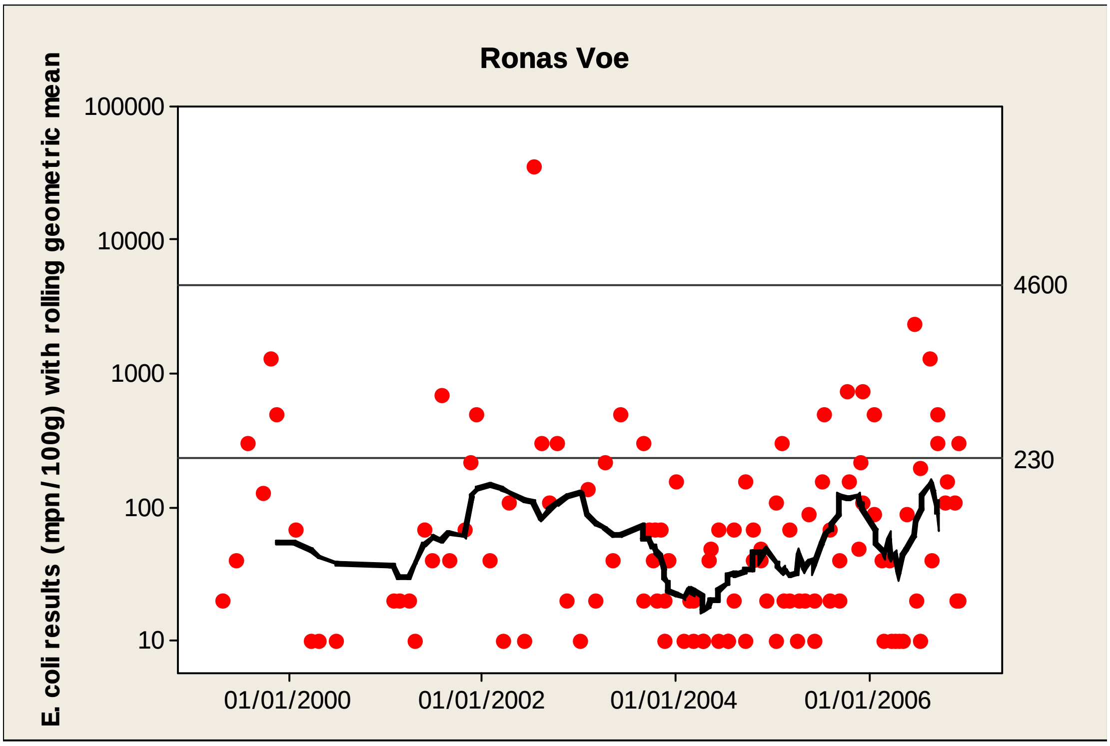

Figure 11.3 Scatterplot of results by date with rolling geometric mean (both sites combined)

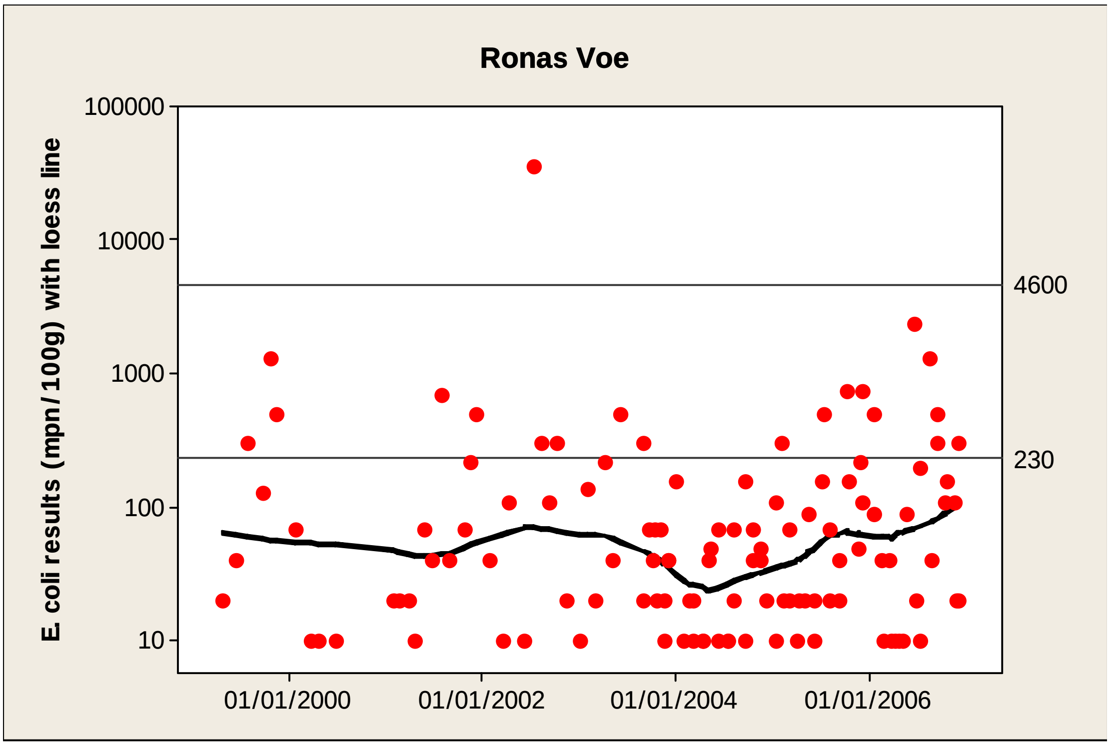

Figure 11.4 Scatterplot of results by date with loess smoother (both sites combined)

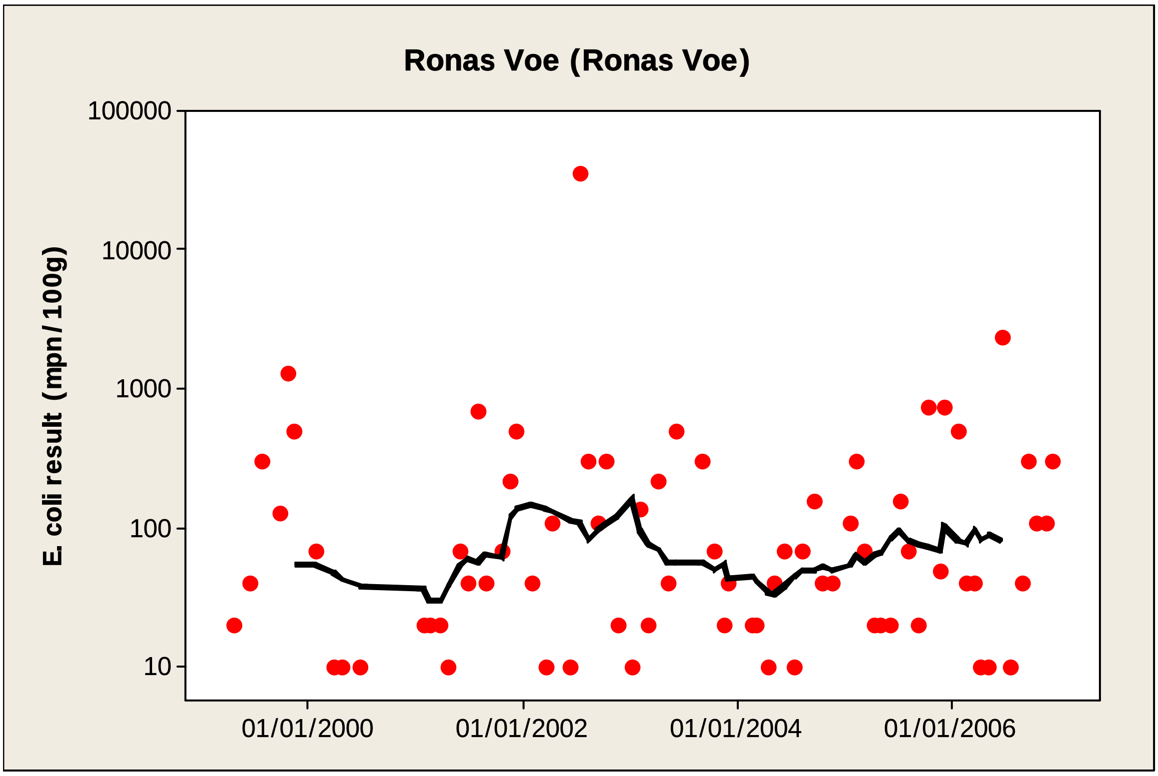

Figure 11.5 Scatterplot of results by date with rolling geometric mean (Ronas Voe)

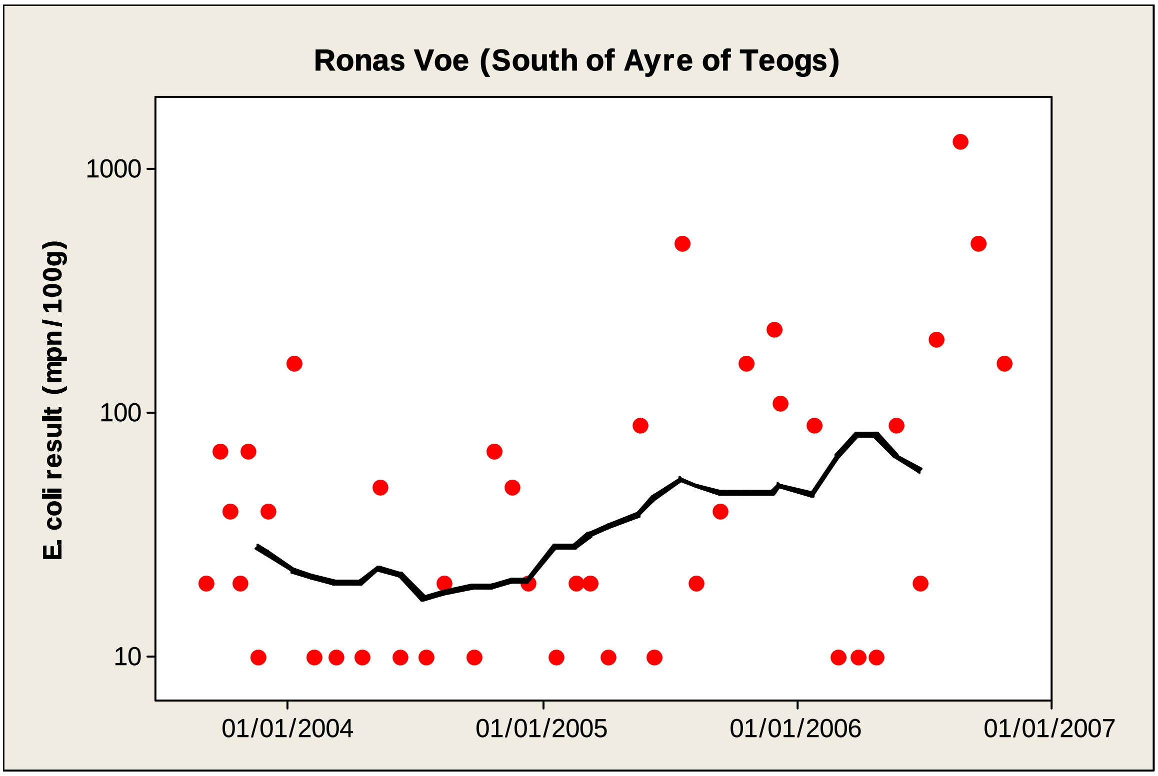

Figure 11.6 Scatterplot of results by date with rolling geometric mean (South of Ayre of Teogs)

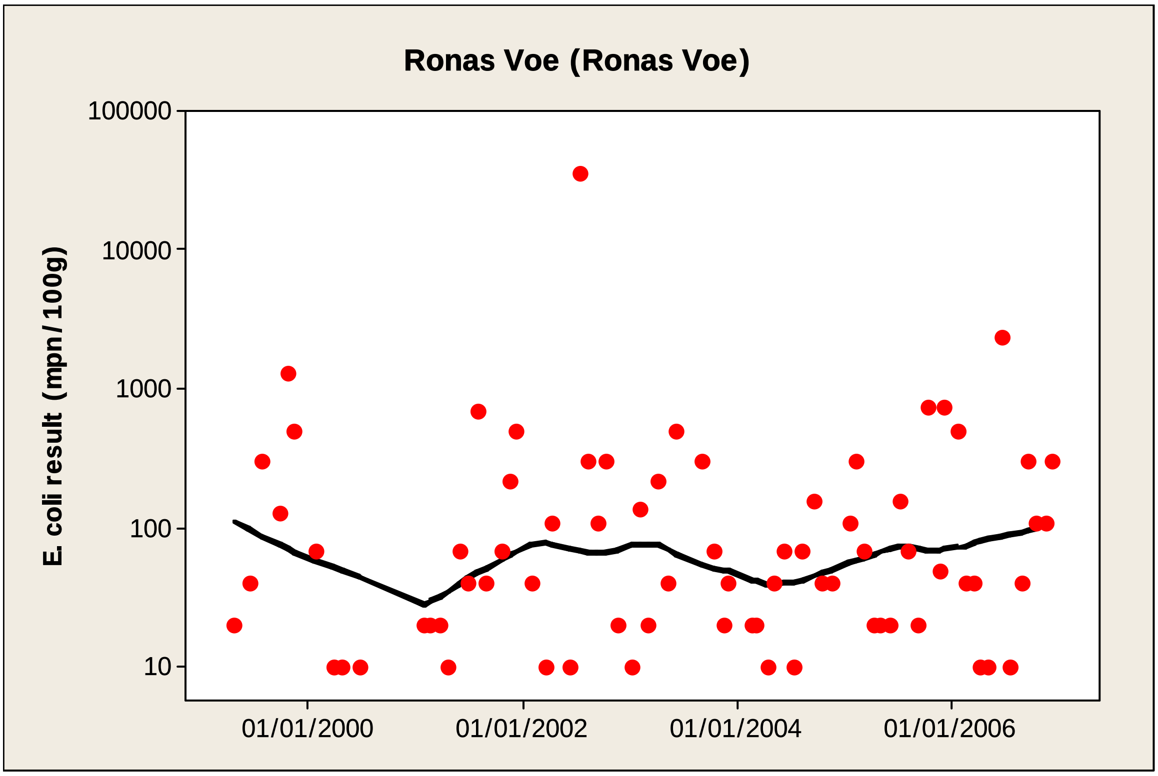

Figure 11.7 Scatterplot of results by date with loess smoother (Ronas Voe)

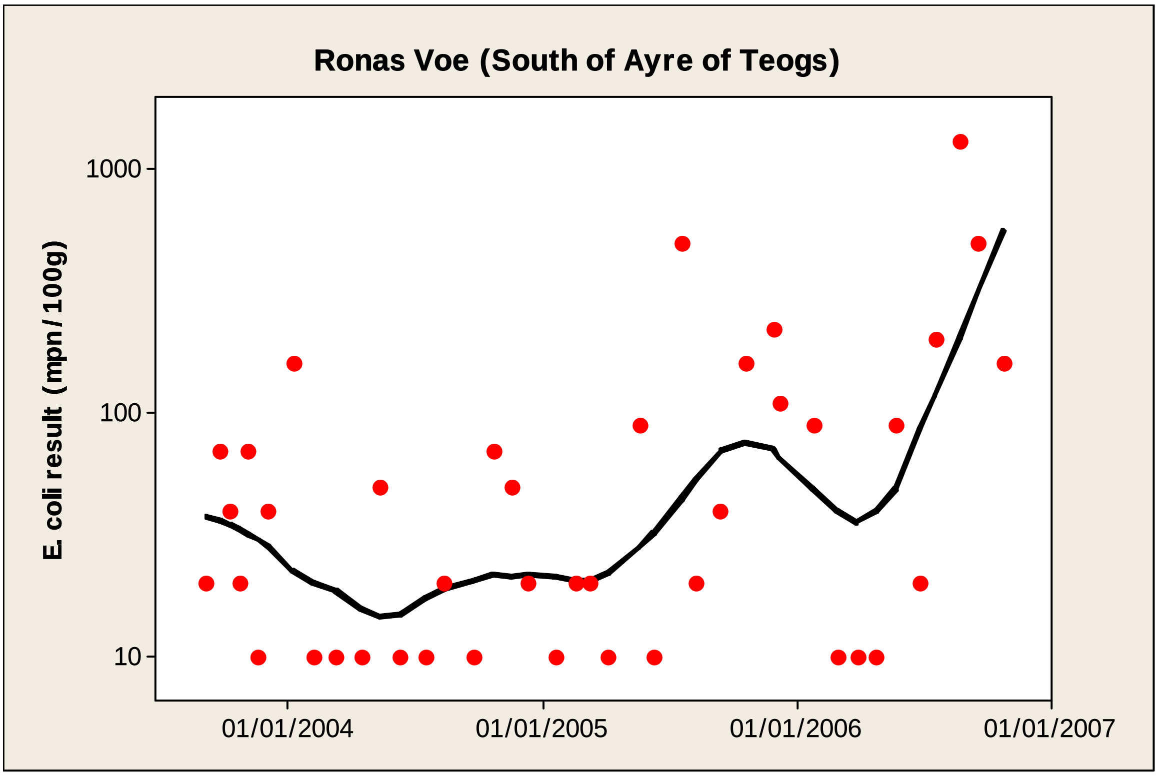

Figure 11.8 Scatterplot of results by date with loess smoother (South of Ayre of Teogs)

Figures 11.6 and 11.8 suggest a recent deterioration in microbiological quality at the South of Ayre of Teogs site. Aside from this, no trends or cycles are apparent from Figures 11.3 to 11.8.

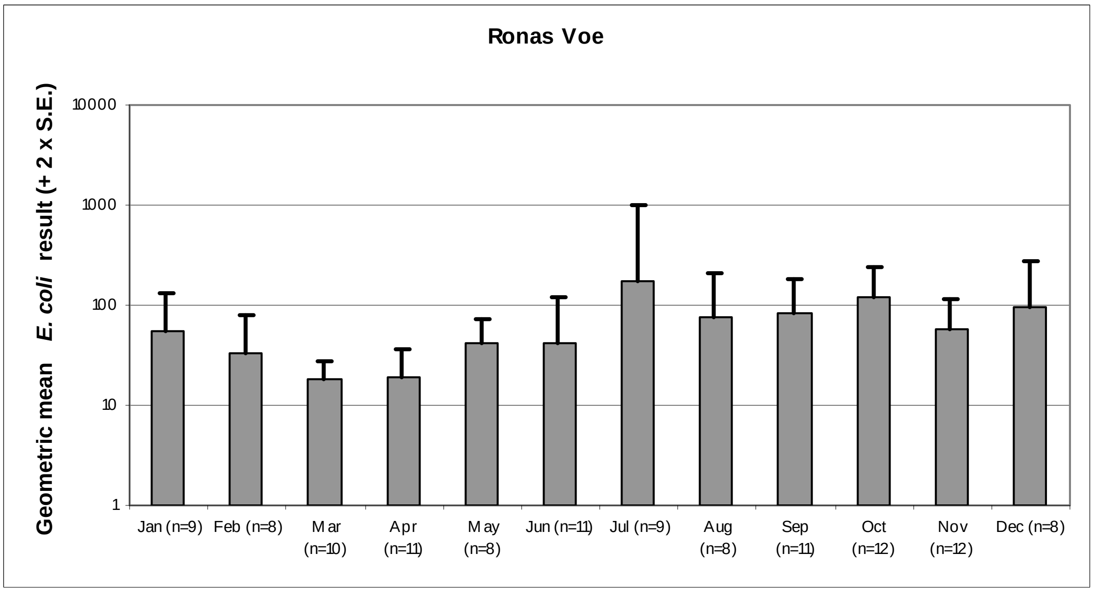

Figure 11.9 Geometric mean result by month (both sites combined)

Highest mean results were in July, and lowest mean results occurred in March and April.

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. This analysis considers the 117 samples taken from Ronas Voe from 1999 to the end of 2006.

11.4.1 Analysis of results by season

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

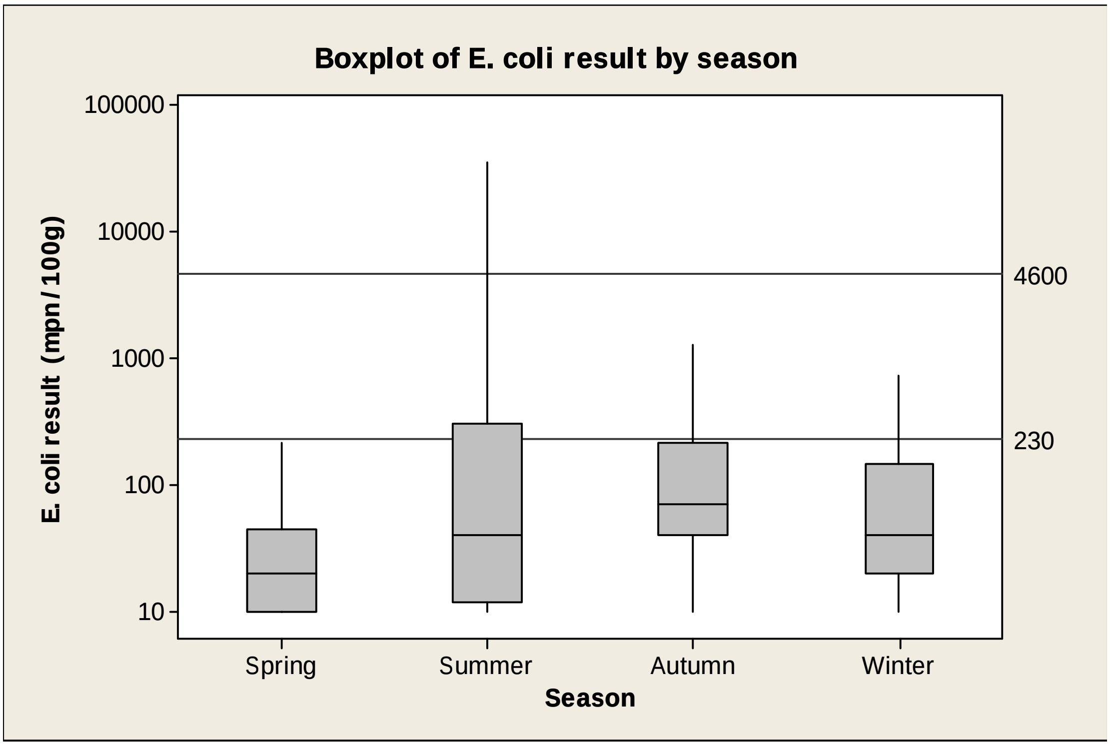

Figure 11.10 Boxplot of result by season (both sites combined)

A significant seasonal effect was observed (One-way ANOVA, p=0.003, Appendix 4). A post ANOVA test indicated that results were lower in the spring than in the summer and autumn (Tukeys comparison, Appendix 4).

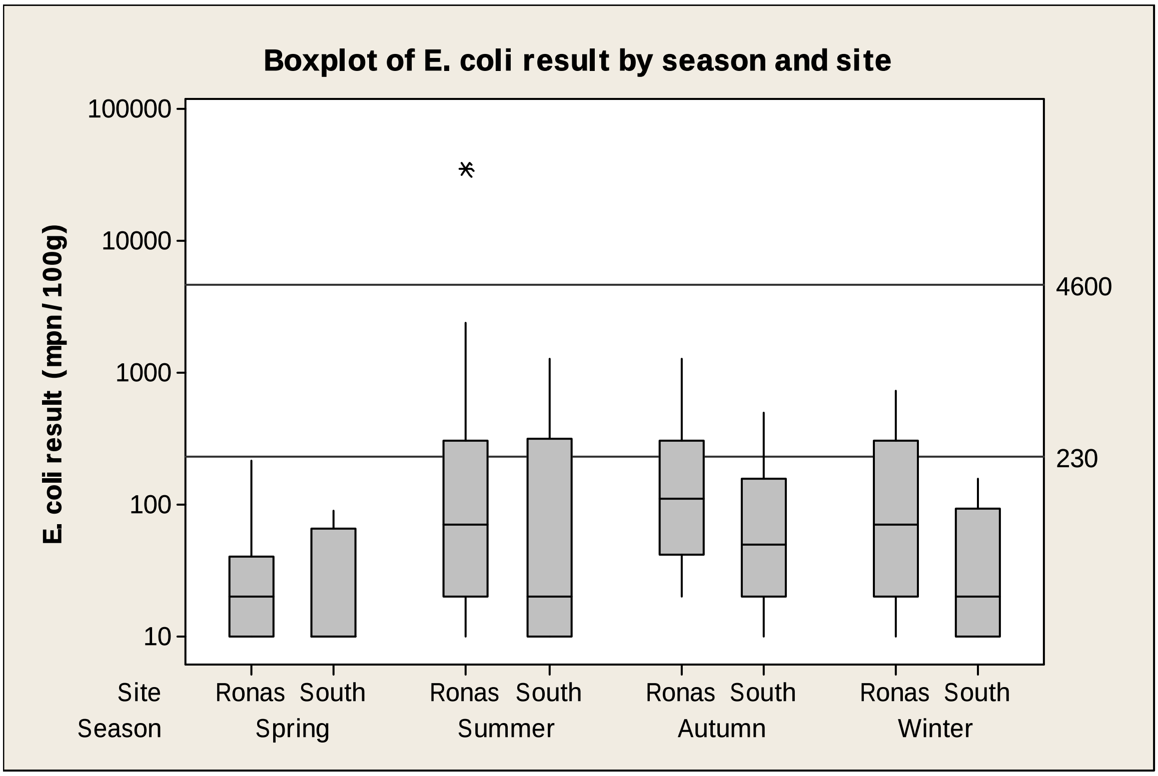

Figure 11.11 Boxplot of result by season and site

When the results from the two sites were compared to season separately, the relationship was significant for the Ronas Voe site (One-way ANOVA, p=0.005, Appendix 4) but not the South of Ayre of Teogs site (One-way ANOVA, p=0.341, Appendix 4). A post ANOVA test indicated that results were lower in the spring than in the summer and autumn for the Ronas Voe site (Tukeys comparison, Appendix 4). It must be noted however that more samples were gathered from the Ronas Voe site (74) than from South of Ayre of Teogs (43).

11.4.2 Analysis of results by recent rainfall

The nearest weather station is Baltasound, approximately 41 km to the north east of the production area for which uninterrupted rainfall data is available for 1/1/2003 to 31/10/2006 inclusive.

The coefficient of determination was calculated for *E. coli* results and rainfall in the previous 2 days at Baltasound. Figure 11.10 presents a scatterplotsof *E. coli* result and rainfall. Figure 11.11 and 11.12 present boxplots of results by rainfall quartile (quartile 1 = 0 to 0.80 mm, quartile 2 = 0.80 to 3.60 mm, quartile 3 = 3.60 to 8.525 mm, quartile 4 = more than 8.525 mm).

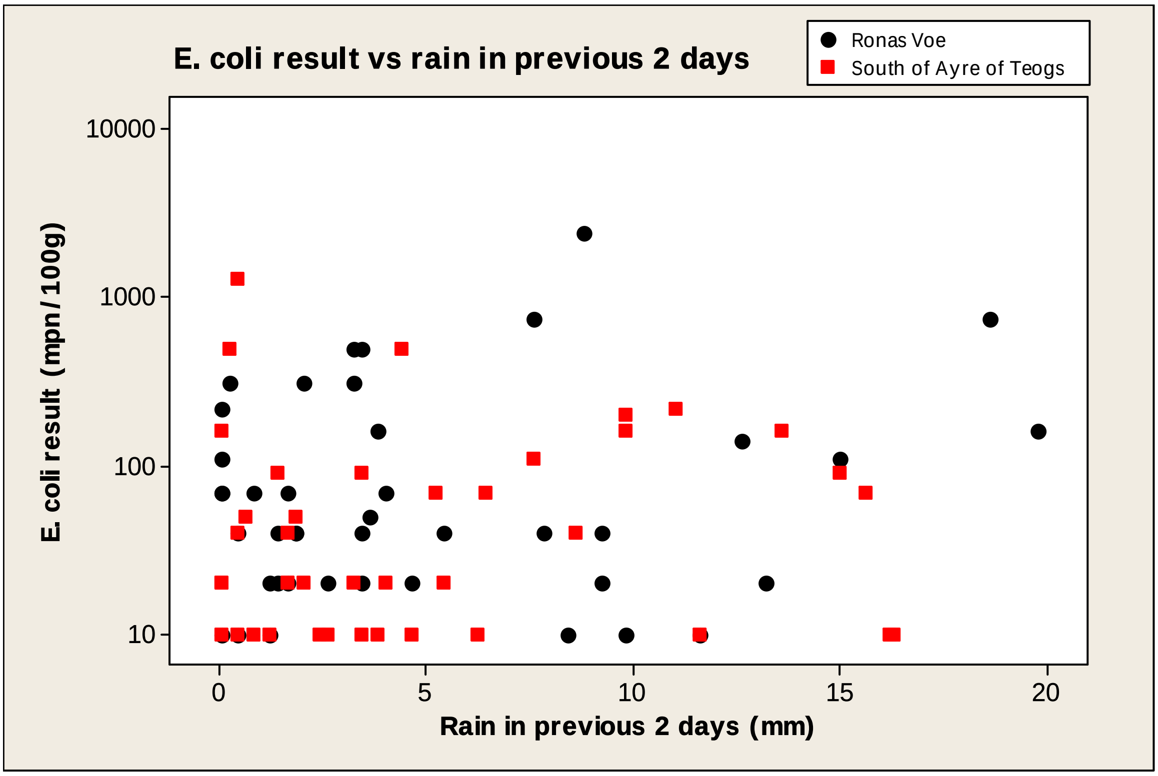

Figure 11.12 Scatterplot of result against rainfall in previous 2 days

The coefficients of determination indicate that there is no relationship between the *E. coli* result and the rainfall in the previous two days either when both sites are considered together (Adjusted R-sq=0.3%, p=0.266, Appendix 4), or for South of Ayre of Teogs (Adjusted R-sq=0.0%, p=0.627, Appendix 4) or Ronas Voe separately (Adjusted R-sq=0.4%, p=0.287, Appendix 4).

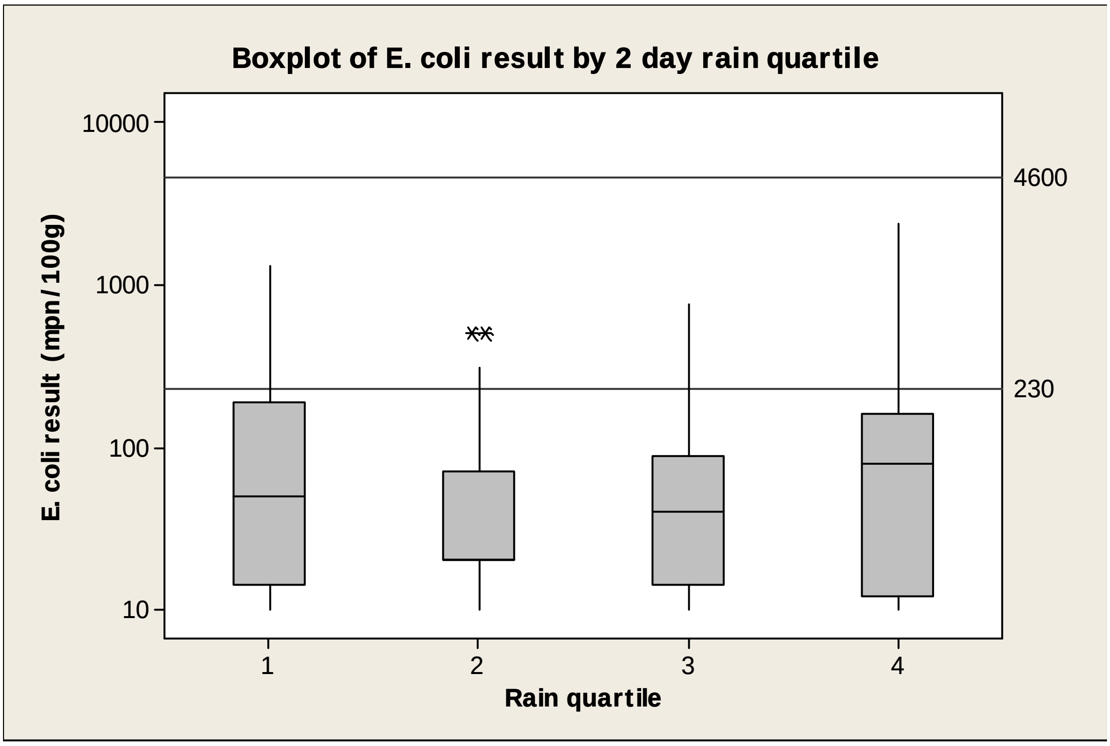

Figure 11.13 Boxplot of result by rainfall in previous 2 days quartile (both sites combined)

No difference between the results for each rain quartile was found when both sites were considered together (One way ANOVA, p=0.476, Appendix 4).

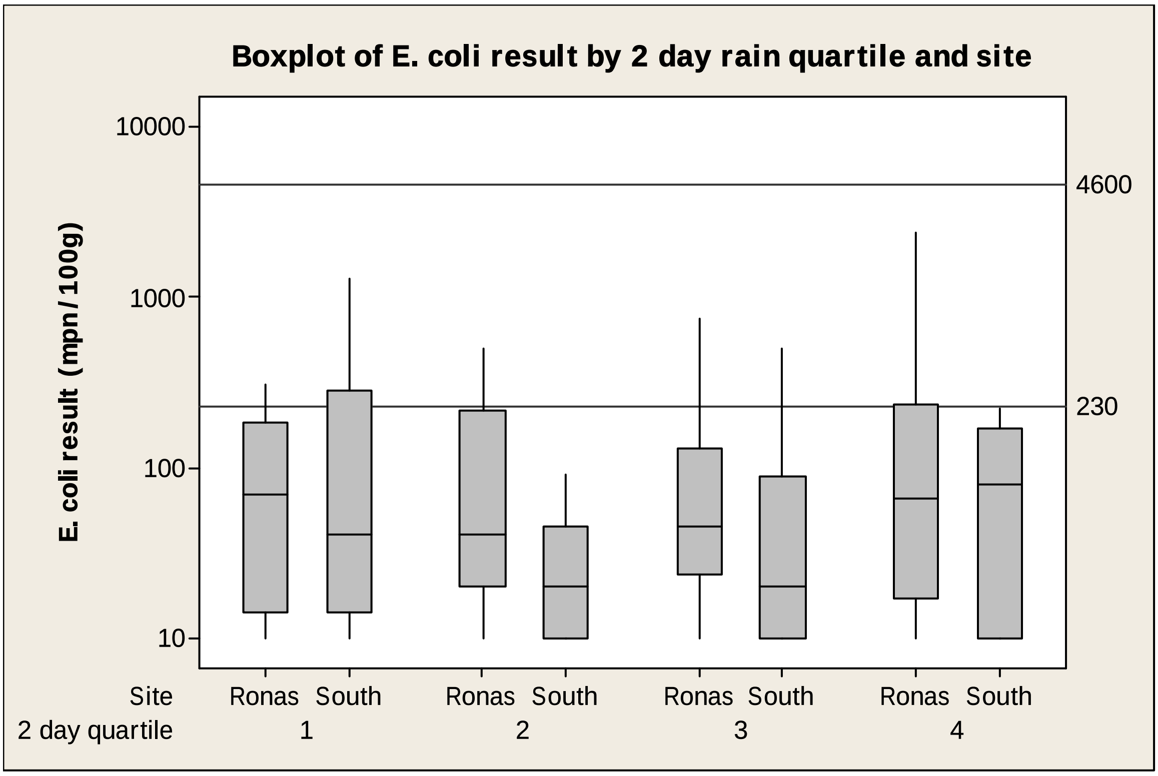

Figure 11.14 Boxplot of result by rainfall in previous 2 days quartile and site

When considered separately, no significant difference was found between the results for each rain quartile for either South of Ayre of Teogs (One way ANOVA, p=0.250, Appendix 4) or Ronas Voe (One way ANOVA, p=0.955, Appendix 4).

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 Ronas Voe was investigated in an identical manner to the above. Interquartile ranges for 7 days rainfall were as follows; quartile 1 = 0 to 9.1 mm; quartile 2 = 9.1 to 17.8 mm; quartile 3 = 17.8 to 28.3 mm; quartile 4 = more than 28.3 mm.

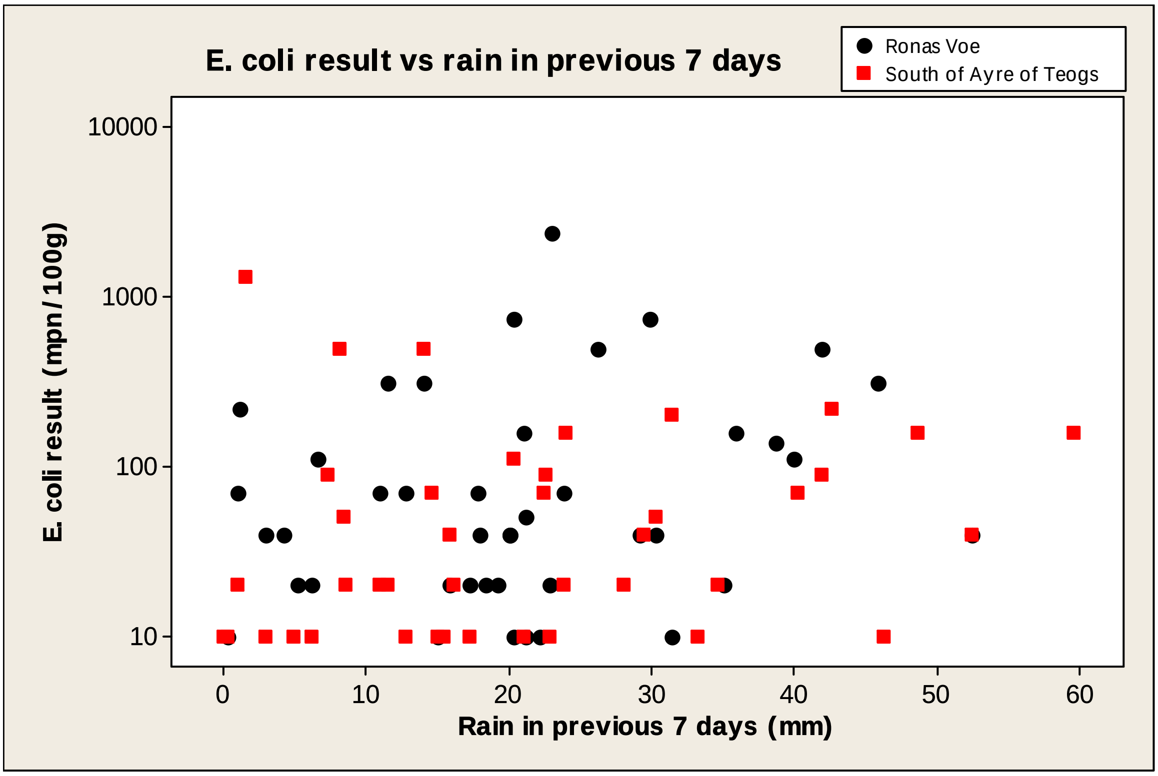

Figure 11.15 Scatterplot of result against rainfall in previous 7 days

The coefficient of determination indicates that there is no relationship between the *E. coli* result and the rainfall in the previous seven days either when both sites are considered together (Adjusted R-sq=3.1%, p=0.061, Appendix 4) or for South of Ayre of Teogs (Adjusted R-sq=2.2%, p=0.178, Appendix 4) or Ronas Voe (Adjusted R-sq=2.2%, p=0.172, Appendix 4) separately.

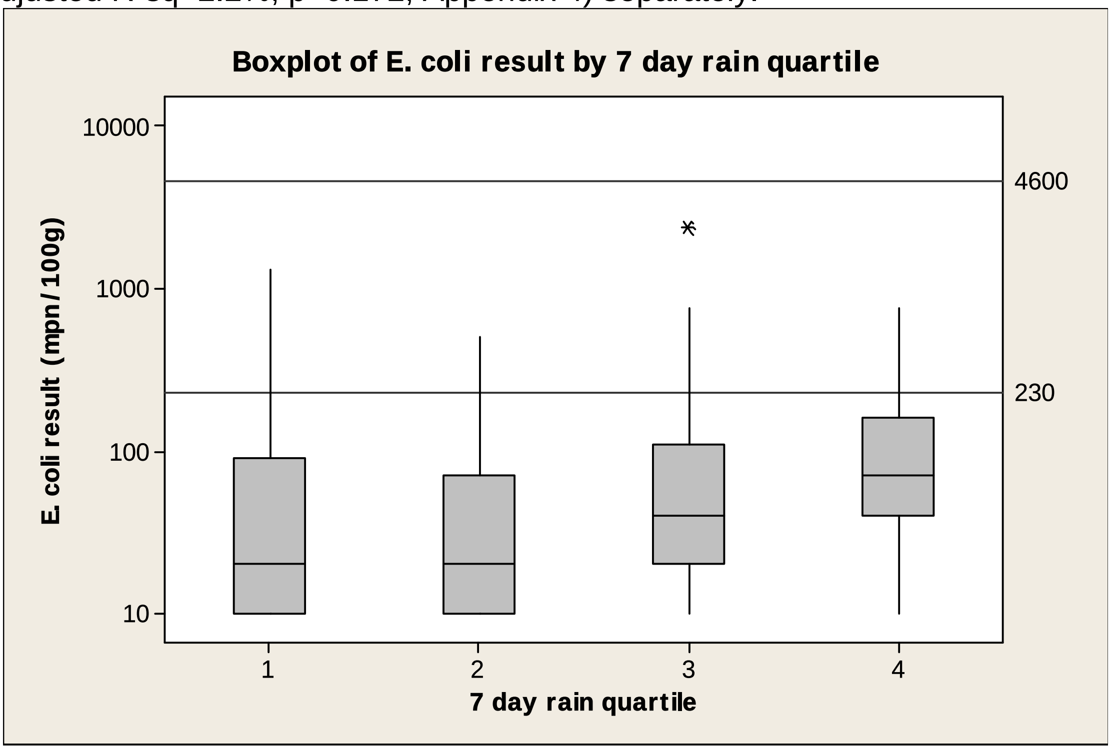

Figure 11.16 Boxplot of result by rainfall in previous 7 days quartile (both sites combined)

There was no significant difference between results for each quartile when both sites were considered separately (One way ANOVA, p=0.374, Appendix 4).

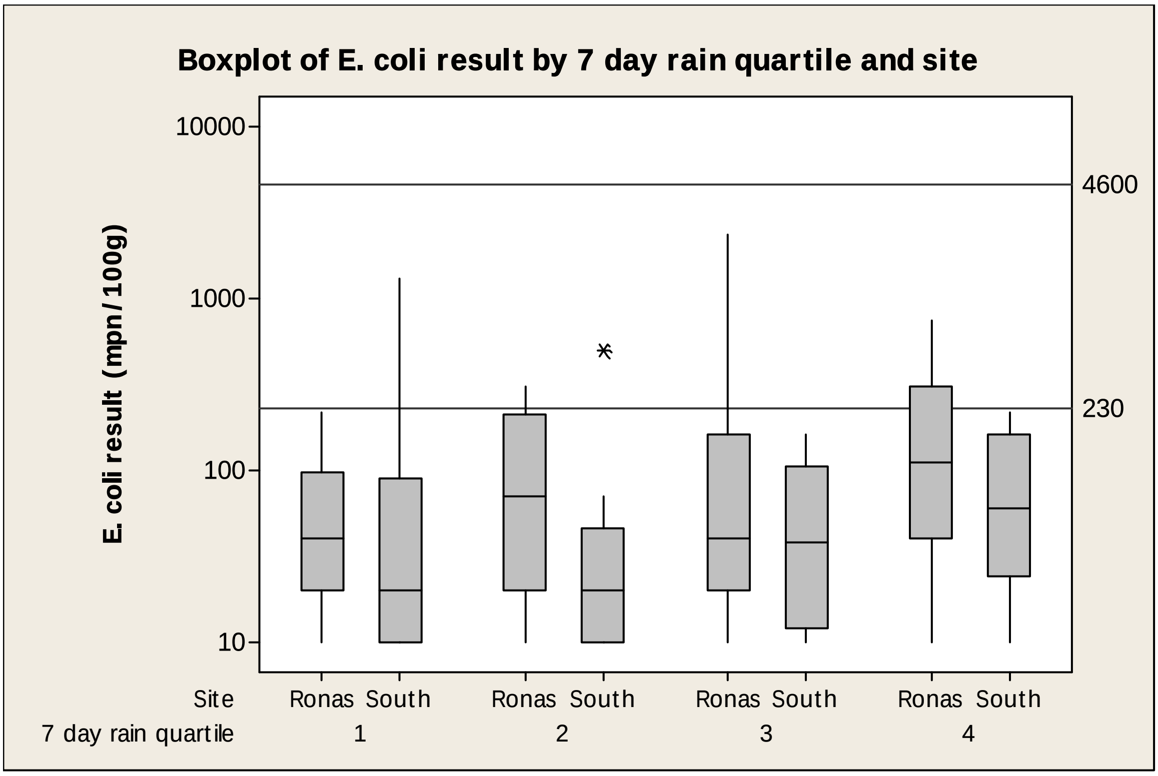

Figure 11.17 Boxplot of result by rainfall in previous 7 days quartile and site

When considered separately, no significant difference was found between the results for each rain quartile for either South of Ayre of Teogs (One way ANOVA, p=0.569, Appendix 4) or Ronas Voe (One way ANOVA, p=0.698, Appendix 4).

Overall, higher recent rainfall does not appear to be associated with higher contamination of shellfish in the voe for either site, or when the production area is considered as a whole. The influence of rainfall on microbiological quality will depend on factors such as local geology, topography and land use.

11.4.3 Analysis of results against tidal effects

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 fecal contamination from livestock into the voe. Tidal ranges in the voe are small, ranging from 0.7 to 1.1 m. Figure 11.11 presents a boxplot of *E. coli* results by size of tide categorised by lunar state at the time of sampling. Small tides occur 8-11 days after a full/new moon, medium tides occur 12-14 and 5-7 days after a new/full moon, and large tides occur 15 and 0-4 days after a new/full moon. 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 11.18.

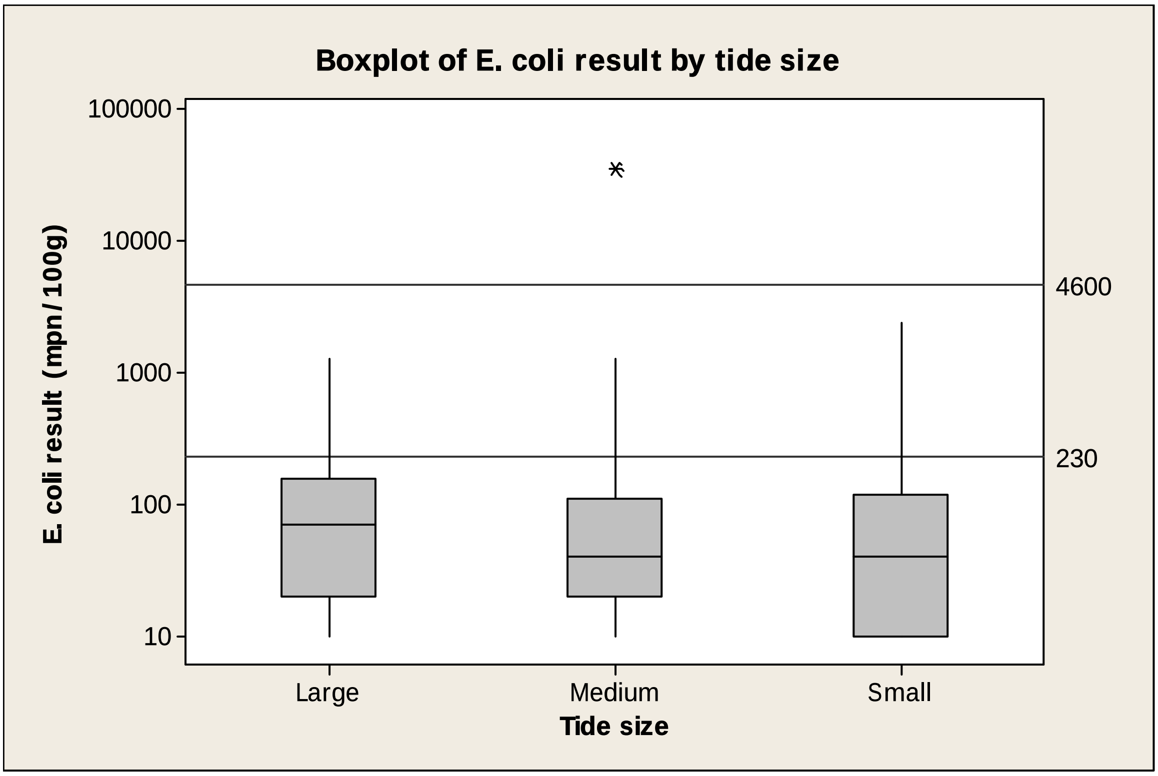

Figure 11.18 Boxplot of result by tide size (both sites combined)

There was no statistically significant influence of tide size detected by this analysis (One way ANOVA, p=0.836, Appendix 4). This may be expected, as the tidal range is small and the voe is large and deep.

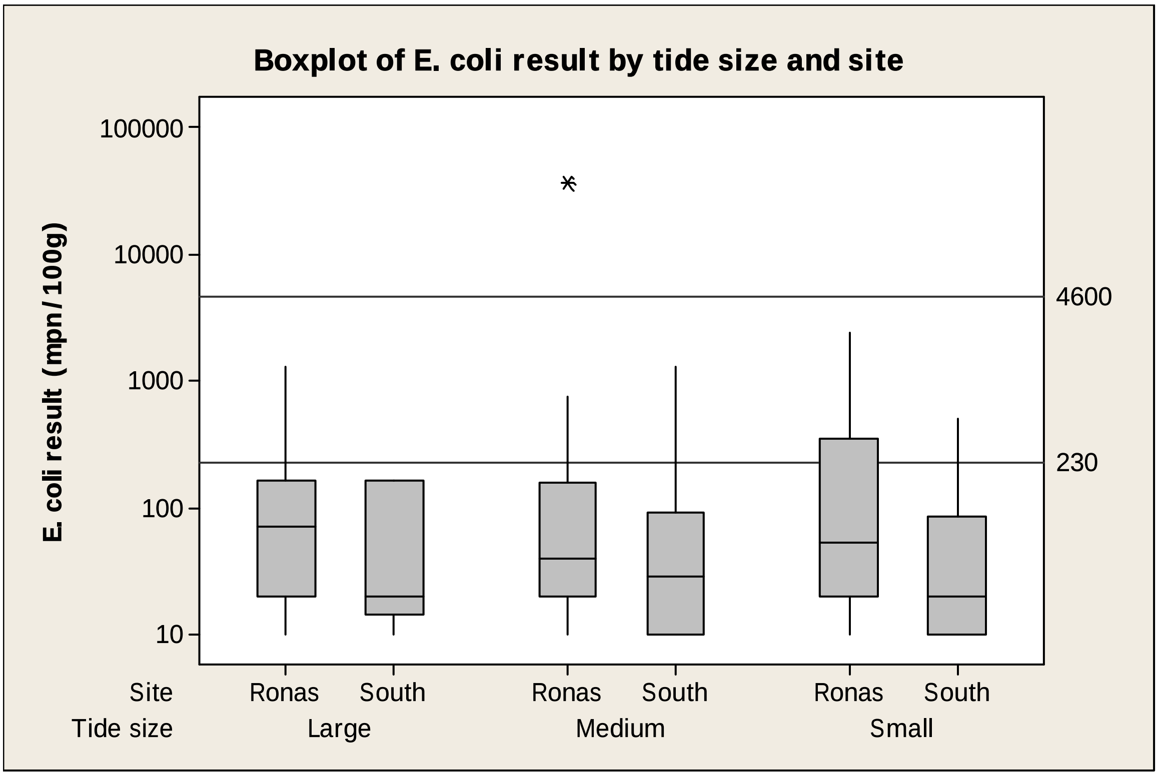

Figure 11.19 Boxplot of result by tide size and site

When considered separately, tide size was found to have no significant effect on the results for either South of Ayre of Teogs (One way ANOVA, p=0.684, Appendix 4) or Ronas Voe (One way ANOVA, p=0.915, Appendix 4).

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.

Water temperature at the time of sample collection was only recorded on 3 occasions up to the end of 2006, so no analysis was possible.

11.4.5 Wind direction

Wind speed and direction is likely to significantly change water circulation patterns in Ronas 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 (where data was available), and mean result by mean wind direction in the previous 7 days is plotted in Figure 11.20 for all data, and by individual site in Figures 11.20 and 11.21.

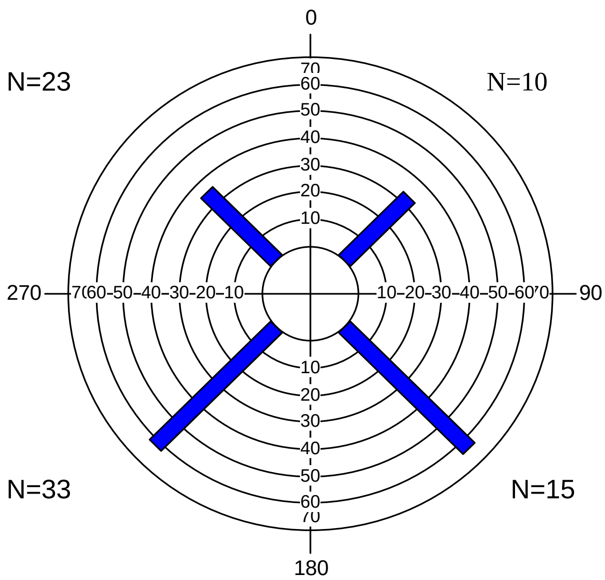

Figure 11.20 Circular histogram of mean *E. coli* result by wind direction (both sites combined)

A weak correlation between wind direction and *E. coli* result was found (circular-linear correlation, r=0.224, p=0.02, Appendix 4). Results were higher when the wind was blowing from the south than when it was blowing from the north, suggesting that these winds may result in increased transport of faecal contamination into the production sites.

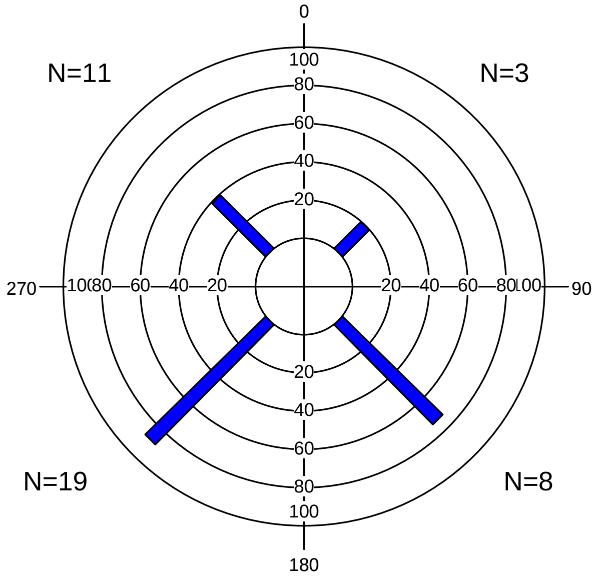

Figure 11.21 Circular histogram of mean *E. coli* result by wind direction (Ronas Voe only)

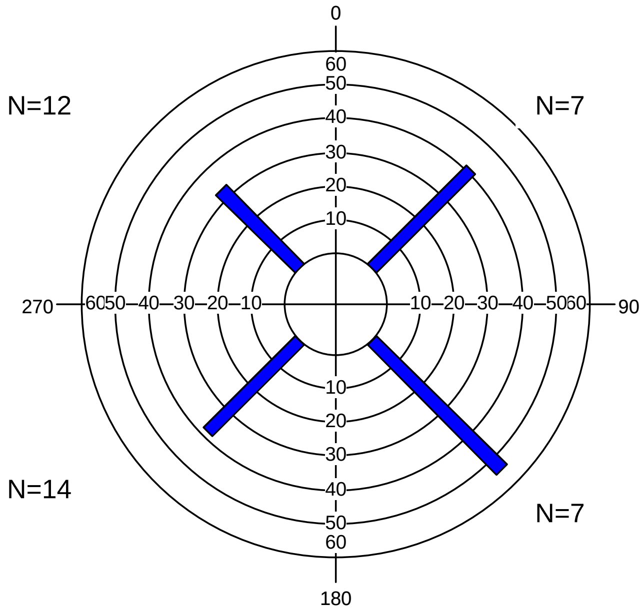

Figure 11.20 Circular histogram of mean *E. coli* result by wind direction (South of Ayre of Teogs only)

When results from the two sites were subjected to separate analyses, a correlation between wind direction and results was found at the Ronas Voe site where higher results followed a southerly wind (circular-linear correlation, r=0.293, p=0.038, 41 observations, Appendix 4) but not at the South of Ayre of Teogs site (circular-linear correlation, r=0.191, p=0.258, 40 observations, Appendix 4).

11.4.6 Discussion of environmental effects

A seasonal effect was found, with results in the spring being lower than in other seasons, and this relationship was only detected for the Ronas Voe site. No relationship was found between recent rainfall and results. No influence of tide size was apparent. It was not possible to investigate the effects of temperature. Southerly winds were associated with increased contamination, but only at the Ronas Voe site. Environmental effects were far less influential on results than geographic location.

11.5 Sampling frequency

When a production area has had the same (non-seasonal) classification for 3 years, and the geometric mean of the results falls within a certain range it is recommended that the sampling frequency may be decreased from monthly to bimonthly. This is not applicable for Ronas Voe, as the area had seasonal classifications in 2004, 2005 and 2007.

12. Designated Shellfish Growing Waters Data

A part of the production area considered in this report is also a SEPA shellfish growing water which was designated in 2002. The extent of the area and the location of the SEPA monitoring point are shown on Figure 12.1.

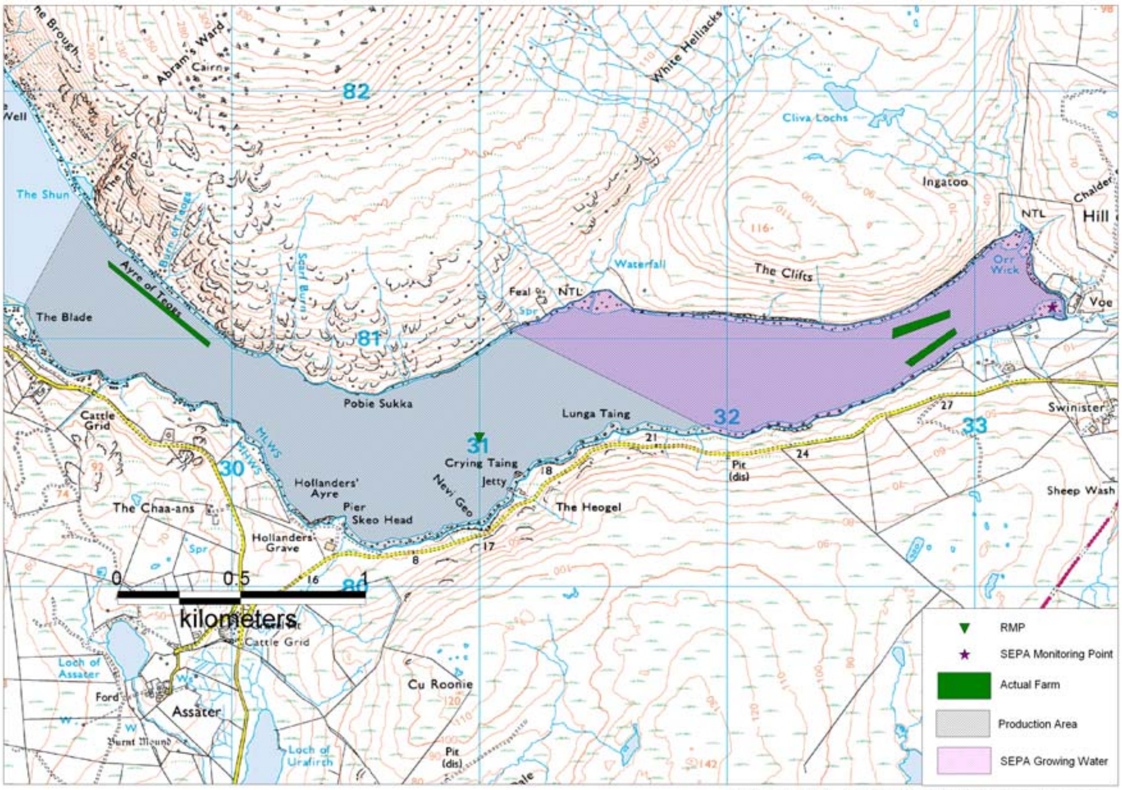

Figure 12.1 Map showing SEPA designated growing water and monitoring points

The monitoring regime requires the following testing:

- Quarterly for salinity, dissolved oxygen, pH, temperature and visible oil
- Twice yearly for metals in water
- Annually for metals and organohalogens in mussels
- Quarterly for faecal coliforms in mussels

Monitoring started in 2003, and results to the end of 2006 have been provided by SEPA. Monitoring results for faecal coliforms in mussels are presented in Table 12.1.

Table 12.1. SEPA faecal coliform results (faecal coliforms / 100g) for shore mussels gathered from Ronas Voe.

	Site	Ronas Voe	Ronas Voe
	OS Grid Ref.	HU 310 806	HU 33312 81134
2003	Q1	140	-
	Q2	-	-
	Q3	-	2400
	Q4	-	310
2004	Q1	-	70
	Q2	-	90
	Q3	-	>18000*
	Q4	-	200
2005	Q1	-	90
	Q2	-	70
	Q3	-	16000
	Q4	-	9100
2006	Q1	-	500
	Q2	-	500
	Q3	-	310
	Q4	-	40

* Assigned a nominal value of 36000 for the calculation of the geometric mean.

All but one of the samples were gathered from the shore at the head of the voe. The geometric mean result for all samples is 473 faecal coliforms / 100g. Results ranged from 40 to >18000 faecal coliforms / 100g indicating large fluctuations in microbial contamination at this monitoring point, with highest results usually occurring in quarter 3. This may attributable to its proximity to a freshwater input carrying varying loadings of faecal contamination originating from livestock.

Levels of faecal coliforms are usually closely correlated to levels of *E. coli* often at a ratio of approximately 1:1. The ratio depends on a number of factors, such as environmental conditions and the source of contamination and as a consequence the results presented in Table 12.1 are not directly comparable with other shellfish testing results presented in this report. Assuming they are roughly comparable, the level of contamination in shore mussels taken from the current SEPA monitoring point is considerably higher that the overall geometric mean result of 54.8 *E.coli* mpn /100g observed in rope mussels in the voe. This may be expected as the sampling site is in the intertidal zone at the head of the voe, whereas the rope mussels are located in deeper, better-mixed waters.

Monitoring results for chemical and physical parameters are not presented in this report.

13. Bathymetry and Hydrodynamics

Figure 13.1 Ronas Voe Bathymetry map

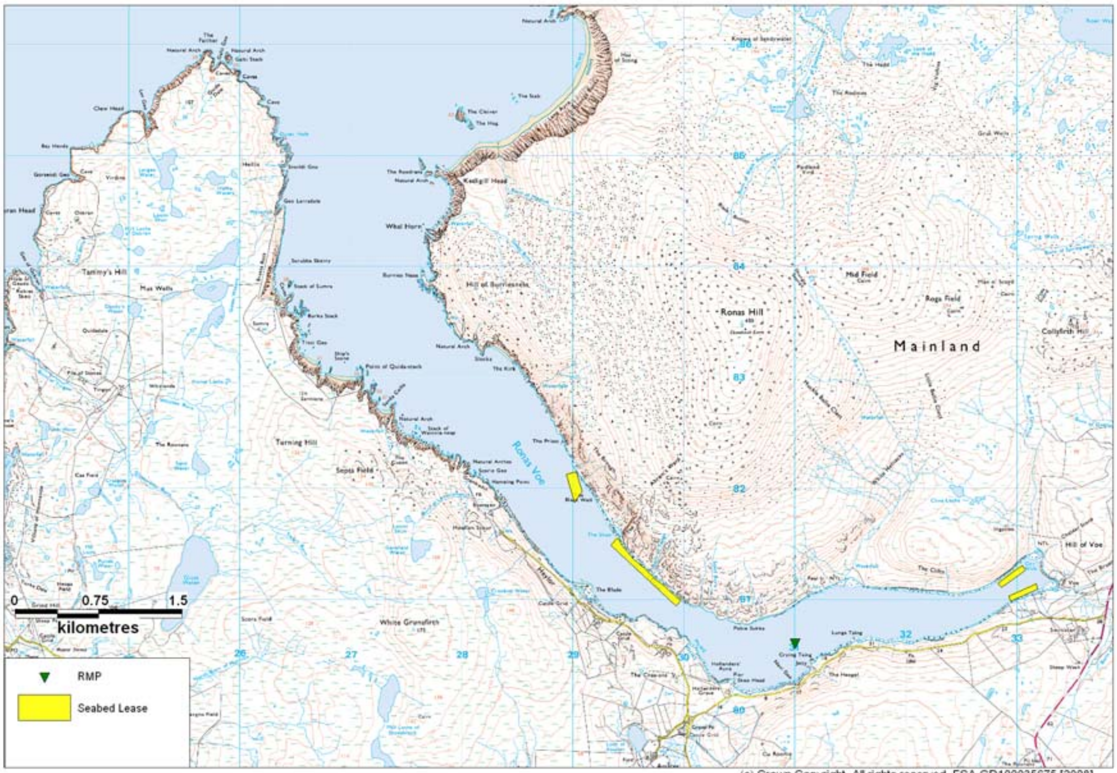

Figure 13.2 Ronas Voe OS map

The bathymetry map above shows depths ranging from <5 metres to >30 metres with drying areas located at the head of the voe as well as along some stretches of both shores.

Ronas Voe is a fjordic loch with two sills that split the loch into two main basins (see Figure 13.1) The innermost basin is oriented generally east to west and is shallow at the head of the loch. In its main body, it is deeper than the outer basin and shelves more steeply away from the sides of the voe. Water flow to and from this basin will be constricted not only by the relatively shallow sill but also by the physical geography of the land as the loch is very narrow at this point. It can be expected that flushing times will be greater for this portion of the loch. Fresh water entering the voe at the head may tend to ride over the deeper, saline water and stratification may be present.

Water in the outer basin is less subject to freshwater input and so would be expected to be more saline. This basin is shallower than the inner basin and salinity reduction in this basin would be expected to be lower than in Basin 2.

Table 13.1 Ronas Voe Characteristics

Loch length	8.8 km
Maximum depth	42 m
Volume (at low water)	108.4 million m^3
Fresh/tidal, per thousand	5.1
Mean depth at low water	17.7m
Watershed	30 km^2
Runoff (million m^3 per year)	27.3
Salinity reduction	0.2 ppt
Flushing time	6 days
Sills	2
Sill 1 max depth	15 m
Sill 1 mean depth	11 m
Sill 2 max depth	16 m
Sill 2 mean depth	9 m
Basin 1 depth	33 m
Basin 2 depth	42 m

Source: Edwards & Sharples, Catalogue of Scottish Sea Lochs

Limited salinity profiles were taken during the shoreline survey and the results are represented below. Table 13.2 shows the salinities measured at 1, 3 and 5 metres depths. The locations are mapped in Figure 13.3. As can be seen from the table, for points nearest the head of the voe, very clear stratification exists with salinity increasing as depth increases though even at 5 metres, salinity is still below the 35ppt that is the norm for full strength sea water.

Further out the voe, salinity is more uniform across depth indicating better mixing. Site 1 at South of Ayre of Teogs lies near sill 2 and increased current flow and mixing would be expected in this vicinity. Site 2, further to the west, shows a resumption of stratification, though at salinities closer to sea water.

Lowest surface salinities were recorded at points nearest the head of the voe, where distinct stratification could be seen.

Table 13.2 Salinity profile for Ronas Voe

Site no.	Description	NGR	Depth (m)	Salinity (ppt)	Temperature (ºC)
1	South of Ayre of Teogs	HU 2988 8099	1	34.1	11.5
			3	34.1	11.4
			5	34.1	11.4
2	South of Ayre of Teogs	HU 2951 8130	1	34.2	11.5
			3	34.5	11.5
			5	34.6	11.5
3	Ronas Voe (northern)	HU 3268 8103	1	28.5	12.7
			3	28.6	12.6
			5	32.2	13.3
4	Ronas Voe (northern)	HU 3289 8111	1	36.5	11.9
			3	28.4	12.1
			5	32.3	12.7
5	Ronas Voe (southern)	HU 3272 8091	1	28.9	12.0
			3	29.4	12.1
			5	30.5	12.2
6	Ronas Voe (southern)	HU 3291 8102	1	26.5	11.7
			3	28.8	12.0
			5	30.8	12.3

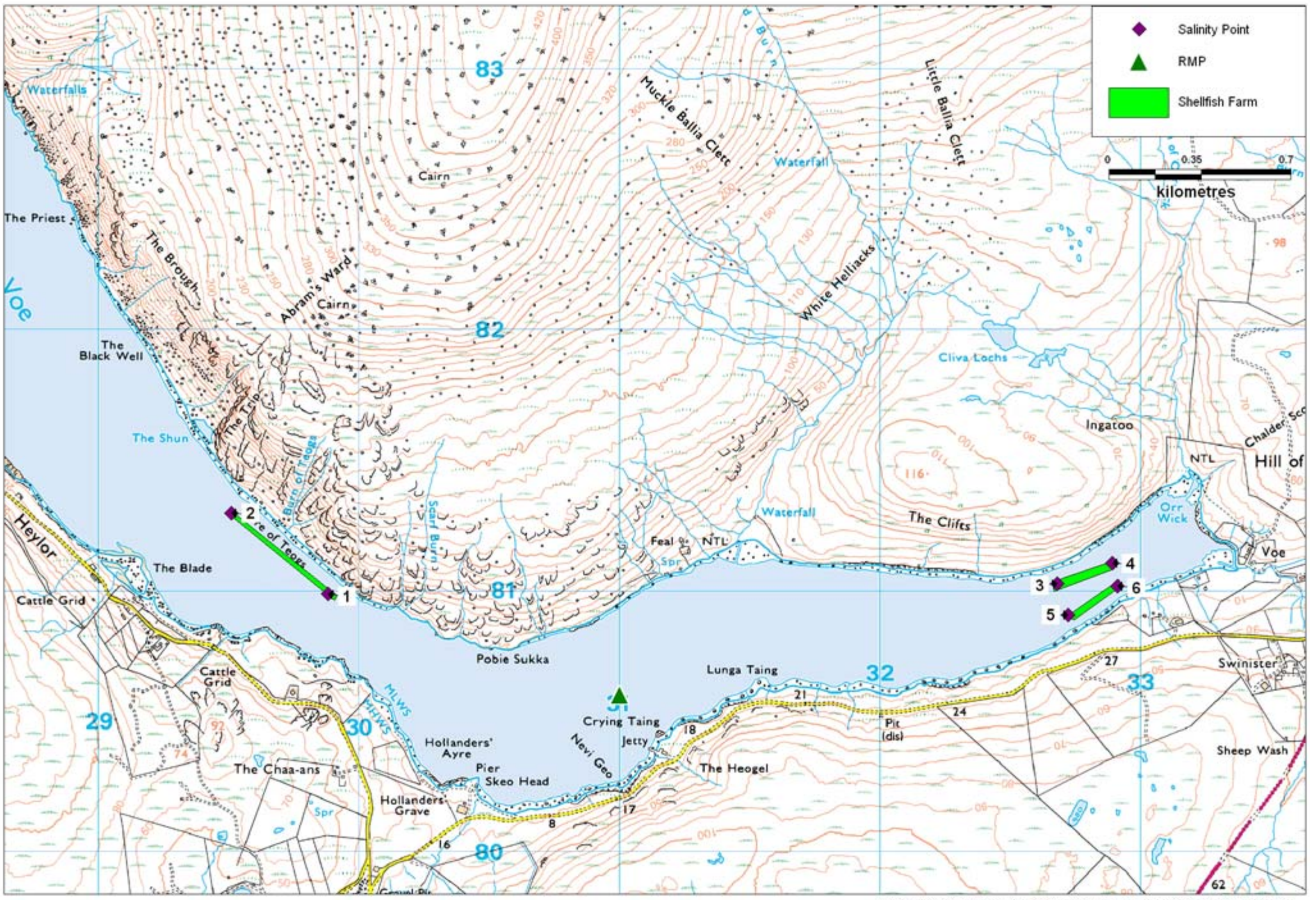

Figure 13.3 Map of salinity profile points for Ronas Voe

13.1 Tidal Curve and Description

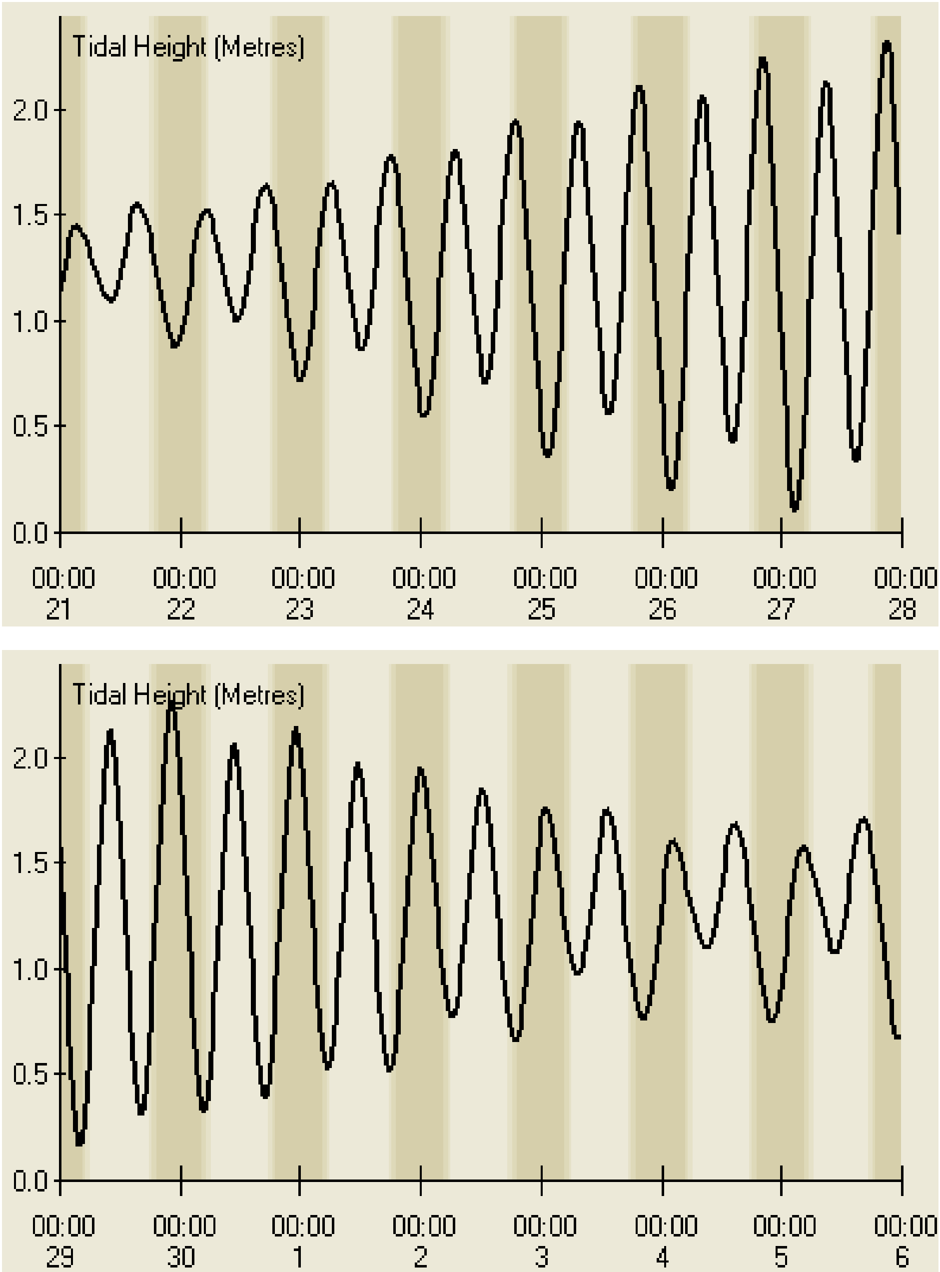

Figure 13.4 Tidal curve for Hillswick 21st September – 6th October 07

0294 Hillswick is a Secondary Non-Harmonic port.
The tide type is Semi-Diurnal.

Highest High Water	MHWS	2.0 m
Lowest High Water	MHWN	1.6 m
Highest Low Water	MLWN	0.8 m
Lowest Low Water	MLWS	0.4 m

No tidal stream information is available for Ronas Voe.

A hydrographic survey was undertaken by Shetland Seafood Quality Control on behalf of Aqua Farm Ltd., in support of an application related to a caged fish farm at OS grid reference HU 3215 8075.

Results of this survey indicated that at grid reference above, current speeds indicated weak flushing and that at depth (at 2.2 m and 10.2 m above seabed), currents of between 0 and 3 cm/s occurred over 50% of the time. Near the surface, however, mean current speeds measured over a 15 day period were 5.7 m/s, indicating a moderate level of flushing.

13.2 Conclusions regarding effect on impacting sources

Faecal contamination carried into the voe via freshwater streams is likely to significantly impact the two sets of mussel lines located near the head of the loch which shows stratification, though salinities recorded at 5 metres depth were still substantially below that of full strength sea water.

Reduced flushing due to the impact of the sill would tend to keep contaminants hanging around and mixing within the basin. The hydrographic survey undertaken in the vicinity in 2006 confirms that the area is poorly flushing with weak currents.

The quicker-flushing surface layer of fresher water would then be transported across the sill into the seaward basin where it would be more fully mixed. Within this basin, lower freshwater input may lead to local stratification, as was observed in the salinity profiles. The mussel farm at South of Ayre of Teogs would be expected to experience significantly less contamination than the farms at the head of the voe.

14. River Flow

Ronas Voe has a small catchment area of 30 km^2 relative to its high water area of 6.6 km^2. There are no river gauging stations on rivers or burns feeding into Ronas Voe.

The following streams were measured and sampled during the shoreline survey. These represented the largest freshwater inputs to Ronas Voe.

Table 14.1 River flows and loadings

No.	Location	Date Sampled	Width (m)	Depth (m)	Flow (m/s)	Flow (m3/day)	*E. coli* (cfu/100ml)	Loading (*E. coli*/day)
1	HU 29349 81693	21/09/2007	2	0.03	0.15	778	190	1.5×10^9
2	HU 33457 81052	21/09/2007	1.5	0.28	0.18	6532	22	1.4×10^9
3	HU 29733 81222	21/09/2007	1	0.14	0.15	1814	60	1.1×10^9
4	HU 29202 80840	05/12/2007	0.13	0.03	0.332	112	900	1.0×10^9
5	HU 31461 81185	05/12/2007	4.8	0.18	0.34	25380	2	5.1×10^8
6	HU 33189 81430	05/12/2007	2.3	0.16	0.46	14630	1	1.5×10^8
7	HU 29170 80943	05/12/2007	0.9	0.04	0.293	911	10	9.1×10^7
8	HU 29182 80957	05/12/2007	0.96	0.06	0.143	712	9	6.4×10^7

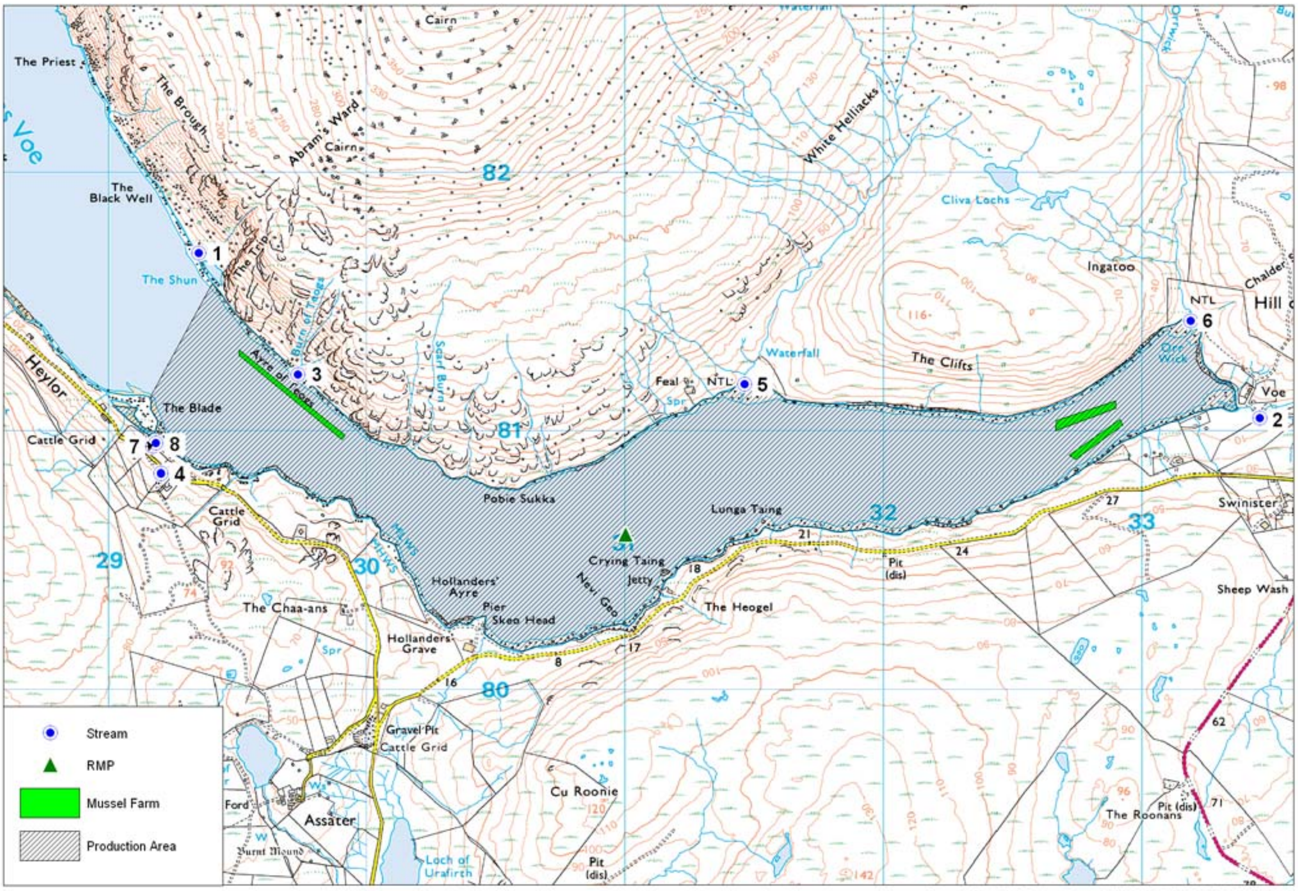

Figure 14.1 Map of significant streams and loadings

Levels of contamination (*E. coli* cfu/100ml) were generally an order of magnitude lower in December, apart from in one stream (4) which was suspected to receive a septic input from a neighbouring house due to its odour. No streams were sampled on both occasions, so a direct comparison is not possible, but it must be noted that total loading may be underestimated in relative terms for rivers.sampled and measured in December.

Stream 3 discharges very close to the South of Ayre of Teogs site, and streams 2 and 6 discharge close to the Ronas Voe sites. Levels of contamination in these streams, as measured on the shoreline survey, were relatively low. The cumulative effects of these and other smaller watercourses will influence *E. coli* levels in Ronas Voe, although no attempt to quantify this effect has been made. The upper voe where the Ronas Voe sites are located is likely to be most heavily influenced by freshwater input, as demonstrated by the salinity profiles taken during the shoreline survey.

15. Shoreline Survey Overview

The shoreline survey was conducted on the 21st to 22nd September 2007. A second visit was undertaken on the 26th November to measure additional watercourses and to sample mussels South of Ayre of Teogs site.

Within the production area, there are three crown estates leases occupied by mussel farms. The site named South of Ayre of Teogs consists of four lines of SMART sheets which are 2 m deep. The site named Ronas Voe consists of two areas of conventional mussel lines.

All dwellings on the shores of the voe are assumed to be on private septic tanks. A few were seen during the survey, but none had overflows which were discharging directly into the voe. All of these dwellings lie on the southern shore of the voe.

Most of the land around the voe is grassland grazed by sheep that can roam relatively freely. There is a small cattle farm near the head of the voe. The cattle here are constrained in the area that they can graze, but were observed directly around the stream and in the vicinity of the foreshore.

A number of streams discharge into the voe, and these carried low to moderate loadings of *E. coli*. The surrounding land that they drain is a mixture of moorland and pasture.

A total of 9 seawater samples were taken during the course of the survey. These indicated that the water around the Ronas Voe mussel sites was considerably more contaminated than that around the South of Ayre of Teogs site. Salinity measurements and profiles indicated that at the Ronas Voe site, the salinity was markedly lower than at the South of Ayre of Teogs site, and there was a layer of fresher water at the surface here. At both sites, surface salinity decreased marginally across the site from west to east.

Mussel samples taken on the shoreline survey also indicated that the Ronas Voe sites were more heavily contaminated than the South of Ayre of Teogs site. In the two instances where it was possible to sample rope mussels from near the surface, and at 5 m depth, the sample taken near the surface (750 and 1700 mpn/100g) returned a higher result than those taken from lower down (700 and 290 mpn/100g).

Boat traffic appeared to be minimal, and associated with the fish and mussel farms. The few dwellings around the voe appeared to be in year round occupancy.

Rabbits and their droppings were ubiquitous in the area. Small numbers of gulls and cormorants were also noted. A flock of approximately 100 geese was seen near the head of the voe during the December visit.

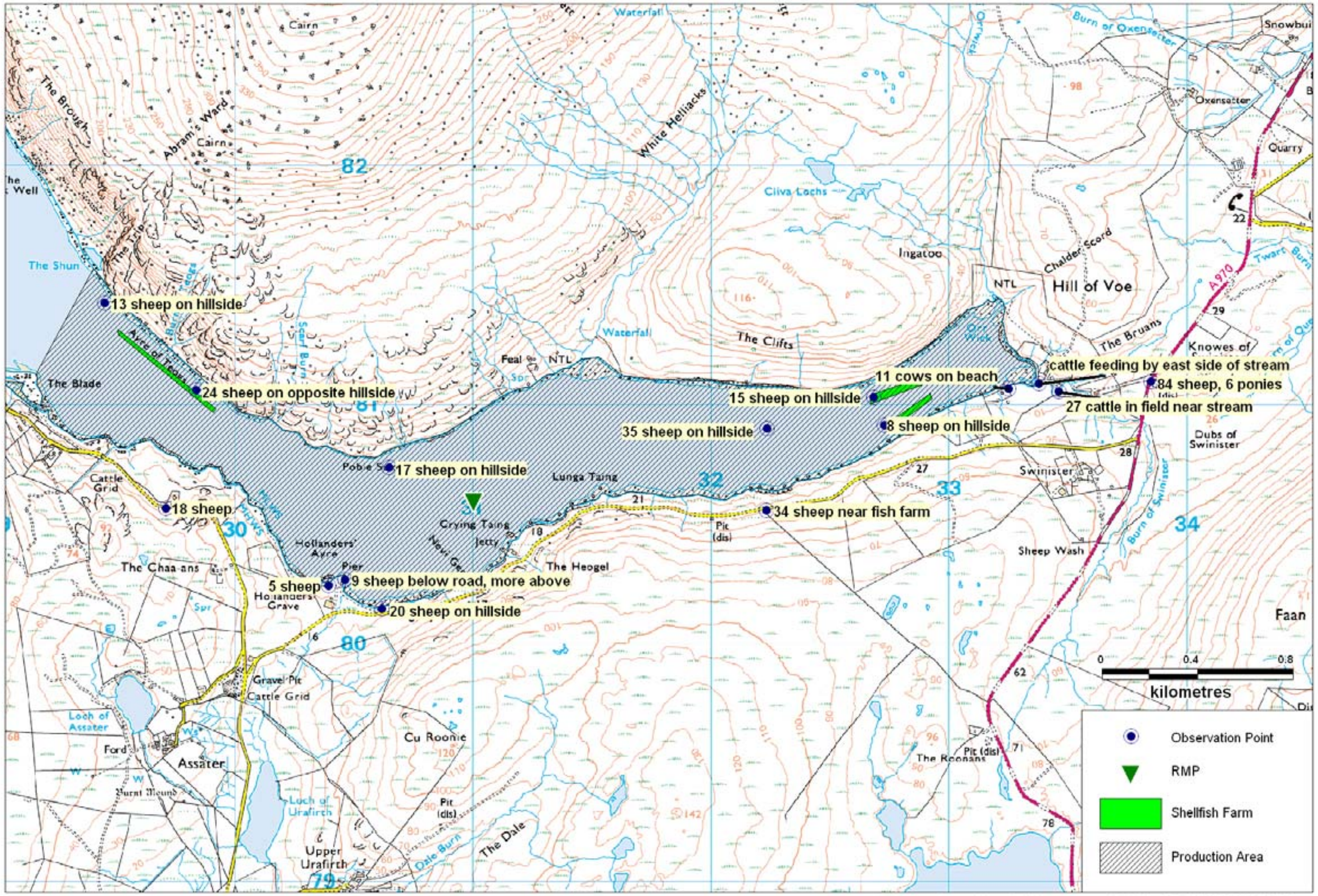

Figure 15.1 Summary of shoreline survey findings

16. Overall Assessment

Human sewage inputs

The human population in census output areas neighbouring Ronas Voe at the last census was 571. These cover a large area, and the population resident on the shores of the voe is much smaller than this, and all dwellings are located on the south shore of the voe. The area is not connected to mains sewerage. A number of septic tanks were found during the course of the shoreline survey, but none appeared to have an overflow to the loch. None were close enough to the shellfisheries have significant impacts. In conclusion, human sewage inputs are of little importance to the sampling plan.

Agricultural inputs

There is no arable agriculture in the vicinity of the voe. Land cover adjacent to the voe is mainly improved and acid grassland much of which is used for grazing livestock. Sheep are grazed all around the voe, and a few cattle are kept at the head of the voe. Livestock had access to the shore and to streams around the voe. It is likely that contamination originating from livestock is carried in mainly via runoff, and significantly affects water quality in the voe, particularly given the absence of other major sources of contamination.

Soils in the area are classed as poorly draining. This indicates that a higher proportion of rainfall would result in runoff into the voe, carrying with it faecal material deposited by livestock as well as other animals.

In conclusion, the most significant aggregation of livestock was the cattle at the head of the loch, which is close to the two Ronas Voe sites, and this should be taken into consideration in the sampling plan.

Wildlife inputs

Rabbits are ubiquitous around the loch, and constitute a relatively minor source of diffuse pollution. The same is true of seabirds such as gulls. Seals, cetaceans, and otters are likely to be resident in or visit the area, but not in large numbers. A flock of geese was noted at the head of the loch during the December visit, but it is uncertain whether they were resident or passing through. Overall, wildlife impacts to the fisheries at Ronas Voe are likely to be minor, and in some cases unpredictable and will therefore not be explicitly taken into account in determining the sampling plan, although impacts from wildlife may sometimes contribute to the bacterial contamination of shellfish.

Seasonal variation

Historical monitoring results were higher in the summer and autumn compared to the spring, with intermediate results in the winter.

Livestock numbers in the area as a whole are highest during the summer months (May to October) when lambs and calves are present. During the warmer months livestock may access streams to drink and cool off more frequently.

Seasonal changes in population due to an influx of tourists would not be likely to have a large impact in this area. No tourist attractions, accommodation, campsites or caravan parks were observed during the shoreline survey.

Due to the seasonality of historic monitoring results and livestock numbers, monthly sampling should be continued.

Rivers and Streams

The catchment area for Ronas Voe is 30 km^2, which is relatively small given the area of the voe itself is 6.6 km^2. Streams and small rivers discharge at various points around the voe. *E. coli* concentrations measured during the shoreline survey ranged from low to moderate.

The cumulative effect of these watercourses will significantly influence *E. coli* levels in Ronas Voe. The head of the voe, which is shallow and receives significant freshwater inputs will be most heavily influenced by freshwater inputs, as demonstrated by the salinity profiles taken during the shoreline survey. Nearer the mouth of the voe, where the South of Ayre of Teogs site is located, the freshwater influence will be lower. Contamination is likely to be higher where the water is fresher, and this should be taken into consideration in the sampling plan.

Meteorology, hydrology and movement of contaminants

Rainfall patterns at Baltasound (the nearest rainfall station) show rainfall is highest from September through to January. An increase in rainfall in September after the drier summer months may be expected to wash a flush of bacteria from the surrounding land into the production area. However, no correlation between rainfall in the previous 2 or 7 days and historic monitoring results was found.

A correlation between wind direction and historic *E. coli* monitoring results was found, with lower results occurring during periods of southerly winds. This correlation was only found for the Ronas Voe sites, and not at South of Ayre of Teogs, although the reason for this is unclear.

Because the voe contains two sills, currents are likely to be higher over the sills and lower within the basins. Hydrographic survey data confirm that this is the case in the innermost basin. Freshwater and the bacterial loading it carries forms a surface layer within the inner basin and to a lesser extent within the outer basin and so contaminants levels are likely to be higher toward the surface particularly at the Ronas Voe sites near the head of the voe. Due to weak tidal regimes, wind driven flows are likely to have a greater influence over movement of contaminants.

Salinity profiles taken during the course of the shoreline survey indicated that at the head of the voe, around the Ronas Voe site, near the surface, salinity was lower indicating a significant freshwater influence. Little or no freshwater influence was found at the South of Ayre of Teogs site. At both sites, surface salinity decreased marginally across the site from west to east.

Analysis of results

Historic shellfish hygiene monitoring results are available from 1999 to present, with samples collected from two reported locations, one on the Ronas Voe sites and one from the South of Ayre of Teogs site. Contamination levels were higher at the Ronas Voe sites than at the South of Ayre of Teogs site. Measurements taken as part of the shoreline survey are consistent with this, and these findings should be taken into consideration in the sampling plan.

Recent changes in classification indicate that monthly monitoring should be continued. Environmental, geographical and seasonal effects on these results are discussed in previous sections of this assessment.

SEPA have reported shellfish growing waters monitoring results from 2003 onward. Shore mussel samples tested for faecal coliforms gave a higher geometric mean result than the geometric mean *E. coli* result from the FSAS monitoring programme. It might be expected that higher levels of contamination are found at this sampling location, which is in the intertidal zone at the head of the voe, compared to rope mussels grown offshore, as watercourse enters the voe here, livestock have access to the shoreline and there is some human habitation.

Seawater samples taken during the shoreline survey gave results ranging from <1 to 60 *E. coli* cfu/100ml. Higher results were obtained from the areas of lower salinity, towards the head of the voe around the Ronas Voe sites.

Levels of contamination and calculated bacterial loadings for streams discharging into the production area were fairly low relative to the size of the loch. As noted in the previous paragraph, highest results were found at lower salinities so it is likely that these inputs are responsible for carrying most of the contamination into the production area.

Mussel samples taken from South of Ayre of Teogs on the shoreline survey gave lower results than those taken from Ronas Voe, but it must be noted that these were taken on different occasions and so are not directly comparable. At the two locations where mussel samples were taken from two different depths from the Ronas Voe site, the sample taken from the surface gave a higher result than those taken at a 5 m depth on both occasions. It was not possible to sample at different depths from the South of Ayre of Teogs site, and the sheets here only extend to a depth of 2 m. This is consistent with the salinity profiles indicating that water is fresher (and hence likely to be more contaminated) at the surface, and this should be taken into consideration in the sampling plan.

Summary

Factors of relevance to the sampling plan are as follows:

- Seasonality and variability of historic monitoring results and diffuse agricultural inputs, together with the instability in classification would suggest monthly monitoring is appropriate.
- Results obtained from historic monitoring and the shoreline survey demonstrate that the Ronas Voe sites are more contaminated than the South of Ayre of Teogs site, suggesting that the sites should be classified separately.
- Limited results from the shoreline survey tentatively suggest that contamination is higher at the surface at the Ronas Voe site, so the RMP here should be set near the surface.
- It is suggested that the RMP at the Ronas Voe site should be set at the eastern end of one of the farms, where freshwater influence is slightly stronger, and on the southern block, which is closer to a concentration of livestock and dwellings.
- It is suggested that the RMP for the South of Ayre of Teogs site should be set in the middle of the site, adjacent to where the Burn of Teogs discharges.

17. Recommendations

The current production are boundaries are given as ‘the area to east of line drawn between HU 2916 8113 to HU 2940 8157 extending to MHWS’. Given the clear difference in levels of contamination between the sites, it is recommended that the production area is split to allow them to be classified separately. Recommended boundaries for the Ronas Voe: South of Ayre of Teogs production area are ‘the area bounded by lines drawn between HU 2916 8113 to HU 2940 8157 and HU 3046 8028 to HU 3046 8079 and extending to MLWS’. Recommended boundaries for the Ronas Voe: East production area are ‘the area to the east of a line drawn between HU 3233 8108 and HU 3233 8065 and extending to MLWS.’.

For the Ronas Voe: East production area, it is recommended that the RMP be set at HU 3292 8103, at the end of the site where salinity was marginally lower at 1m depth, and closer to the south shore where possible contamination sources weer located. A tolerance of 20m is suggested as it allows for samples to be taken from ropes with mature stock. Samples should be taken from within 1m of the surface to capture any possible freshwater influence at the surface.

For the Ronas Voe: South of Ayre of Teogs production area, it is recommended that the RMP be set at HU 2967 8118, adjacent to where the Burn of Teogs discharges. A tolerance of 20 m is suggested to allow for samples to be taken from ropes with mature stock. Samples should be taken from within 1m of the surface to capture any possible freshwater influence at the surface.

Due to seasonality of results and livestock numbers, and recent changes in classification status, it is recommended that monthly monitoring is continued.

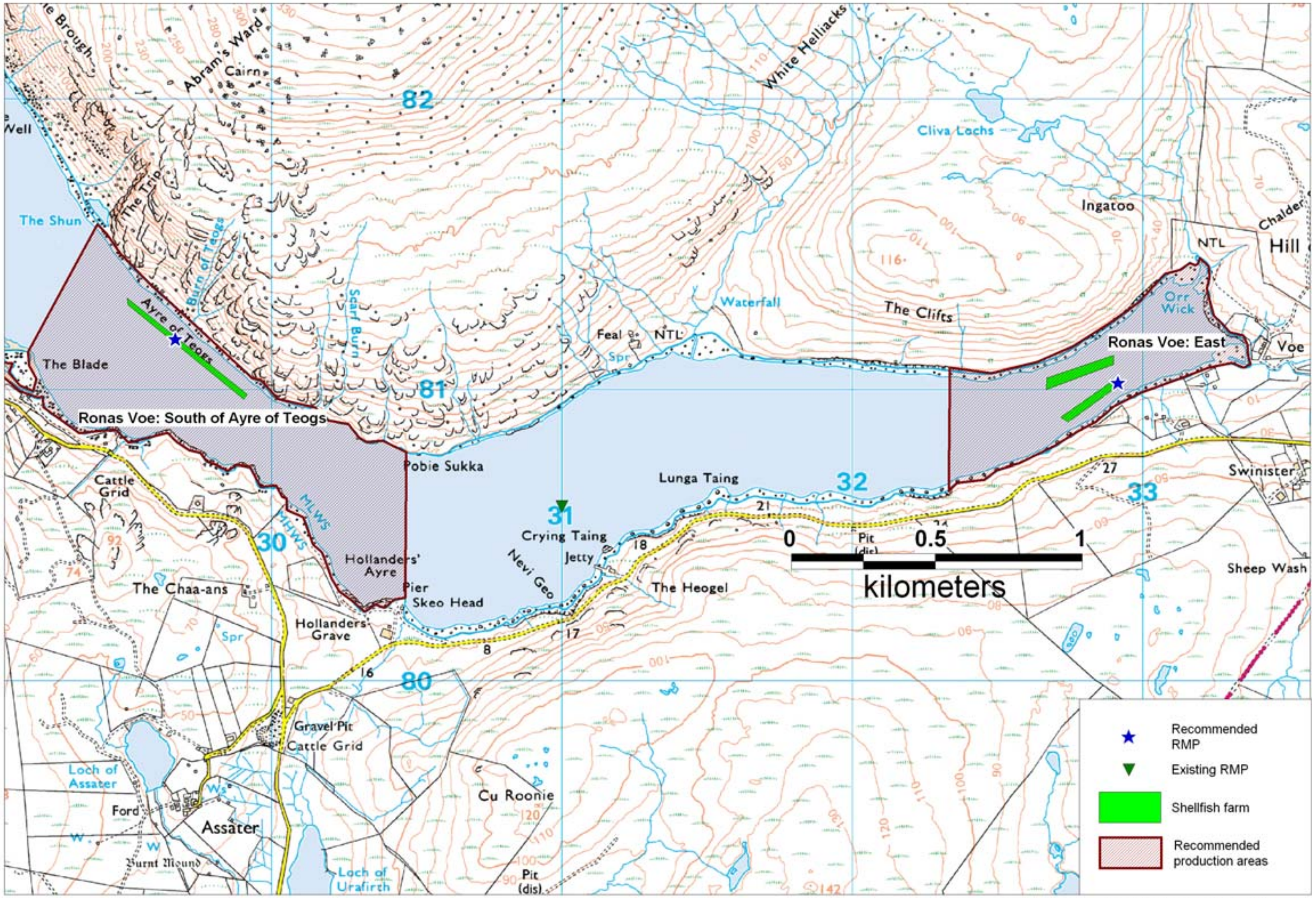

Figure 17.1 Recommended production area boundaries and RMPs

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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

Ronas Voe
SI 239

Scottish Sanitary Survey Project

Shoreline Survey Report

Prod. area:	Ronas Voe
Site name:	South of Ayre of Teogs; Ronas Voe
Species:	Common mussels
Harvester:	Johnson Shellfish; Michael Laurenson
Local Authority:	Shetland Islands Council
Status:	2007 = A - April & May, B June to December 2008 = A - March B - January & February
Date Surveyed:	21-22 September 2007; 5 December 2007
Surveyed by:	21-22/09/07: Ron Lee (Cefas), Sean Williamson (NAFC) 05/12/07: Al Cook (Cefas), Sean Williamson & Kathryn Winter (NAFC)
Existing RMP:	Ronas Voe: SI23944108
Area Surveyed:	See map in Figure 1

Weather observations

21/09/07: squally showers
22/09/07: cloudy with occasional showers – light wind
05/12/07: fresh south west wind, overcast, with occasional showers

Site Observations

Fishery

This shoreline survey was triggered by the score Ronas Voe received in the risk matrix (total score 38). This site scored highly on the risk analysis due to a change in classification and unexpected results from monitoring.

The active fishery consists of three separate Crown Estates leases. One, farmed by Johnson Shellfish, is at South Of Ayre of Teogs where mussels are grown in four lines of sheets using the SMART system. The sheets are only two metres deep. The other two leases, designated Ronas Voe and farmed by Mr. Laurenson, are conventional mussel lines at the upper end of the voe. There are 3 sets of lines in each of these leases. The identified RMP for the production area (at SI23944108) does not lie within any of the three leases. The actual grid reference used for collecting RMP samples at this site is HU 32734 80905.

The mussels at South of Ayre of Teogs site could not be examined or sampled in September as the sheets were too heavy to raise from the boat used for the survey. Mussels were sampled by scraping off the sheets at two positions on this fishery in December. The mussels on the northern lease of the Ronas Voe site were juvenile and only one sample could be obtained. The mussels at the southern lease of the Ronas Voe site were more mature and large enough shellfish were found in places to sample at two positions, each at two depths.

Sewage/Faecal Sources

There are no permitted communal sewage discharges into the voe It is therefore assumed that all of the dwellings will be on private septic tanks. A number of these were recorded during the survey but no explicit septic tank pipes were seen entering the voe. All of the small number of dwellings lie on the southern side of the voe.

The Burn of Swinister and the Burn of Orrwick both enter the head of the voe. The former was accessible by foot and was measured and sampled at the time of the survey. A number of other small streams and very minor freshwater inputs enter the voe along the shore, including in the vicinity of the fisheries. Two small freshwater inputs on the northern side of the voe were measured and sampled on 21/09/07 by landing from the boat. Some could not be measured or sampled as the squalls at the time were too strong to land. Several streams and minor freshwater inputs on the southern side of the voe were measured on 22/09/07 but could not be sampled on that date as the laboratory could not receive samples on a Saturday. Some of the minor inputs shown on the Ordnance Survey 1:25000 map were not seen during the survey although it was raining prior to, and on the dates of the survey.

Seasonal Population

There are very few dwellings round the voe and most seemed to be in permanent occupancy.

Boats/Shipping

Apart from one small, moored motorboat, the only boats observed on the voe were those associated with the fish and mussel farms.

Land Use

Most of the land around the voe is grassland grazed by sheep that can roam relatively freely. There is a small cattle farm near the head of the voe. The cattle here are constrained in the area that they can graze but were seen directly around the stream in the vicinity and on the foreshore.

Wildlife/Birds

Rabbits and their droppings were seen at a number of places on the hillside around the voe. Relatively small numbers of gulls and a few cormorants were observed during the survey, many on the mussel floats/lines themselves.

General Observations

There are few homes in the area which lie on the southern side of the voe and which appear to have individual septic tanks. There has historically been no requirement in Scotland to register these individual systems and so little record is available regarding their age, type, size or location. The Shetland

Island Council currently provides a septic tank clean out service, for which it has recently begun to charge a fee.

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

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

Specific observations taken on site are mapped in Figure 1 and listed in Table 1. Photographs of specific observations are given in Figures 4-23.

Sampling

Samples were initially collected from the area surveyed on 21/09/07. Samples could not be collected on 22/09/07 as this was a Saturday and samples could not be submitted to the laboratory; if stored, they would have been outside the recommended time lapse between sampling and commencement of the tests. A revisit was therefore undertaken on 5/12/07 so that potentially significant inputs that had been recorded, but not sampled, in September, could be sampled.

Salinity and temperature profiles recorded in the vicinity of the mussel lines are given in Table 2.

Water and shellfish samples were collected at sites as illustrated in Figures 2 and 3. Samples were transferred to cool boxes after collection and transported to the laboratory where they were analysed for *E. coli*. Bacteriology results are given in Tables 3 (water) and 4 (shellfish).

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

Acknowledgements

We would like to thank Mr Michael Laurenson for assisting with the survey on 21/09, in particular for the loan of a boat. We would also like to thank Santiago De La Ceusta and Justin Watson of Johnson Shellfish for assistance in accessing the South of Ayre of Teogs site on 05/12.

Figure 1. Map of Shoreline Observations

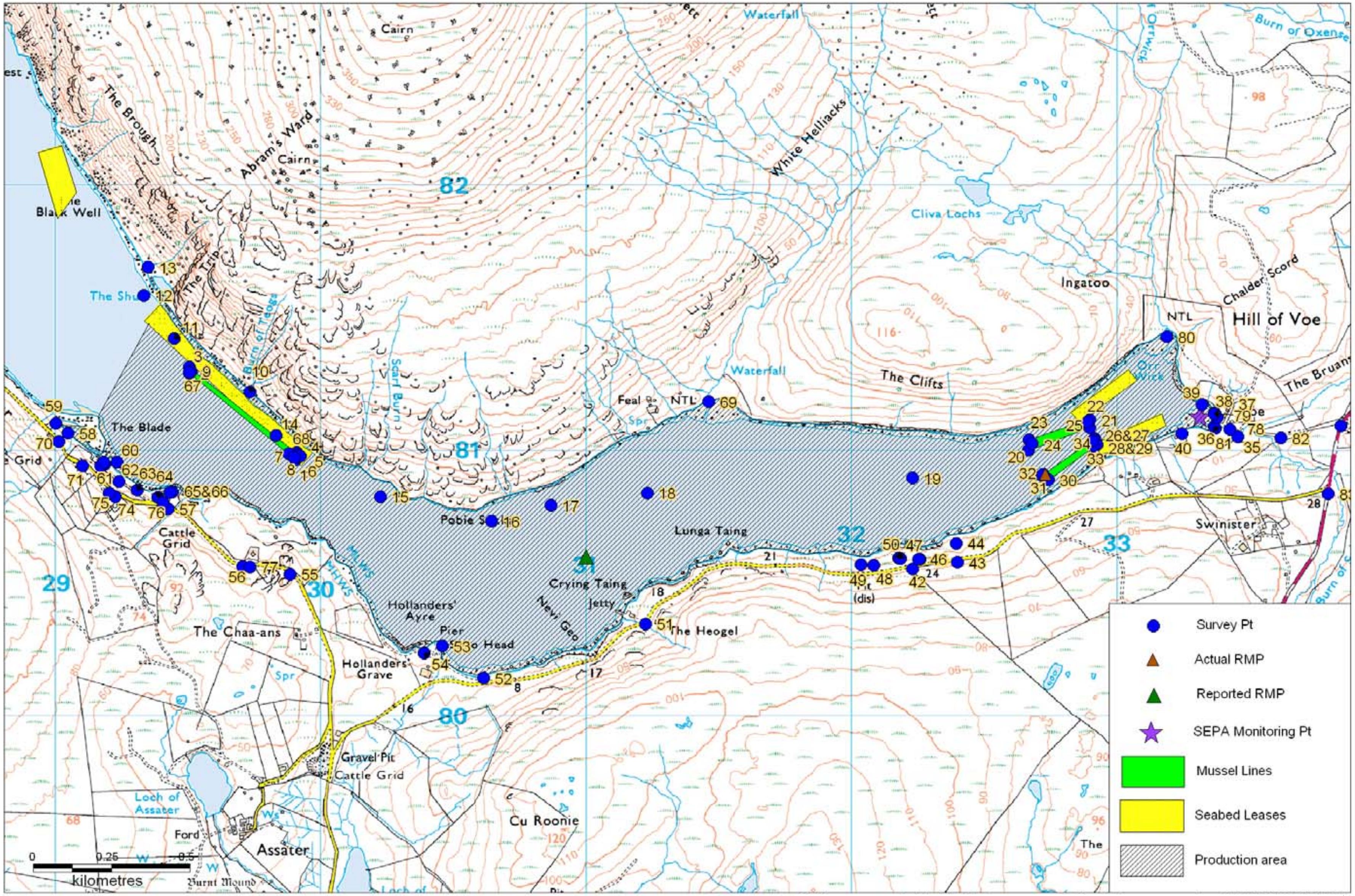


Table 1. Shoreline Observations

No.	Date	NGR	East	North	Associated photograph	Description
1	21-SEP-07 10:07:14AM	HU 29904 80967	429904	1180967	Figure 4	Corner of Johnson's mussel lines
2	21-SEP-07 10:09:42AM	HU 29505 81293	429505	1181293		Corner of Johnson's mussel lines
3	21-SEP-07 10:09:54AM	HU 29503 81316	429503	1181316		Corner of Johnson's mussel lines
4	21-SEP-07 10:12:29AM	HU 29915 80985	429915	1180985	Figure 5	Corner of Johnson's mussel lines
5	21-SEP-07 10:12:29AM	HU 29916 80984	429916	1180984		Corner of Johnson's mussel lines
6	21-SEP-07 10:12:34AM	HU 29922 80979	429922	1180979		Salinity profile – see Table 3
7	21-SEP-07 10:19:41AM	HU 29878 80988	429878	1180988		No observation recorded
8	21-SEP-07 10:21:44AM	HU 29900 80974	429900	1180974		Seawater sample (Ronas 1) – 11.20
9	21-SEP-07 10:28:51AM	HU 29510 81301	429510	1181301		Salinity profile – see Table 3 Seawater sample (Ronas 2) – 11.29
10	21-SEP-07 10:36:44AM	HU 29733 81222	429733	1181222	Figure 6	Small stream – width 1 m; depth 14 cm; flow 0.15 m/s Freshwater sample (Ronas 3)
11	21-SEP-07 10:45:15AM	HU 29447 81423	429447	1181423		13 sheep on hillside
12	21-SEP-07 10:46:15AM	HU 29332 81587	429332	1181587		2 photographs
13	21-SEP-07 10:55:52AM	HU 29349 81693	429349	1181693		2 small streams combine: width 2m; depth 3 cm; flow 0.15 m/s Freshwater sample (Ronas 4) 11.49 Rabbit droppings ++ on foreshore Sheep droppings ±
14	21-SEP-07 11:01:48AM	HU 29832 81058	429832	1181058		24 sheep on opposite hillside
15	21-SEP-07 11:05:38AM	HU 30225 80827	430225	1180827	Figure 7	2 small streams approximately 1 km further east of location – sudden squall – couldn't land to measure or sample
16	21-SEP-07 11:08:14AM	HU 30644 80734	430644	1180734		Very small stream; 17 sheep on hillside
17	21-SEP-07 11:09:28AM	HU 30868 80794	430868	1180794	Figure 8	Fish Farm

No.	Date	NGR	East	North	Associated photograph	Description
18	21-SEP-07 11:11:21AM	HU 31231 80841	431231	1180841		Salinity profile – see Table 3 Seawater sample (Ronas 5) – 12.12
19	21-SEP-07 11:16:27AM	HU 32231 80897	432231	1180897		35 sheep on hillside
20	21-SEP-07 11:18:35AM	HU 32667 81002	432667	1181002	Figure 9	Corner of northern Laurenson mussel lines
21	21-SEP-07 11:19:47AM	HU 32899 81087	432899	1181087		Corner of northern Laurenson mussel lines
22	21-SEP-07 11:19:59AM	HU 32899 81118	432899	1181118		Corner of northern Laurenson mussel lines
23	21-SEP-07 11:21:10AM	HU 32669 81041	432669	1181041		Corner of northern Laurenson mussel lines
24	21-SEP-07 11:22:40AM	HU 32680 81028	432680	1181028		Salinity profile – see Table 3 Seawater sample (Ronas 6) 12.23 Mussel sample (Ronas 7) combined 1-3 m depth (small size) 12.34 10 gulls nearby; 15 sheep on hillside
25	21-SEP-07 11:45:59AM	HU 32890 81108	432890	1181108		Salinity profile – see Table 3 Seawater sample (Ronas 8)
26	21-SEP-07 11:49:00AM	HU 32917 81046	432917	1181046		Corner of southern Laurenson mussel lines
28	21-SEP-07 11:49:06AM	HU 32921 81034	432921	1181034		Corner of southern Laurenson mussel lines
29	21-SEP-07 11:49:12AM	HU 32927 81023	432927	1181023		Corner of southern Laurenson mussel lines
30	21-SEP-07 11:50:33AM	HU 32743 80890	432743	1180890		Corner of southern Laurenson mussel lines
31	21-SEP-07 11:50:50AM	HU 32717 80906	432717	1180906	Figure 10	Corner of southern Laurenson mussel lines
32	21-SEP-07 11:51:26AM	HU 32723 80912	432723	1180912		Salinity profile – see Table 3 Seawater sample (Ronas 9) 12.55 Mussel sample (Ronas 10) surface 12.55 Mussel sample (Ronas 11) 5 m 12.56 7 gulls, 2 cormorants on lines 26 gulls on shore 8 sheep on hillside

No.	Date	NGR	East	North	Associated photograph	Description
33	21-SEP-07 12:08:27PM	HU 32912 81019	432912	1181019		Salinity profile – see Table 3 Seawater sample (Ronas 12) 13.10
34	21-SEP-07 12:11:35PM	HU 32908 81036	432908	1181036		Mussel sample (Ronas 13) surface 13.15 Mussel sample (Ronas 14) 5 m 13.20
35	21-SEP-07 12:56:19PM	HU 33457 81052	433457	1181052	Figure 11	Large stream width 1.5 m; depth 28 cm; flow 0.18 m/s Freshwater sample (Ronas 15) 14.08 26 cattle in fields near stream 6 dwellings nearby
36	22-SEP-07 7:52:56AM	HU 33373 81085	433373	1181085		Cattle feeding by shore east side of stream No observable septic tank outfalls Large amount of miscellaneous (non-sewage related) debris above MHWS
37	22-SEP-07 7:57:53AM	HU 33378 81127	433378	1181127		?pipe/hole at side of hill – no flow
38	22-SEP-07 8:03:23AM	HU 33370 81142	433370	1181142		Surface run-off by house: width 26 cm; depth 3 cm; flow 0.27 m/s Mussel shells on beach
39	22-SEP-07 8:05:27AM	HU 33321 81174	433321	1181174		Surface seepage over a 5 m stretch
40	22-SEP-07 8:10:07AM	HU 33246 81064	433246	1181064		11 cows on beach 100m east 20 cows and 1 bull in fields above
41	22-SEP-07 8:20:11AM	HU 33846 81093	433846	1181093		Approximately 70 sheep on east side of valley 6 sheep on west side Also 2 ponies and 8 sheep on easternmost croft
42	22-SEP-07 8:26:18AM	HU 32230 80555	432230	1180555	Figure 12	Installation above fish farm 12 sheep on hill east of fish farm 4 sheep by fish farm 18 sheep west of fish farm
43	22-SEP-07 8:35:59AM	HU 32400 80579	432400	1180579		Small stream: width 35 cm; depth 18 cm; flow 0.002 m/s
44	22-SEP-07 8:41:59AM	HU 32396 80651	432396	1180651		Small stream (recorded at 43) enters voe
45	22-SEP-07 8:51:06AM	HU 32257 80590	432257	1180590	Figure 13	Small stream: width 30 cm; depth 17 cm; flow 0.045 m/s

No.	Date	NGR	East	North	Associated photograph	Description
46	22-SEP-07 8:55:02AM	HU 32253 80592	432253	1180592		Very small stream: width 50 cm; depth 5 cm; flow 0.02 m/s
47	22-SEP-07 8:58:04AM	HU 32178 80595	432178	1180595		Surface run-off; too small to measure
48	22-SEP-07 9:04:08AM	HU 32085 80569	432085	1180569		Very small stream: width 18 cm; depth 7 cm; flow 0.10 m/s
49	22-SEP-07 9:09:59AM	HU 32035 80571	432035	1180571		Very small stream: width 10 cm; depth 5 cm; flow 0.17 m/s
50	22-SEP-07 9:15:32AM	HU 32185 80594	432185	1180594		Surface run-off: too small to measure
51	22-SEP-07 9:25:52AM	HU 31224 80347	431224	1180347		Building on shore by fish farm 2 round pens on southern side of voe 4 round pens on northern side of voe – plus launch and work boat
52	22-SEP-07 9:28:34AM	HU 30614 80142	430614	1180142		2 fishing boats; 1 voe boat; mussel grading raft 20 sheep on hillside
53	22-SEP-07 9:38:24AM	HU 30457 80263	430457	1180263	Figure 14	Pier below Aquafarms Ltd Pipe leads from shed to pier and water Fishing boat and voe boat on western side of pier 9 sheep on hillside below road – others above road
54	22-SEP-07 9:43:32AM	HU 30390 80237	430390	1180237	Figure 15	Approx 15 cm plastic pipe from Aquafarm building leading to approximately 6 m beyond MHWS 5 sheep by Aquafarm buildings
55	22-SEP-07 9:50:34AM	HU 29884 80534	429884	1180534		Sheep droppings ++ and rabbits on hillside
56	22-SEP-07 9:51:52AM	HU 29705 80563	429705	1180563		House above shore. 18 sheep and two geese in field to west. Land run-off across field
57	22-SEP-07 9:54:09AM	HU 29424 80780	429424	1180780		2 houses above shore.
58	22-SEP-07 9:58:24AM	HU 29046 81066	429046	1181066		House on hill above. No signs of septic tank outlets in the area. Razor and other clam shells on shore.
59	22-SEP-07 10:00:27AM	HU 29001 81104	429001	1181104		Stream enters voe. Width: 1.5m; depth 18 cm; flow 0.06 m/s. Septic smell.

No.	Date	NGR	East	North	Associated photograph	Description
60	22-SEP-07 10:05:46AM	HU 29231 80956	429231	1180956	Figure 16	30 cm ID pipe discharges into stream. Pipe discharge appeared to be a combination of a small stream and a pipe emerging below house.
61	22-SEP-07 10:07:48AM	HU 29185 80949	429185	1180949	Figure 17	Pipe below house – second small pipe nearby also joins the small stream.
62	22-SEP-07 10:19:10AM	HU 29238 80884	429238	1180884	Figure 18	50 cm diameter pipe emerges from hillside. 2 houses on hillside above. Small stream from pipe: Width 15cm; depth 4 cm; flow 0.117 m/s.
63	22-SEP-07 10:26:11AM	HU 29307 80851	429307	1180851		Abandoned vehicles along approximately 20 m of shore.
64	22-SEP-07 10:29:24AM	HU 29384 80825	429384	1180825		Very small stream below houses. Disappears into shore – too small to measure. No sign of septic tank outlets.
65	22-SEP-07 10:32:56AM	HU 29440 80844	429440	1180844		Eastern limit of leg.
66	22-SEP-07 10:34:57AM	HU 29430 80842	429430	1180842		Large amount of mussel shells on beach.
67	05-DEC-07 10:51:05AM	HU 29505 81296	429505	1181296		Ronas 1 water sample, Ronas 1 mussel sample. (Site consists of 4 x 4 lines of pipes with sheets suspended underneath)
68	05-DEC-07 11:05:49AM	HU 29908 80994	429908	1180994		Ronas 2 water sample, Ronas 2 mussel sample.
69	05-DEC-07 11:27:21AM	HU 31461 81185	431461	1181185		Stream 480cm wide. Depth and flow measured at 4 places across transect. (13cm, 0.211 m/s) (15 cm, 0.330m/s) (23cm, 0.453m/s) (20cm, 0.368m/s). Water sample Ronas 3 fresh.
70	05-DEC-07 12:09:27PM	HU 29012 81034	429012	1181034	Figure 19	Septic tank, no apparent overflow, 1 house.
71	05-DEC-07 12:12:36PM	HU 29102 80942	429102	1180942	Figure 20	Septic tank, no apparent overflow, 1 house.
72	05-DEC-07 12:23:53PM	HU 29170 80943	429170	1180943	Figures 21	Stream (may receive seepage from septic tank (WP71). 90cm x 4 cm x 0.293 m/s. Water Ronas 4 fresh.
73	05-DEC-07 12:24:11PM	HU 29182 80957	429182	1180957		Stream 96 cm x 6 cm x 0.143 m/s. Water Ronas 5 fresh.
74	05-DEC-07 12:34:55PM	HU 29224 80826	429224	1180826		4 houses, no obvious septic tanks. Any septics might overflow into stream (WP75)

No.	Date	NGR	East	North	Associated photograph	Description
75	05-DEC-07 12:39:48PM	HU 29202 80840	429202	1180840		Stream next to houses, some odour. 13cmx3cmx0.332m/s. Water Ronas 6 fresh.
76	05-DEC-07 12:46:16PM	HU 29406 80803	429406	1180803		2 new looking wooden houses (under construction?). No septic tanks seen, but lengths of orange sewer pipes lying around
77	05-DEC-07 12:49:53PM	HU 29732 80562	429732	1180562		House with septic tank in back garden (no overflow seen).
78	05-DEC-07 1:04:20PM	HU 33426 81080	433426	1181080		Circa 100 geese disturbed by survey staff.
79	05-DEC-07 1:05:59PM	HU 33368 81140	433368	1181140	Figure 22	House with septic tank in back garden (no overflow seen).
80	05-DEC-07 1:12:59PM	HU 33189 81430	433189	1181430	Figure 23	Burn of Orrwick 230 cm wide. Depth and flow measured at 4 places across transect. (20cm, 0.283 m/s) (23cm, 0.689 m/s) (16cm, 0.573 m/s) (6cm, 0.312 m/s). Water Ronas 7 fresh.
81	05-DEC-07 1:27:48PM	HU 33368 81092	433368	1181092	Figure 24	Livestock feeder on shore, small amount of dung nearby.
82	05-DEC-07 1:33:04PM	HU 33618 81048	433618	1181048		New looking wooden house.
83	05-DEC-07 1:34:48PM	HU 33798 80837	433798	1180837		2 houses plus outbuildings about 200m SW of here

Table 2. Salinity profiles

Site	NGR	Depth (metres)	Salinity (ppt)	Temperature (ºC)
South of Ayre of Teogs	HU 2988 8099	1	34.1	11.5
		3	34.1	11.4
		5	34.1	11.4
South of Ayre of Teogs	HU 2951 8130	1	34.2	11.5
		3	34.5	11.5
		5	34.6	11.5
Ronas Voe (northern)	HU 3268 8103	1	28.5	12.7
		3	28.6	12.6
		5	32.2	13.3
Ronas Voe (northern)	HU 3289 8111	1	26.5	11.9
		3	28.4	12.1
		5	32.3	12.7
Ronas Voe (southern)	HU 3272 8091	1	28.9	12.0
		3	29.4	12.1
		5	30.5	12.2
Ronas Voe (southern)	HU 3291 8102	1	26.5	11.7
		3	28.8	12.0
		5	30.8	12.3

Table 3. Water Sample Results

No.	Date	Sample	Type	NGR	*E. coli* (cfu/100ml)
1	21/09/07	Ronas 1	Sea	HU 2990 8097	2
2	21/09/07	Ronas 2	Sea	HU 2951 8130	<1
3	21/09/07	Ronas 3	Fresh	HU 2973 8122	60
4	21/09/07	Ronas 4	Fresh	HU 2935 8169	190
5	21/09/07	Ronas 5	Sea	HU 3123 8084	4
6	21/09/07	Ronas 6	Sea	HU 3268 8103	30
7	21/09/07	Ronas 8	Sea	HU 3289 8111	60
8	21/09/07	Ronas 9	Sea	HU 3272 8091	16
9	21/09/07	Ronas 12	Sea	HU 3291 8102	40
10	21/09/07	Ronas 15	Fresh	HU 3346 8105	22
11	05/12/07	Ronas Dec 1	Sea	HU 2951 8130	<1
12	05/12/07	Ronas Dec 2	Sea	HU 2991 8099	<1
13	05/12/07	Ronas Dec 3	Fresh	HU 3146 8119	2
14	05/12/07	Ronas Dec 4	Fresh	HU 2917 8094	10
15	05/12/07	Ronas Dec 5	Fresh	HU 2918 8096	9
16	05/12/07	Ronas Dec 6	Fresh	HU 2920 8084	900
17	05/12/07	Ronas Dec 7	Fresh	HU 3319 8143	1

Table 4. Shellfish Sample Results

No.	Date	Sample	Type	NGR	*E. coli* (MPN/100g)	Depth (metres)
1	21/09/07	Ronas 7	mussel	HU 3268 8103	2200	1-3
2	21/09/07	Ronas 10	mussel	HU 3272 8091	750	Surface
3	21/09/07	Ronas 11	mussel	HU 3272 8091	700	5
4	21/09/07	Ronas 13	mussel	HU 3291 8104	1700	Surface
5	21/09/07	Ronas 14	mussel	HU 3291 8104	290	5
6	05/12/07	Ronas Dec m1	mussel	HU 2951 8130	40	1
7	05/12/07	Ronas Dec m2	mussel	HU 2991 8099	<20	1

Fig. 2. Water sample results map

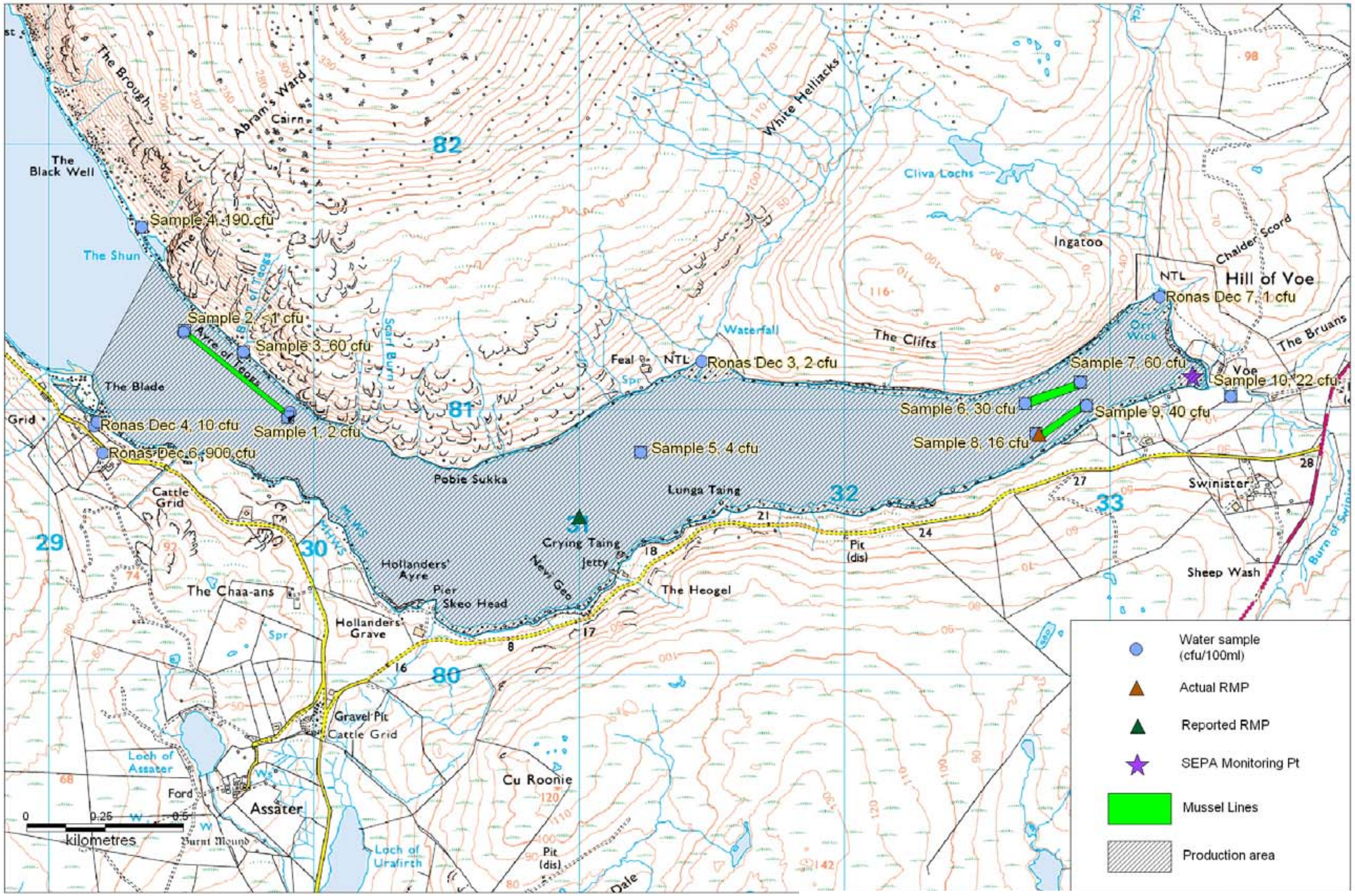
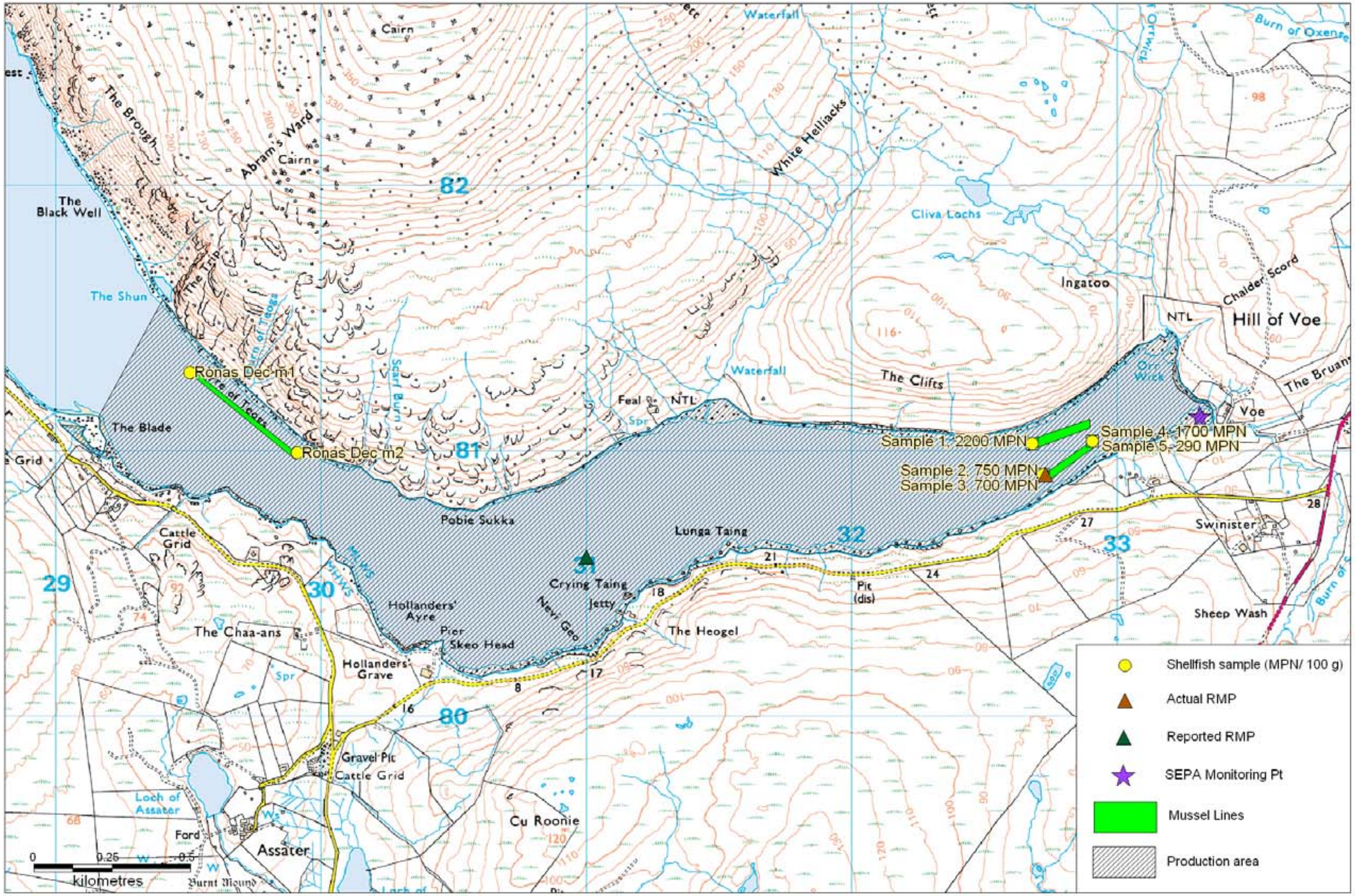


Figure 3. Shellfish sample results map



Photographs

Figure 4. Ronas Voe-0020. Mussel sheets - South Of Ayre of Teogs

Figure 5. Ronas Voe-0022. Hillside at South of Ayre of Teogs

Figure 6. Ronas Voe-0023. Land run-off – South of Ayre of Teogs

Figure 7. Ronas Voe-0027. Two streams east of South of Ayre of Teogs

Figure 8. Ronas Voe-0029. Fish farm

Figure 9. Ronas Voe-0030. Ronas Voe north site mussel lines

Figure 10. Ronas Voe-0031. Ronas Voe south site mussel lines

Figure 11. Ronas Voe-0036. Burn at head of voe plus cattle

Figure 12. Ronas Voe-0047. Land run-off in foreground. Fish farm in voe

Figure 13. Ronas Voe-0050. Land run-off

Figure 14. Pipe entering water from pier

Figure 15. Ronas Voe-0061
Pipe below Aquafarms Ltd.

Figure 16. Ronas Voe-0063. Stream and pipe

Figure 17. Ronas Voe-0064. Pipe below dwelling

Figure 18. Ronas Voe-0068. Pipe

Figure 19. Ronas Dec 1. Septic tank

Figure 20. Ronas Dec 2. Septic tank

Figure 21. Ronas Dec 3. Stream

Figure 22. Ronas Dec 5. Septic tank

Figure 23. Ronas Dec 6. Stream

Figure 23. Ronas Dec 7. Livestock feeder

Sampling Plan for Ronas Voe

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
Ronas Voe: East	Ronas Voe	TBA	Mussel	Rope	HU 3292 8103	43292	118103	20	1m	Hand	Monthly	Sheltand Islands	Sean Williamson George Williamson Kathryn Winter Marion Slater	Dawn Manson
Ronas Voe: South of Ayre of Teogs	South of Ayre of Teogs	TBA	Mussel	SMART sheet	HU 2967 8118	42967	118118	20	1m	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.

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

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

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

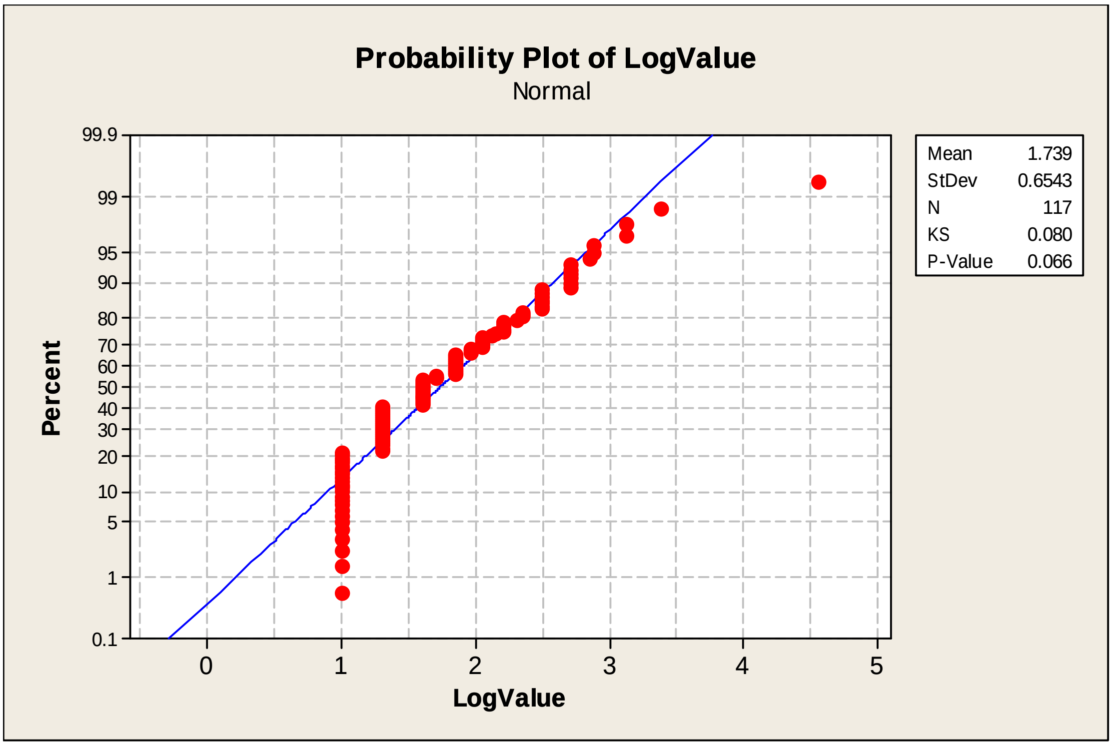
Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^8
Cow	230,000	23,600	5.4×10^9
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^8
Pig	3,300,000	2,700	8.9×10^8
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^8
Human	13,000,000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

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

Statistical Data

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

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



T-Test comparison of all results by site

Two-sample T for LogValue

Site	N	Mean	StDev	SE Mean
Ronas Voe	74	1.838	0.688	0.080
South of Ayre of Teogs	43	1.568	0.559	0.085

Difference = mu (Ronas Voe) - mu (South of Ayre of Teogs)
Estimate for difference: 0.270
95% CI for difference: (0.039, 0.502)
T-Test of difference = 0 (vs not =): T-Value = 2.31 P-Value = 0.023 DF = 102

Paired T-Test comparison of results by site when both sites were sampled on the same day

Paired T for Ronas Voe logresult (sameday) - South of Ayre of Teogs (sameda)

	N	Mean	StDev	SE Mean
Ronas Voe logresult (sam	19	1.792	0.604	0.139
South of Ayre of Teogs (	19	1.442	0.501	0.115
Difference	19	0.349	0.620	0.142

95% CI for mean difference: (0.050, 0.648)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.45 P-Value = 0.024

ANOVA comparison of results by season (both sites combined) with Tukeys comparison)

```
Source   DF      SS     MS     F      P
Season    3   5.851  1.950  5.03  0.003
Error   113  43.815  0.388
Total   116  49.667

S = 0.6227   R-Sq = 11.78%   R-Sq(adj) = 9.44%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      29  1.3653  0.3998  (---------*--------)
2      28  1.8903  0.8884                    (---------*--------)
3      35  1.9210  0.5350                      (--------*-------)
4      25  1.7481  0.5880               (---------*---------)
                          -----+---------+---------+---------+----
                             1.25      1.50      1.75      2.00

Pooled StDev = 0.6227


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Season

Individual confidence level = 98.97%


Season = 1 subtracted from:

Season    Lower  Center   Upper  -----+---------+---------+---------+----
2        0.0945  0.5250  0.9555              (----------*----------)
3        0.1477  0.5556  0.9636                (---------*---------)
4       -0.0607  0.3828  0.8262          (-----------*----------)
                                 -----+---------+---------+---------+----
                                   -0.40      0.00      0.40      0.80


Season = 2 subtracted from:

Season    Lower   Center   Upper  -----+---------+---------+---------+----
3       -0.3813   0.0307  0.4426     (----------*---------)
4       -0.5893  -0.1422  0.3048  (----------*-----------)
                                  -----+---------+---------+---------+----
                                    -0.40      0.00      0.40      0.80


Season = 3 subtracted from:

Season    Lower   Center   Upper  -----+---------+---------+---------+----
4       -0.5983  -0.1729  0.2526  (----------*---------)
                                  -----+---------+---------+---------+----
                                    -0.40      0.00      0.40      0.80
```

ANOVA comparison of results by season (Ronas Voe site only) with Tukeys comparison

```
Source  DF      SS     MS     F      P
Season   3   5.819  1.940  4.73  0.005
Error   70  28.713  0.410
Total   73  34.532

S = 0.6405   R-Sq = 16.85%   R-Sq(adj) = 13.29%
```

```
                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
1      20  1.3843  0.3968  (--------*-------)
2      19  1.9954  0.9238                (-------*-------)
3      20  2.0722  0.5238                  (-------*-------)
4      15  1.9332  0.6063             (--------*---------)
                           ---------+---------+---------+---------+
                                 1.40      1.75      2.10      2.45

Pooled StDev = 0.6405


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Season

Individual confidence level = 98.95%


Season = 1 subtracted from:

Season    Lower  Center   Upper  ----+---------+---------+---------+-----
2        0.0713  0.6110  1.1508              (----------*----------)
3        0.1551  0.6878  1.2206                (----------*---------)
4       -0.0266  0.5489  1.1243            (-----------*----------)
                                 ----+---------+---------+---------+-----
                                   -0.50      0.00      0.50      1.00


Season = 2 subtracted from:

Season    Lower   Center   Upper  ----+---------+---------+---------+-----
3       -0.4629   0.0768  0.6165      (----------*---------)
4       -0.6441  -0.0622  0.5197   (-----------*----------)
                                  ----+---------+---------+---------+-----
                                    -0.50      0.00      0.50      1.00


Season = 3 subtracted from:

Season    Lower   Center   Upper  ----+---------+---------+---------+-----
4       -0.7144  -0.1390  0.4364  (----------*-----------)
                                  ----+---------+---------+---------+-----
                                    -0.50      0.00      0.50      1.00
```

ANOVA comparison of results by season (South of Ayre of Teogs site only)

```
Source  DF      SS     MS     F      P
Season   3   1.069  0.356  1.15  0.341
Error   39  12.076  0.310
Total   42  13.146

S = 0.5565   R-Sq = 8.14%   R-Sq(adj) = 1.07%


                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N    Mean   StDev  --------+---------+---------+---------+-
1       9  1.3232  0.4273  (-----------*------------)
2       9  1.6686  0.8137          (------------*-----------)
3      15  1.7194  0.4966              (--------*---------)
4      10  1.4705  0.4553      (-----------*-----------)
                           --------+---------+---------+---------+-
                                1.20      1.50      1.80      2.10
```

Pooled StDev = 0.5565

Regression analysis - log Result versus rain in previous 2 days (both sites combined)

The regression equation is
log result for rain = 1.61 + 0.0143 Rain in prev 2

Predictor	Coef	SE Coef	T	P
Constant	1.61494	0.09091	17.76	0.000
Rain in prev 2	0.01434	0.01282	1.12	0.266

S = 0.591413   R-Sq = 1.5%   R-Sq(adj) = 0.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.4379	0.4379	1.25	0.266
Residual Error	81	28.3313	0.3498		
Total	82	28.7692			

Unusual Observations

Obs	Rain in prev 2	log result for rain	Fit	SE Fit	Residual	St Resid
41	16.3	1.0000	1.8487	0.1591	-0.8487	-1.49 X
52	19.8	2.2041	1.8989	0.2009	0.3052	0.55 X
58	18.6	2.8751	1.8817	0.1865	0.9933	1.77 X
74	8.8	3.3802	1.7412	0.0814	1.6391	2.80R
78	0.4	3.1139	1.6207	0.0874	1.4933	2.55R

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

Regression analysis - log Result versus rain in previous 2 days (South of Ayre of Teogs)

The regression equation is
logres rain = 1.54 + 0.0088 Rain in prev 2

Predictor	Coef	SE Coef	T	P
Constant	1.5369	0.1271	12.09	0.000
Rain in prev 2	0.00884	0.01805	0.49	0.627

S = 0.575500   R-Sq = 0.6%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.0795	0.0795	0.24	0.627
Residual Error	39	12.9168	0.3312		
Total	40	12.9963			

Unusual Observations

Rain in logres

Obs	prev 2	rain	Fit	SE Fit	Residual	St Resid
9	16.2	1.0000	1.6802	0.2216	-0.6802	-1.28 X
20	16.3	1.0000	1.6811	0.2232	-0.6811	-1.28 X
39	0.4	3.1139	1.5405	0.1221	1.5735	2.80R
40	0.2	2.6990	1.5387	0.1245	1.1603	2.07R

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

Regression analysis - log Result versus rain in previous 2 days (Ronas Voe)

The regression equation is
logres rain = 1.69 + 0.0195 Rain in prev 2

Predictor	Coef	SE Coef	T	P
Constant	1.6924	0.1288	13.14	0.000
Rain in prev 2	0.01948	0.01803	1.08	0.287

S = 0.601139   R-Sq = 2.8%   R-Sq(adj) = 0.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.4217	0.4217	1.17	0.287
Residual Error	40	14.4547	0.3614		
Total	41	14.8764			

Unusual Observations

Obs	Rain in prev 2	logres rain	Fit	SE Fit	Residual	St Resid
27	19.8	2.2041	2.0780	0.2833	0.1261	0.24 X
30	18.6	2.8751	2.0547	0.2630	0.8204	1.52 X
38	8.8	3.3802	1.8638	0.1158	1.5164	2.57R

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

ANOVA comparison of log Result versus rainfall quartile in previous 2 days (both sites combined)

Source	DF	SS	MS	F	P
2 day q	3	0.890	0.297	0.84	0.476
Error	79	27.880	0.353		
Total	82	28.769			

S = 0.5941   R-Sq = 3.09%   R-Sq(adj) = 0.00%

```
                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N   Mean   StDev  ---+---------+---------+---------+------
1      17  1.7699  0.6453        (-------------*--------------)
2      29  1.5654  0.5111  (----------*----------)
3      17  1.6565  0.5721   (--------------*-------------)
4      20  1.8152  0.6753           (------------*------------)
                          ---+---------+---------+---------+------
                           1.40      1.60      1.80      2.00
```

Pooled StDev = 0.5941

ANOVA comparison of log Result versus rainfall quartile in previous 2 days (South fo Ayre of Teogs)

Source	DF	SS	MS	F	P
2 day q	3	1.350	0.450	1.43	0.250
Error	37	11.646	0.315		
Total	40	12.996			

S = 0.5610   R-Sq = 10.39%   R-Sq(adj) = 3.12%

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
1       9  1.7689  0.7514            (------------*------------)
2      13  1.3395  0.3578  (----------*---------)
3       9  1.5592  0.5881      (------------*------------)
4      10  1.7453  0.5605             (-----------*-----------)
                          ------+---------+---------+---------+---
                              1.20      1.50      1.80      2.10
```

Pooled StDev = 0.5610

ANOVA comparison of log Result versus rainfall quartile in previous 2 days (Ronas Voe)

Source	DF	SS	MS	F	P
2 day q	3	0.125	0.042	0.11	0.955
Error	38	14.752	0.388		
Total	41	14.876			

S = 0.6231   R-Sq = 0.84%   R-Sq(adj) = 0.00%

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean   StDev  -------+---------+---------+---------+--
1       8  1.7709  0.5538  (-----------------*-----------------)
2      16  1.7490  0.5523      (------------*------------)
3       8  1.7660  0.5719  (-----------------*----------------)
4      10  1.8851  0.7985       (---------------*---------------)
                          -------+---------+---------+---------+--
                               1.50      1.75      2.00      2.25
```

Pooled StDev = 0.6231

Regression analysis - log Result versus rain in previous 7 days (both sites combined)

The regression equation is
log result for rain = 1.50 + 0.00882 Rain in prev 7

Predictor	Coef	SE Coef	T	P
Constant	1.5013	0.1164	12.90	0.000
Rain in prev 7	0.008822	0.004641	1.90	0.061

S = 0.583103   R-Sq = 4.3%   R-Sq(adj) = 3.1%

Analysis of Variance

Source	DF	SS	MS	F	P

Regression	1	1.2285	1.2285	3.61	0.061
Residual Error	81	27.5407	0.3400		
Total	82	28.7692			

Unusual Observations

Obs	Rain in prev 7	log result for rain	Fit	SE Fit	Residual	St Resid
16	52.4	1.6021	1.9636	0.1594	-0.3615	-0.64 X
17	52.4	1.6021	1.9636	0.1594	-0.3615	-0.64 X
18	59.4	2.2041	2.0253	0.1896	0.1788	0.32 X
63	20.4	2.8751	1.6813	0.0641	1.1938	2.06R
74	23.0	3.3802	1.7042	0.0647	1.6760	2.89R
78	1.6	3.1139	1.5154	0.1103	1.5985	2.79R

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

Regression analysis - log Result versus rain in previous 7 days (South of Ayre of Teogs)

The regression equation is
logres rain = 1.41 + 0.00799 Rain in prev 7

Predictor	Coef	SE Coef	T	P
Constant	1.4117	0.1515	9.32	0.000
Rain in prev 7	0.007989	0.005823	1.37	0.178

S = 0.563823   R-Sq = 4.6%   R-Sq(adj) = 2.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.5984	0.5984	1.88	0.178
Residual Error	39	12.3980	0.3179		
Total	40	12.9963			

Unusual Observations

Obs	Rain in prev 7	logres rain	Fit	SE Fit	Residual	St Resid
8	59.4	2.2041	1.8863	0.2393	0.3178	0.62 X
26	8.2	2.6990	1.4773	0.1160	1.2217	2.21R
39	1.6	3.1139	1.4245	0.1441	1.6894	3.10R
40	14.0	2.6990	1.5236	0.0975	1.1754	2.12R

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

Regression analysis - log Result versus rain in previous 7 days (Ronas Voe)

The regression equation is
logres rain = 1.57 + 0.0103 Rain in prev 7

Predictor	Coef	SE Coef	T	P
Constant	1.5743	0.1796	8.77	0.000
Rain in prev 7	0.010349	0.007441	1.39	0.172

S = 0.595615   R-Sq = 4.6%   R-Sq(adj) = 2.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.6861	0.6861	1.93	0.172
Residual Error	40	14.1903	0.3548		
Total	41	14.8764			

Unusual Observations

Obs	Rain in prev 7	logres rain	Fit	SE Fit	Residual	St Resid
10	52.4	1.6021	2.1166	0.2529	-0.5145	-0.95 X
38	23.0	3.3802	1.8123	0.0934	1.5679	2.67R

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

ANOVA comparison of log Result versus rainfall quartile in previous 7 days (both sites combined)

Source	DF	SS	MS	F	P
7 day q	3	1.105	0.368	1.05	0.374
Error	79	27.664	0.350		
Total	82	28.769			

S = 0.5918   R-Sq = 3.84%   R-Sq(adj) = 0.19%

```
                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
1      19  1.5844  0.6216    (---------*----------)
2      18  1.5650  0.5563  (-----------*----------)
3      23  1.6982  0.6470         (---------*---------)
4      23  1.8530  0.5326              (---------*---------)
                           ---------+---------+---------+---------+
                                 1.50      1.75      2.00      2.25
```

Pooled StDev = 0.5918

ANOVA comparison of log Result versus rainfall quartile in previous 7 days (South of Ayre of Teogs)

Source	DF	SS	MS	F	P
7 day q	3	0.681	0.227	0.68	0.569
Error	37	12.315	0.333		
Total	40	12.996			

S = 0.5769   R-Sq = 5.24%   R-Sq(adj) = 0.00%

```
                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      11  1.5517  0.7475      (-----------*----------)
2      10  1.4049  0.5370  (-----------*-----------)
3       8  1.5809  0.4842     (-------------*------------)
4      12  1.7546  0.4758            (----------*-----------)
                           -----+---------+---------+---------+----
                              1.20      1.50      1.80      2.10
```

Pooled StDev = 0.5769

ANOVA comparison of log Result versus rainfall quartile in previous 7 days (Ronas Voe)

Source	DF	SS	MS	F	P
7 day q	3	0.543	0.181	0.48	0.698
Error	38	14.333	0.377		
Total	41	14.876			

S = 0.6142   R-Sq = 3.65%   R-Sq(adj) = 0.00%

```
                          Individual 95% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev    +---------+---------+---------+---------
1       8  1.6294  0.4372   (-------------*--------------)
2       8  1.7650  0.5464      (--------------*-------------)
3      15  1.7608  0.7269         (----------*---------)
4      11  1.9604  0.5922            (-----------*------------)
                             +---------+---------+---------+---------
                           1.20      1.50      1.80      2.10
```

Pooled StDev = 0.6142

ANOVA comparison of results by height of previous tide (both sites combined)

Source	DF	SS	MS	F	P
tide size	2	0.156	0.078	0.18	0.836
Error	114	49.511	0.434		
Total	116	49.667			

S = 0.6590   R-Sq = 0.31%   R-Sq(adj) = 0.00%

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean   StDev  -+---------+---------+---------+--------
Large   32  1.7942  0.5690      (---------------*--------------)
Medium  47  1.7326  0.7166       (------------*-----------)
Small   38  1.7004  0.6546  (-------------*-------------)
                            -+---------+---------+---------+--------
                           1.50      1.65      1.80      1.95
```

Pooled StDev = 0.6590

ANOVA comparison of results by height of previous tide (South of Ayre of Teogs)

Source	DF	SS	MS	F	P
tide size	2	0.247	0.124	0.38	0.684
Error	40	12.898	0.322		
Total	42	13.146			

S = 0.5679   R-Sq = 1.88%   R-Sq(adj) = 0.00%

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean   StDev  ---+---------+---------+---------+------
Large    9  1.6174  0.5333   (---------------*--------------)
Medium  18  1.6306  0.6335        (----------*----------)
Small   16  1.4696  0.5034  (-----------*----------)
                            ---+---------+---------+---------+------
                             1.25      1.50      1.75      2.00
```

Pooled StDev = 0.5679

ANOVA comparison of results by height of previous tide (Ronas Voe)

Source	DF	SS	MS	F	P
tide size	2	0.086	0.043	0.09	0.915
Error	71	34.446	0.485		
Total	73	34.532			

S = 0.6965   R-Sq = 0.25%   R-Sq(adj) = 0.00%

```
                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level    N    Mean   StDev  ----+---------+---------+---------+-----
Large   23  1.8633  0.5788    (-----------------*------------------)
Medium  29  1.7959  0.7675  (---------------*---------------)
Small   22  1.8683  0.7099    (------------------*-----------------)
                         ----+---------+---------+---------+-----
                           1.60      1.76      1.92      2.08
```

Pooled StDev = 0.6965

Circular-linear correlation of wind direction and result (both sites combined)

CIRCULAR-LINEAR CORRELATION		
Ronas Voe (All)		
Analysis begun: 24 January 2008 16:46:18		
Variables (& observations)	r	p
Angles & Linear (81)	0.224	0.02

Circular-linear correlation of wind direction and result (Ronas Voe site only)

CIRCULAR-LINEAR CORRELATION		
Analysis begun: 23 May 2008 13:18:48		
Ronas Voe		
Variables (& observations)	r	p
Angles & Linear (41)	0.293	0.038

Circular-linear correlation of wind direction and result (South of Ayre of Teogs site only)

CIRCULAR-LINEAR CORRELATION		
Analysis begun: 23 May 2008 13:17:30		
South of Teogs		
Variables (& observations)	r	p
Angles & Linear (40)	0.191	0.258

Hydrographic Methods

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

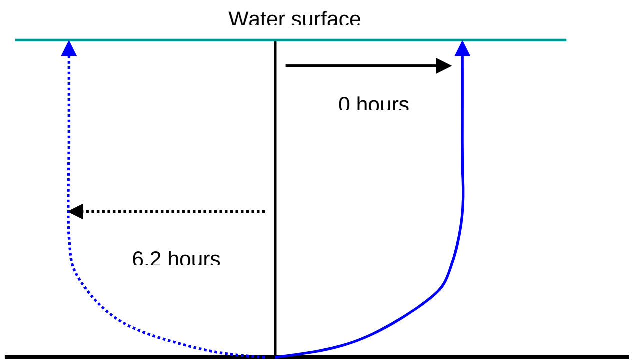
The hydrography at most sites will be assessed on the basis of bathymetry and tidal flow software only and is not discussed in any detail in this document. Selected sites will be assessed in more detail using either: 1) a hydrodynamic model, or 2) an extended consideration of sources, available field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

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

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

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

a)



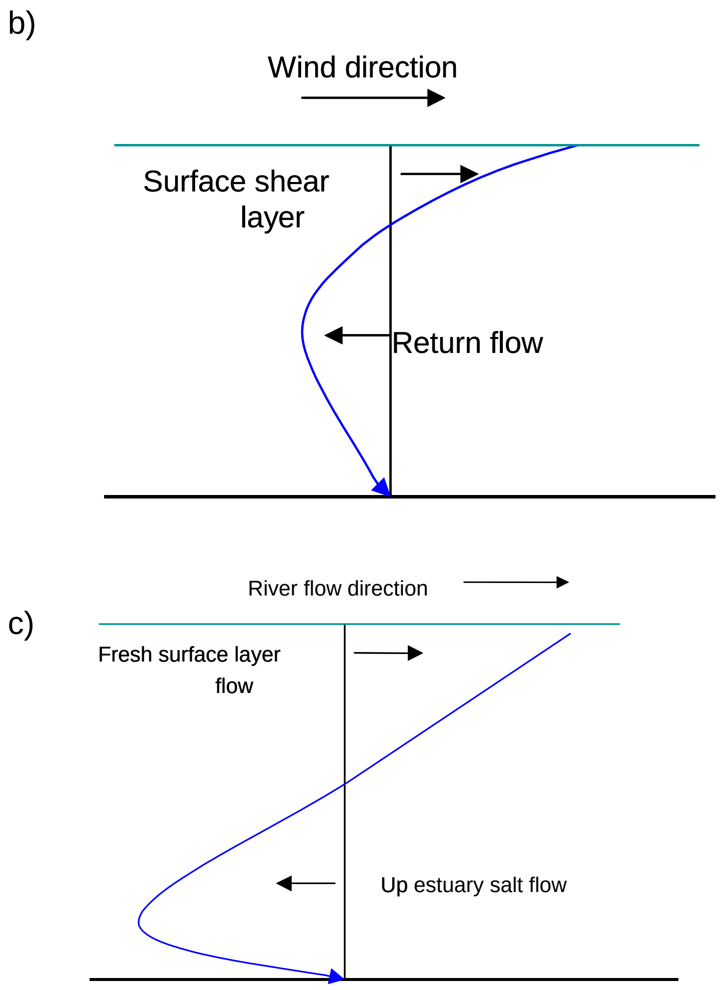


Figure 1. Typical vertical profiles for currents generated by different mechanisms. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main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

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

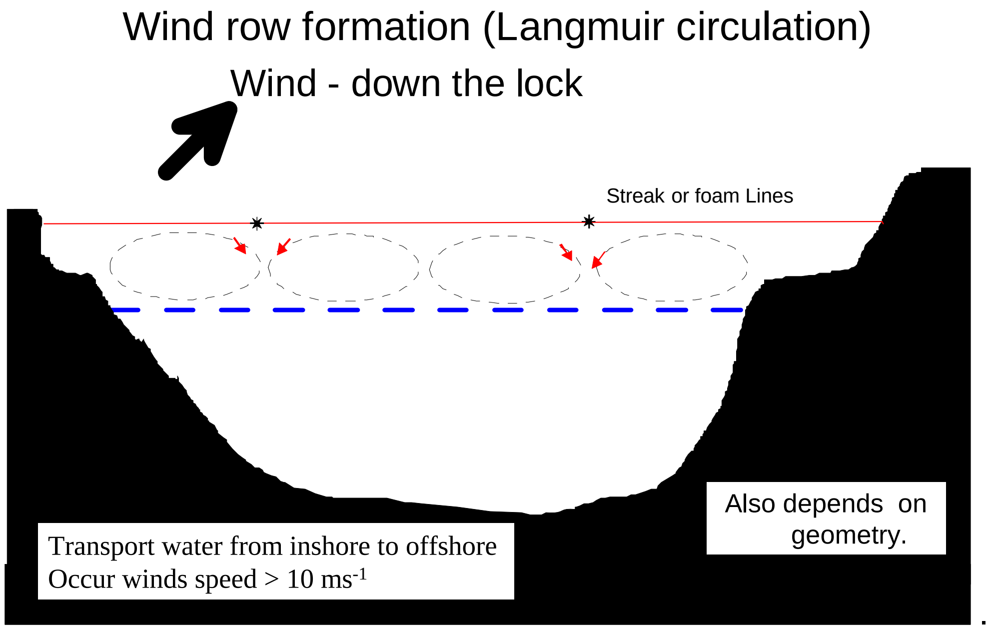


Figure 2: Schematic of wind driven 'wind row' currents. View is down the loch.The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.