Scottish Sanitary Survey Project

Sanitary Survey Report

Loch Inchard

HS 162

August 2008

FOOD STANDARDS AGENCY SCOTLAND

Buidheann Inbhe-Bìdhe an Alba

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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.

1. General Description

Loch Inchard is located in the far northwest of Scotland below Cape Wrath. The nearest town is Kinlochbervie. The mouth of the loch opens to the west and the loch itself extends 6.6km inland turning toward the southeast at its mid point. The maximum water depth is 61m with one sill at 24m depth located near Kinlochbervie Harbour.

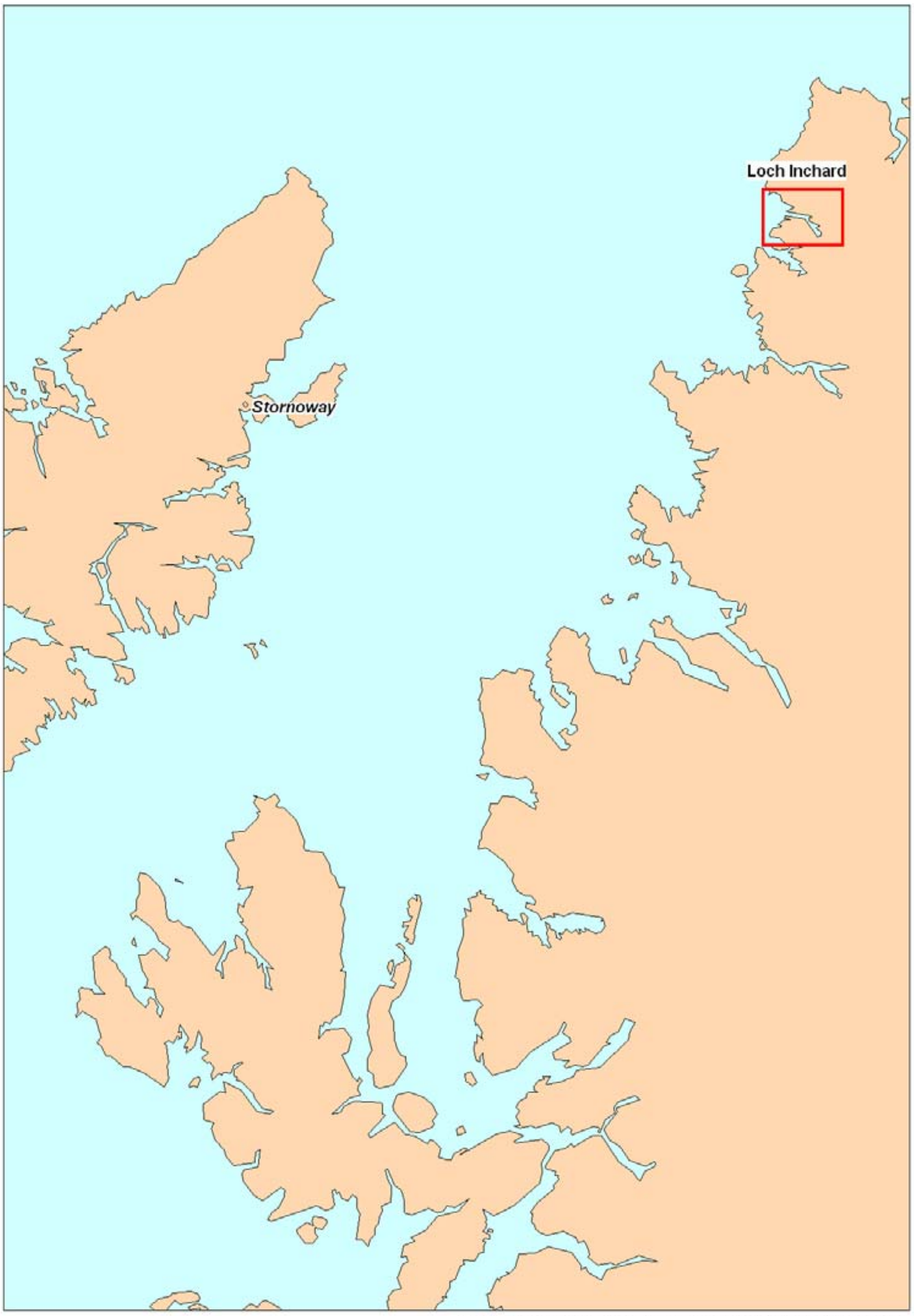

Figure 1.1 Location of Loch Inchard

2. Fishery

The fishery at Loch Inchard is comprised of five long line mussel (Mytilus sp.) farms as listed in Table 2.1 below:

Table 2.1. Loch Inchard shellfish farms

Site	SIN	Species
Site 1 – D. Ross	HS 162 311 08	Common mussels
Site 2 – D. Forbes	HS 162 312 08	Common mussels
Site 3 – C.Morrison	HS 162 313 08	Common mussels
Site 4 – J. Ross	HS 162 314 08	Common mussels
Site 5 – N. Ross	HS 162 315 08	Common mussels

Current production area boundaries are given as the area bounded by a line drawn between NC 2100 5611 and NC 2100 5547 extending inshore to MHWS.

The RMP for the production area is currently located on site 3 – Morrison. The reported RMP grid reference is NC 239 550.

All the sites produce rope-grown mussels on double headed long lines with 5 metre pegged droppers. Long lines attached to floats are laid out in parallel lines anchored at either end within the approved lease area. Vertical lines containing plastic pegs (droppers) are attached to the long lines. New lines are placed before or during spawning between May and early June and spat settle on to the droppers from the surrounding water. The spat are then left to grow for up to three years before reaching marketable size.

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

Harvesting is done in rotation with different lines set out in different years to allow harvesting of some stock every year.

Mussels may be harvested at any time of the year, according to demand. Loch Inchard does not generally experience summer closures due to algal biotoxins.

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

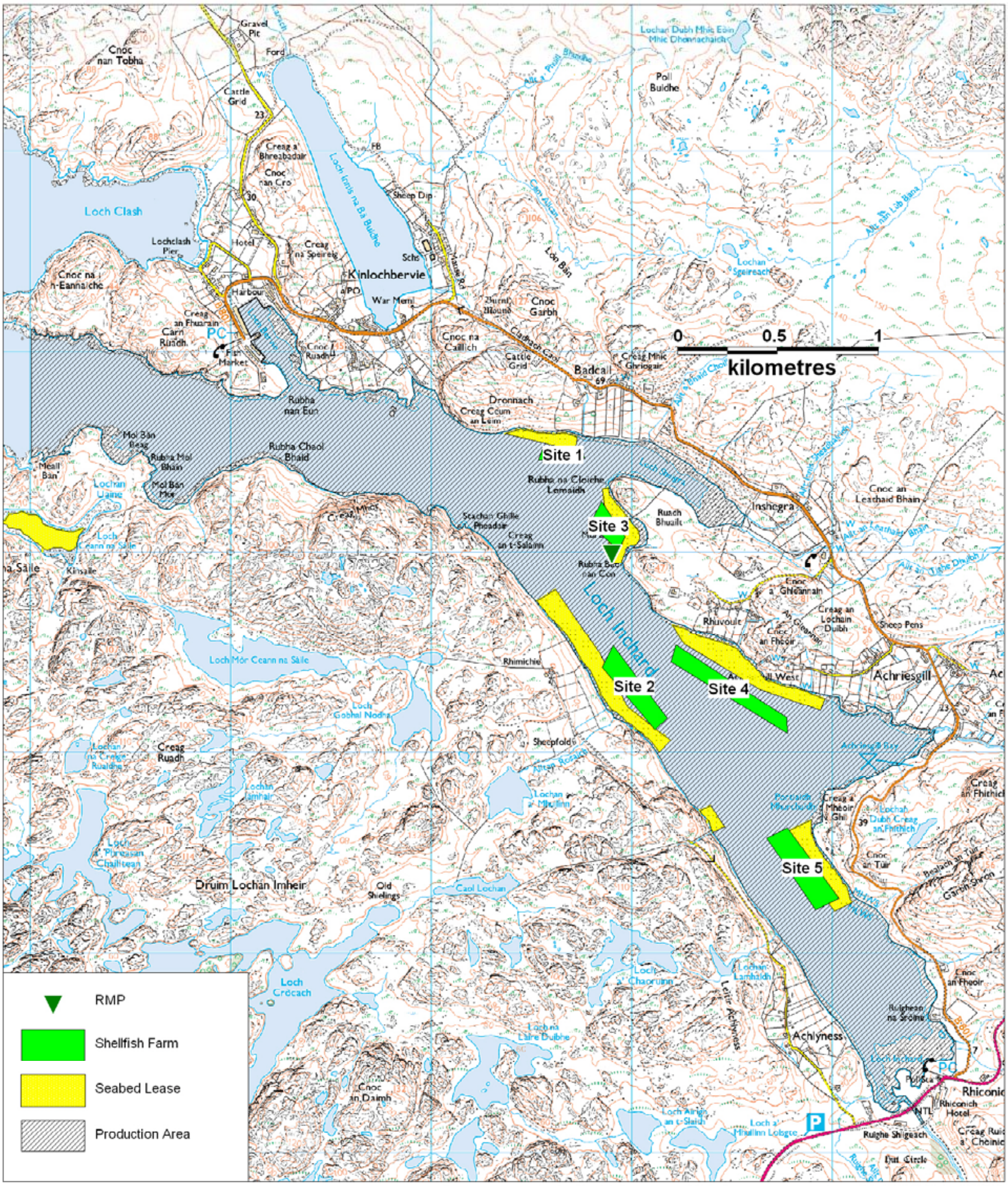

Figure 2.1 Loch Inchard fishery

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 Loch Inchard.

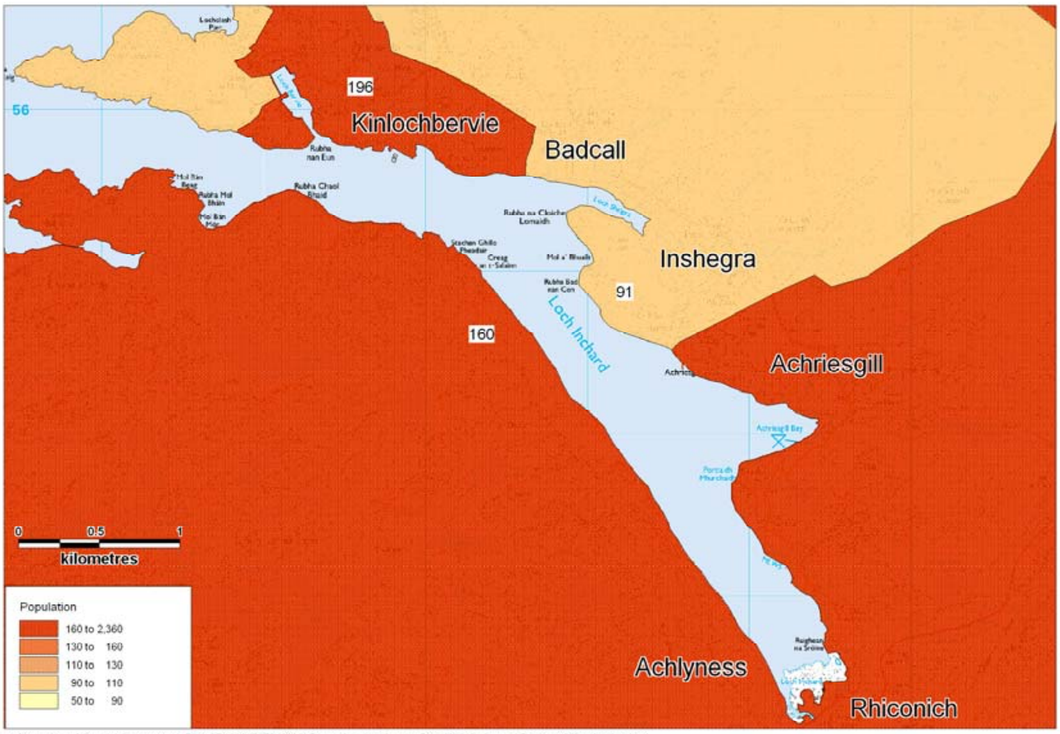

Figure 3.1 Population of Loch Inchard

The population for the three census output areas bordering immediately on Loch Inchard are:

60QT000356	160
60QT000357	196
60QT000358	91
Total	447

On the eastern side of the voe starting from the northwest corner of the loch and travelling south are the settlements of Kinlochbervie, Badcall, Inshegra, Achriesgill and Rhiconich. Achlyness is the only settlement on the western shore of the loch. Most of the population is concentrated along the eastern shoreline of the loch and any associated faecal pollution from human sources will be concentrated in this area.

Hotels and B&Bs in the area offer accommodation for approximately 90 people, with peak demand during the school holidays in July and August.

4. Sewage Discharges

Community septic tanks and sewage discharges were identified by Scottish Water for the area around Loch Inchard. They are detailed in Table 4.1.

Table 4.1 Discharges identified by Scottish Water

NGR	Discharge Name	Discharge Type	Level of Treatment	Consented Design PE
NC 22105570	Kinlochbervie Harbour	Continuous	Septic Tank	254
NC 23905580	Kinlochbervie Innis Place	Continuous	Septic Tank	130
NC 22005620	Kinlochbervie Bervie PS EO	Intermittent	6mm screen on overflow	-
NC 21805640	Kinlochbervie Clash PS EO	Intermittent	6mm screen on overflow	-
NC 22905658	Kinlochbervie Manse Rd PS EO	Intermittent	6mm screen on overflow	-

No sanitary or microbiological data were available for these discharges.

No information on discharge consents had been obtained from SEPA for this area at the time of this writing.

A number of septic tanks and/or outfalls were recorded during the shoreline survey. Their locations have been included in the mapped discharges in Figure 4.1. Observed septic tanks, covers and/or discharge pipes, including results from any associated samples, are listed in Table 4.2.

Table 4.2 Discharges and septic tanks observed during shoreline survey

No.	NGR	Description	Sample No.	Type	*E. coli* (cfu/100ml)
1	NC 25289 53949	Land drain	-	-	-
2	NC 22334 56000	Discharge pipe, no apparent flow	-	-	-
3	NC 22103 56068	Discharge from fisherman's mission PC	-	-	-
4	NC 22167 55924	Storm water overflow from storage tanks	Inchard 15	Fresh	100
5	NC 22169 55800	Kinlochbervie Harbour septic tank	Inchard 13	Sea	20
6	NC 22165 55772	Outfall	-	-	-
7	NC 22965 55830	Kinlochbervie Manse septic tank	-	-	-
8	NC 22926 56605	Manse Road pumping station	-	-	-
9	NC 23552 55980	Pumping station, septic tank? At Badcall	-	-	-
10	NC 25540 52379	Inspection hatch for septic tank at Rhiconich	-	-	-
11	NC 25528 52455	Audible sound of flowing water inside covered pipe at high tide line	-	-	-
12	NC 24865 55214	Septic tank at Old School Rooms B&B.End of pipe dripping. Additional septic tank outfall downstream	-	-	-
13	NC 24854 55221	3 septic tank outfalls, water sample taken downstream	Inchard 23	Fresh	800

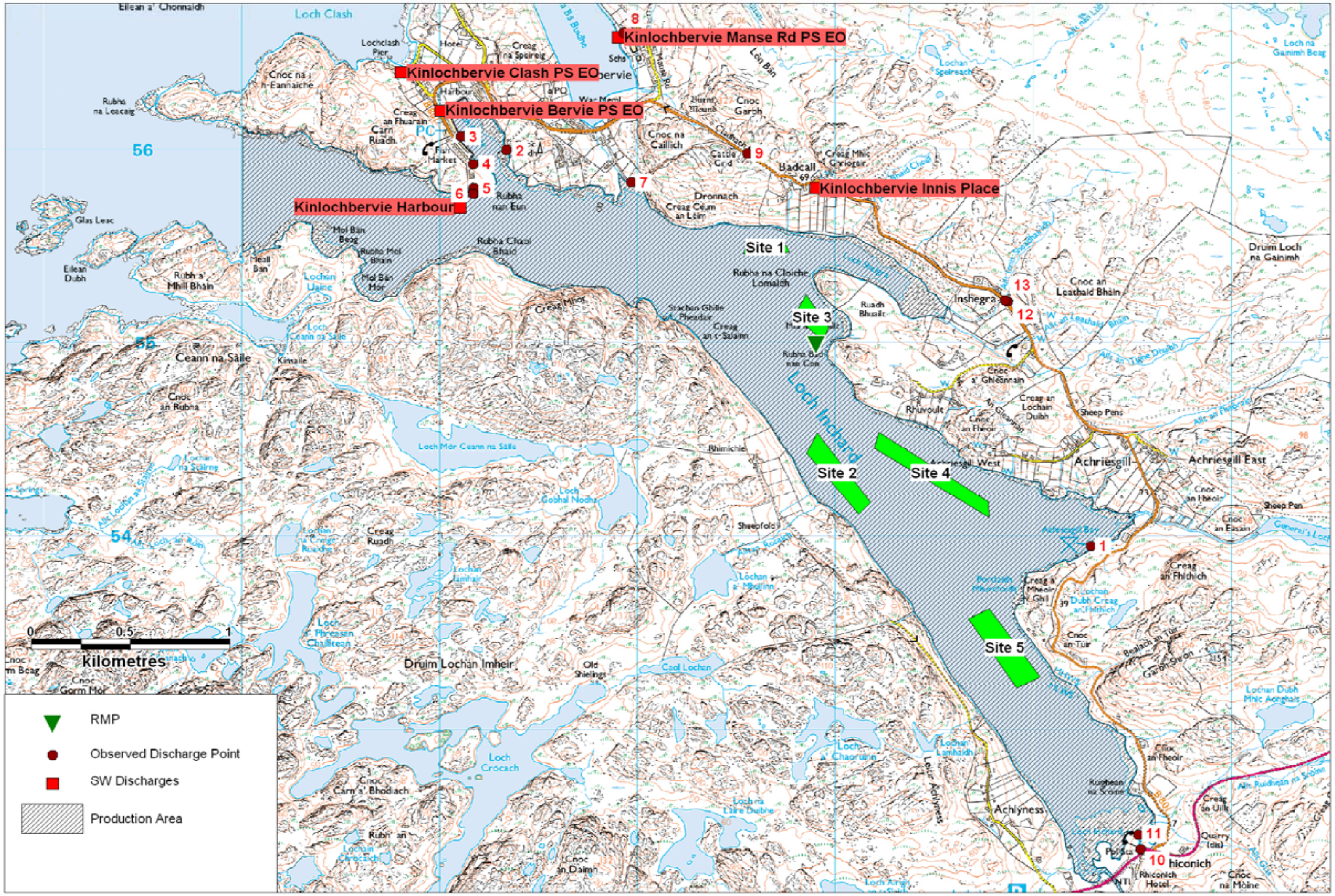

Figure 4.1 Sewage discharges at Loch Inchard

5. Geology and Soils

Component soils and their associations were identified using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute. The relevant soil associations and component soils were then investigated to establish basic characteristics. 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 glossary at the end of this section).

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

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

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

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

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

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

Alluvial soils are confined to principal river valleys and stream channels, with a wide soil textural range and variable drainage. However, the alluvial soils encountered within the Scottish 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 classified as to whether they are characteristically freely or poorly draining. The map of component soils and their associated drainage classes for the area around Loch Inchard can be found in Figure 5.1.

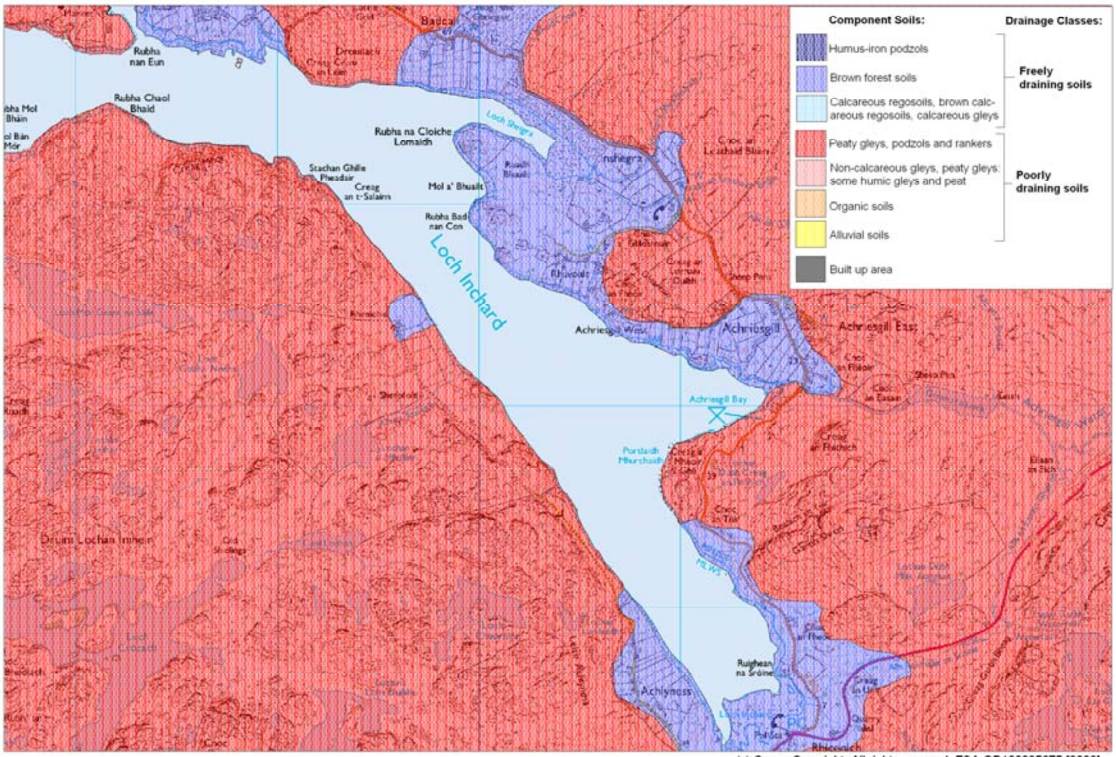

Figure 5.1 Component soils and drainage classes for Loch Inchard

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

The second dominant component soil is brown forest soil. This covers the southern end and some of the eastern coastline of Loch Inchard. There is also a small area of brown forest soils at the northern end of Loch Inchard, surrounding Loch Bervie.

In the poorly draining soils found along much of the Loch Inchard coastline surface run off is likely to be high, as peaty gleys, podzols and rankers are often waterlogged. In the more freely draining soils found along part of the eastern coastline of Loch Inchard, surface runoff is reduced as the permeability of the soil is higher.

The potential for runoff contaminated with E. coli from animal waste is predominantly higher along the western side of the loch.

Glossary of Soil Terminology

Calcareous: Containing free calcium carbonate.

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

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

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

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

6. Land cover

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

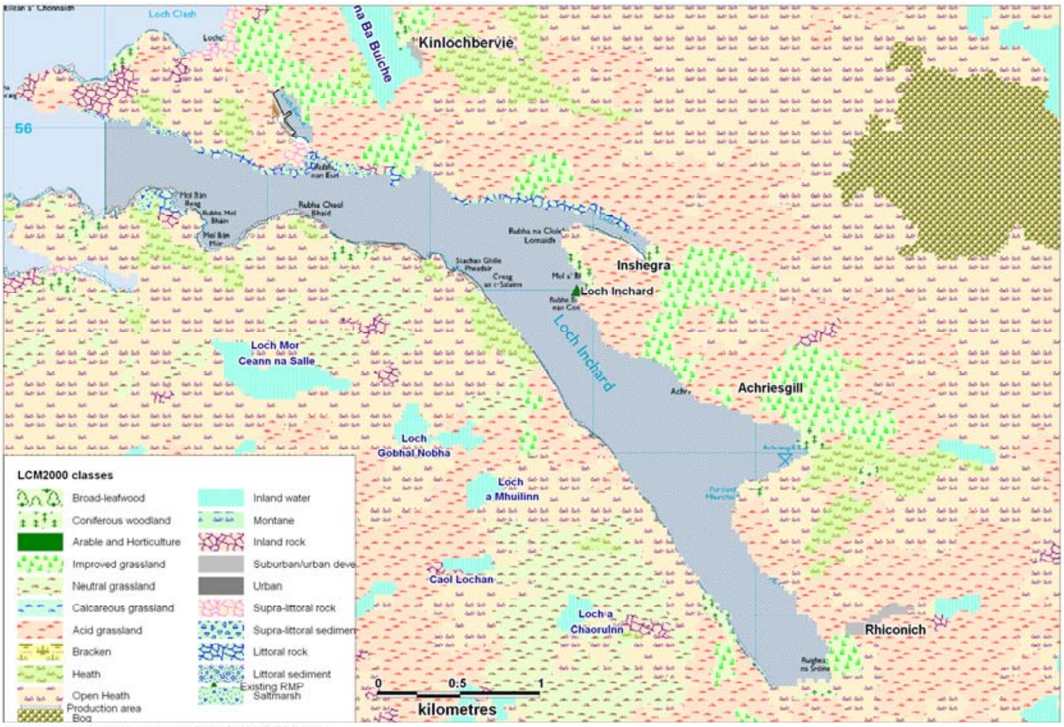

Figure 6.1 LCM2000 class data for Loch Inchard

Most of the land on the eastern side of the loch is acid grassland, improved grassland and open heath. There are also small patches of coniferous woodland, heath and inland rock. The land cover on the west side of the loch is more mixed with patches of heath, open heath, acid grassland, neutral grassland, improved grassland and coniferous woodland. Towards the mouth of the loch there are areas of littoral rock and salt marsh.

The faecal coliform contribution would be expected to be highest from developed areas, like Rhiconich (approx 1.2 – 2.8×10^9 cfu km^{-2} hr^{-1}), with intermediate contributions from the improved grassland (approximately 8.3×10^8 cfu km^{-2} hr^{-1}) and lowest from the other land cover types (approximately 2.5×10^8 cfu km^{-2} hr^{-1}) (Kay *et al*. 2008). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, this being expected to be highest, at more than 100-fold, for the improved grassland.

7. Farm Animals

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

(a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;
(b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human and animal populations in the catchment area, rainfall readings, waste-water treatment, etc.

With regard to potential sources of pollution of animal origin, agricultural census data to parish level was requested from 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 11th – 12th September 2007.

The land surrounding the loch is rugged and rocky. However, the shoreline survey identified that sheep were grazed on both sides of the loch, especially within the central region. Local communication indicated that the numbers recorded on the day of the survey were a fraction of what they had been the previous week, as the majority of the sheep had been sent to market. Estimated numbers for the previous week were approximately 200-300 sheep on the south side and 100 sheep on the north side. The geographical spread of contamination at the shores of the loch is therefore considered to be slightly greater on the south side and therefore needs to be assumed that this factor should be taken into account when identifying the location of a representative monitoring point (RMP).

There is no local information available for the seasonal livestock numbers surrounding Loch Inchard for other periods. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1.

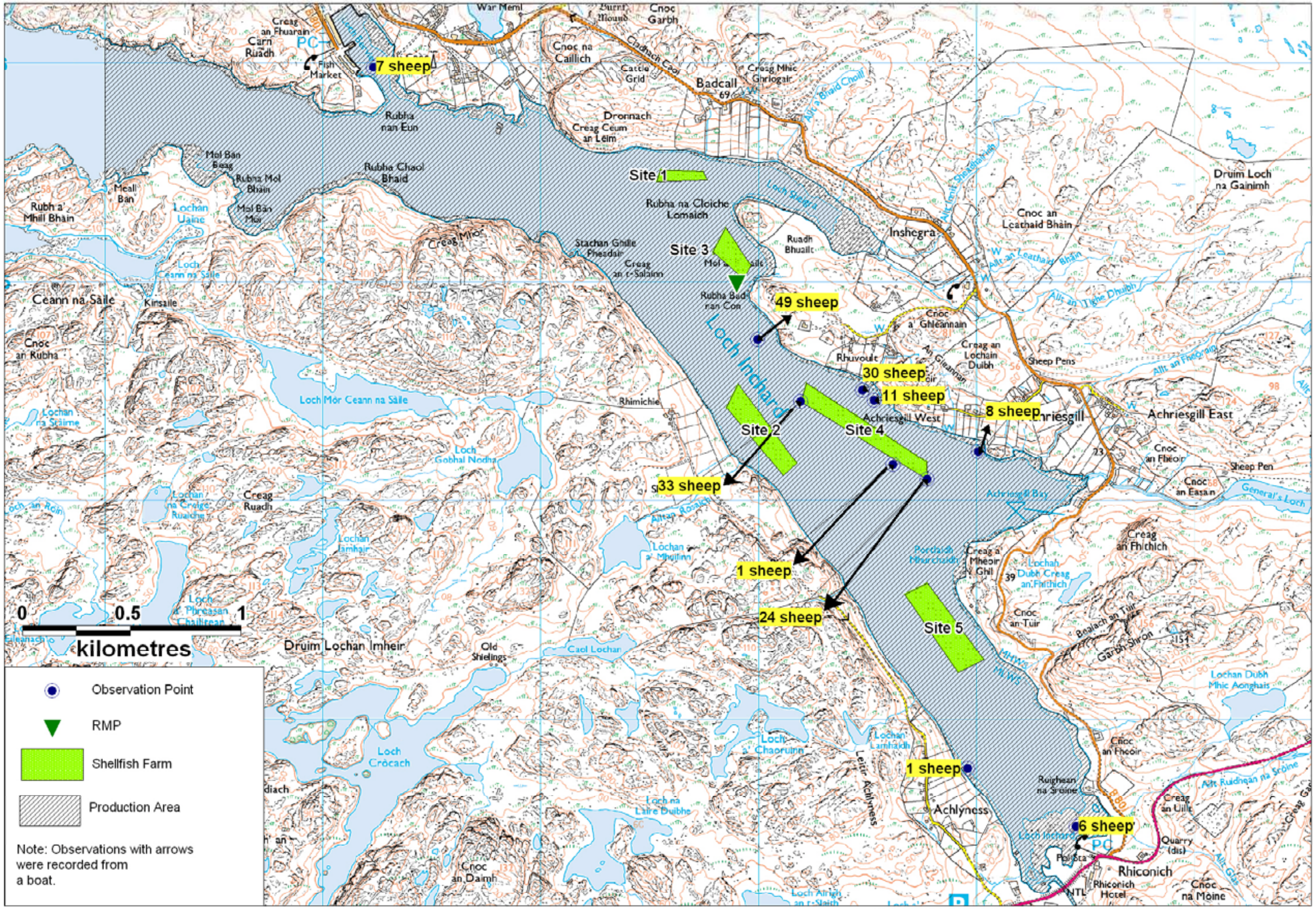

Figure 7.1 Livestock observations at Loch Inchard

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*). Both species can be found along the west coast of Scotland.

Common seals surveys are conducted every 5 years and an estimate of minimum numbers is available through Scottish Natural Heritage. Survey results from 1999 showed minimum numbers at Kinlochbervie to be 69. Additionally, in 2002 the islands around Handa, which lies to the southwest of the entrance to Loch Inchard, was surveyed as a grey seal breeding site and a 10 pups were counted (Sea Mammal Research Unit).

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.

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

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

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

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

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

8.2 Cetaceans

A variety of cetacean species are routinely observed around the west coast of Scotland.

Table 8.1 Cetacean sightings in 2007 – Western Scotland.

Common name	Scientific name	No. sighted*
Minke whale	Balaenoptera acutorostrata	28
Killer whale	*Orcinus orca*	183
Long finned pilot whale	*Globicephala melas*	14
Bottlenose dolphin	*Tursiops truncatus*	
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. Source: Hebridean Whale and Dolphin Trust.

As Loch Inchard is narrow and relatively constricted, it is highly unlikely that the loch would be visited by larger cetaceans. Smaller cetaceans such as harbour porpoises might hunt in the area. Their presence, however, is likely to be fleeting and unpredictable and so will not be taken into account with regard to establishing RMPs for the Loch Inchard production areas.

8.3 Birds

A number of seabird species are known to breed in the Highland Sutherland, most significant of these are described in table 8.2.

Table 8.2 Breeding seabirds of northwest coast Sutherland

Common name	Species	Population	Common name	Species	Population
Northern Fulmar	*Fulmarus glacialis*	23200*	Great Cormorant	*Phalacrocorax carbo*	76*
European shag	*Phalacrocorax aristotelis*	880*	Arctic skua	*Stercorarius parasiticus*	48*
Great Skua	*Stercorarius skua*	216*	Common Gull	*Larus canus*	87*
Lesser Black-backed Gull	*Larus fuscus*	44*	Herring Gull	*Larus argentatus*	544*
Great Black-backed Gull	*Larus marinus*	1058*	Black-legged Kittiwake	*Rissa tridactyla*	21775*
Common Tern	*Sterna hirundo*	95*	Arctic Tern	*Sterna paradisaea*	265*
Common Guillemot	*Uria aalge*	161858	Black Guillemot	*Cepphus grille*	895
Razorbill	*Alca torda*	21657	Atlantic Puffin	*Fratercula arctica*	9046*

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

The majority of large breeding colonies are located on Handa Island, outside Loch Inchard. Distribution of nesting sites near the harvesting areas is not known. Though nesting occurs in early summer, gulls are likely to be present in the area throughout the year. Impact to the fisheries is likely to be very localised where birds rest on floats or oyster trestles.

There is little in the way of intertidal area at Loch Inchard and so wading bird populations are likely to be insignificant, particularly in the vicinity of the shellfish farms.

8.4 Deer

Deer are present throughout much of Scotland in significant numbers. The Deer Commission of Scotland (DCS) conducts counts and undertakes culls of deer in areas that have large deer populations.

Four species of deer are routinely recorded in Scotland, with Red deer (*Cervus elaphus*) being the most numerous, followed by Roe deer (*Capreolus capreolus*), Sika deer (*Cervus nippon*) and Fallow deer (*Dama dama*).

Accurate counts of populations are not available, though estimates of the total populations are >200,000 Roe deer, >350,000 Red deer, < 8,000 Fallow deer and an unknown number of Sika deer. Where Sika deer and Red deer populations overlap, the two species interbreed further complicating counts.

Deer, like cattle and other ruminants, shed *E. coli*, *Salmonella* and other potentially pathogenic bacteria via their faeces and it is likely that some of the indicator organisms detected in the streams feeding into Loch Inchard will be of deer origin.

8.5 Other

The European Otters (*Lutra lutra*) is present around Scotland with some areas hosting populations of international significance. Coastal otters, such as those likely to be found in Loch Inchard, 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). It is not known what the otter population at Loch Inchard might be; however there is little suitable foraging habitat due to the steeply shelving shoreline and so any population present would be limited.

Summary

Wildlife impacts to the fisheries in Loch Inchard are likely to be highly localised and unpredictable. While some wildlife species can harbour bacteria and viruses that can cause illness in humans, their faeces are considered to pose a lower risk to human health than either human or livestock faecal contamination. Consequently, these sources will not materially affect the sampling plan.

9. Meteorological data

The nearest weather station is located at Achfary, approximately 15 km to the SSE of the production area. Uninterrupted rainfall data was supplied for the period 1/1/2003 to 31/12/2007 (total daily rainfall in mm). It is likely that rainfall experienced at Achfary is very similar to that experienced at the production area due to their close proximity. Wind data was not recorded at this station.

The nearest weather station is for which wind data is available is at Stornoway Airport, approximately 25 km to the west of the production area. It is likely that the wind patterns here are broadly similar but not identical to those on Loch Inchard and surrounding land, but it is likely that there are some differences in the wind on any given day (Stornoway is on the east coast of Lewis, Loch Inchard is on the west coast of the mainland). It is also possible that local topography may affect wind patterns differently.

This section aims to describe the local rain and wind patterns and discuss how they may affect the bacterial quality of shellfish within Loch Inchard.

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 Achfary. 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 *.

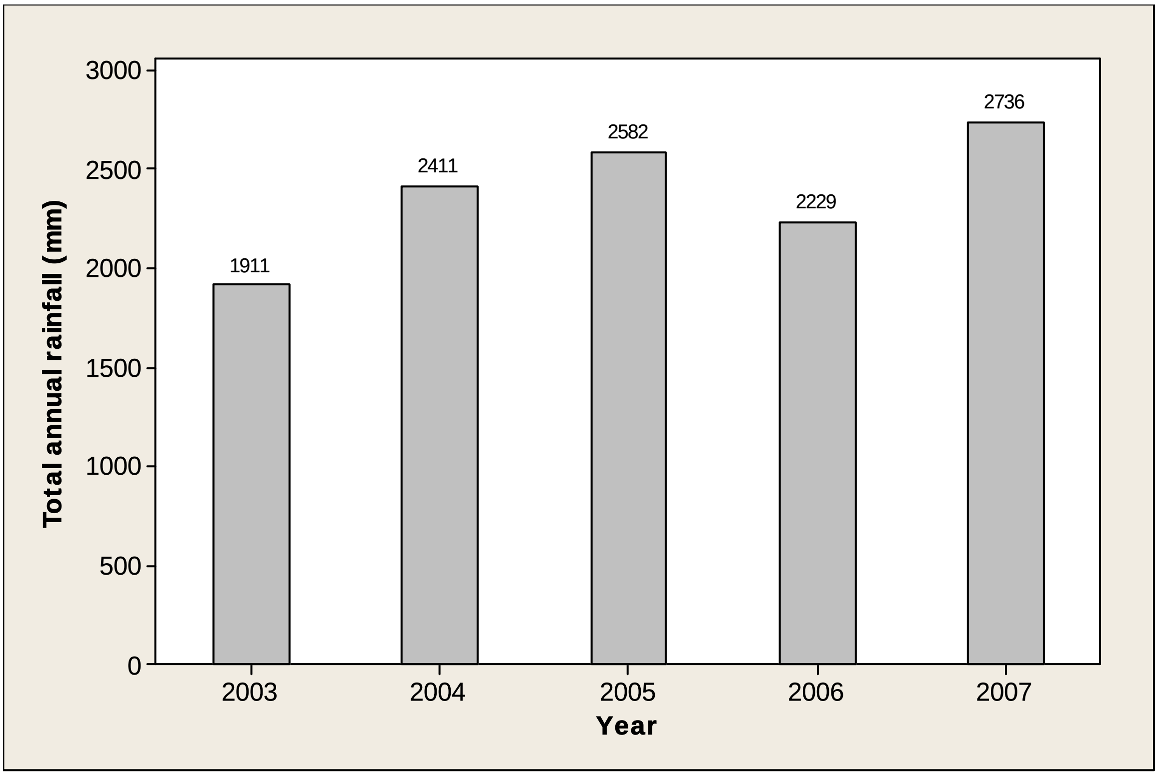

Figure 9.1 Total annual rainfall at Achfary, 2003-2007.

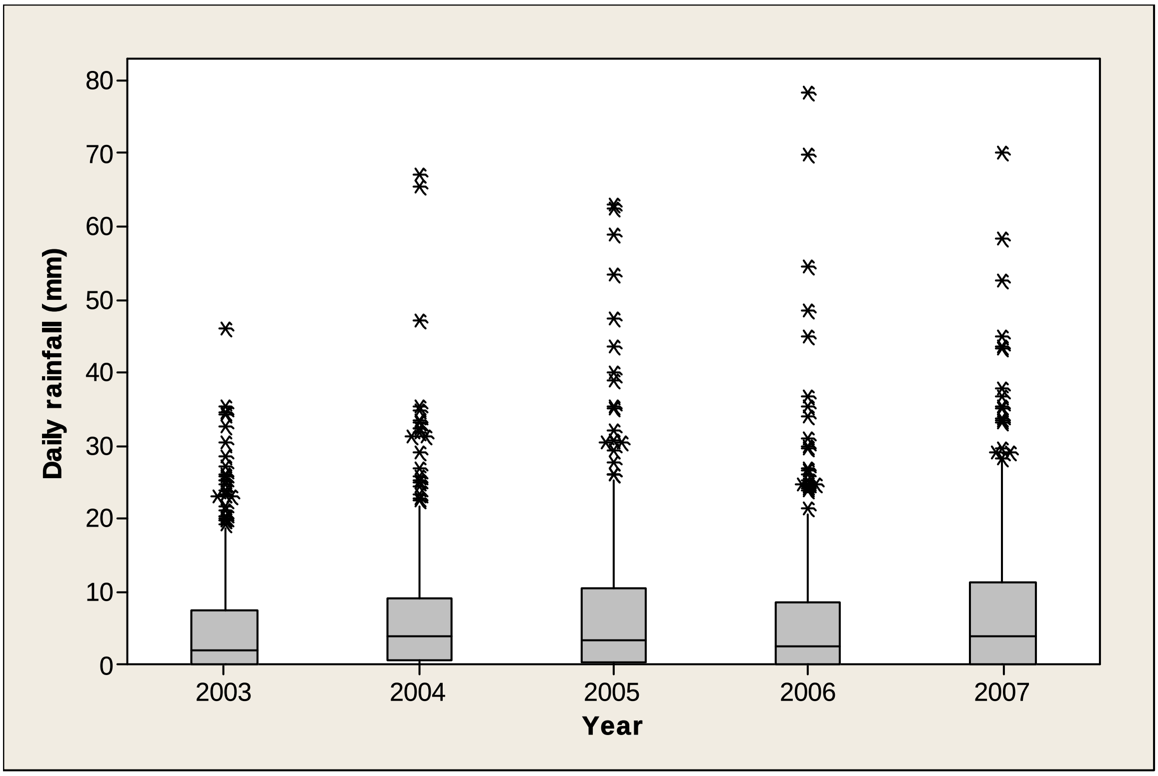

Figure 9.2 Boxplot of daily rainfall values by year, 2003-2007.

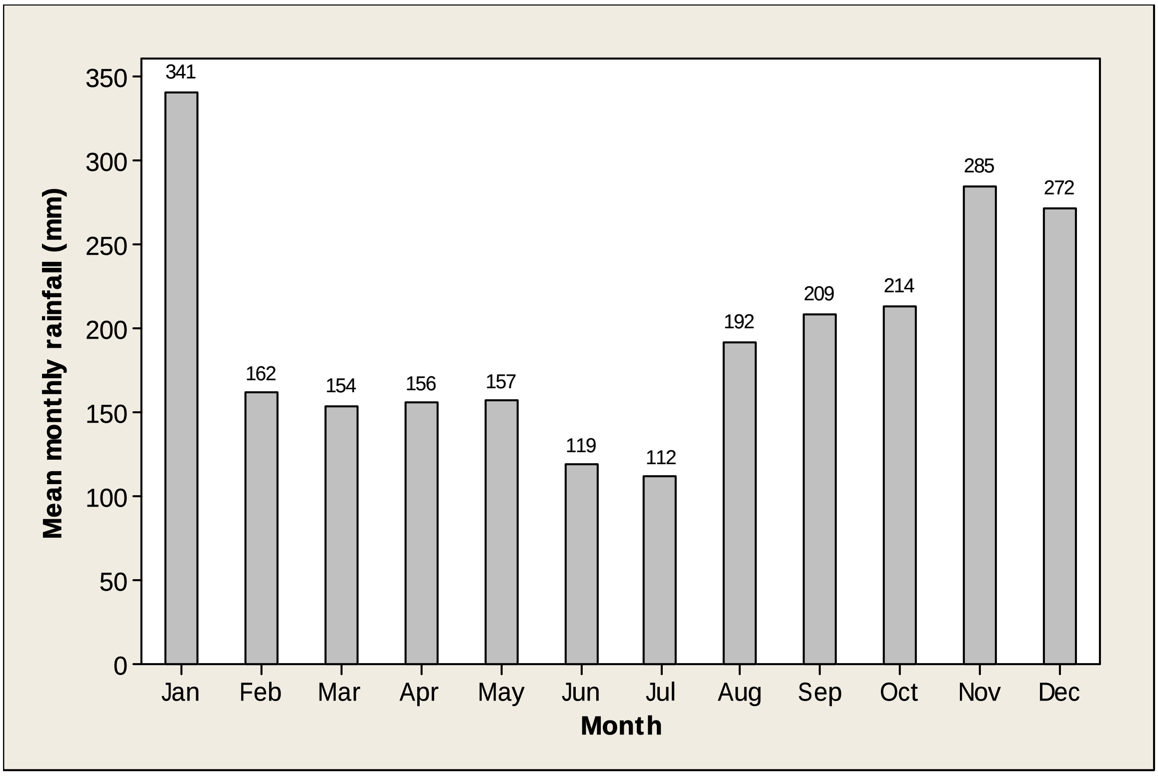

Figure 9.3 Mean total monthly rainfall at Achfary, 2003-2007

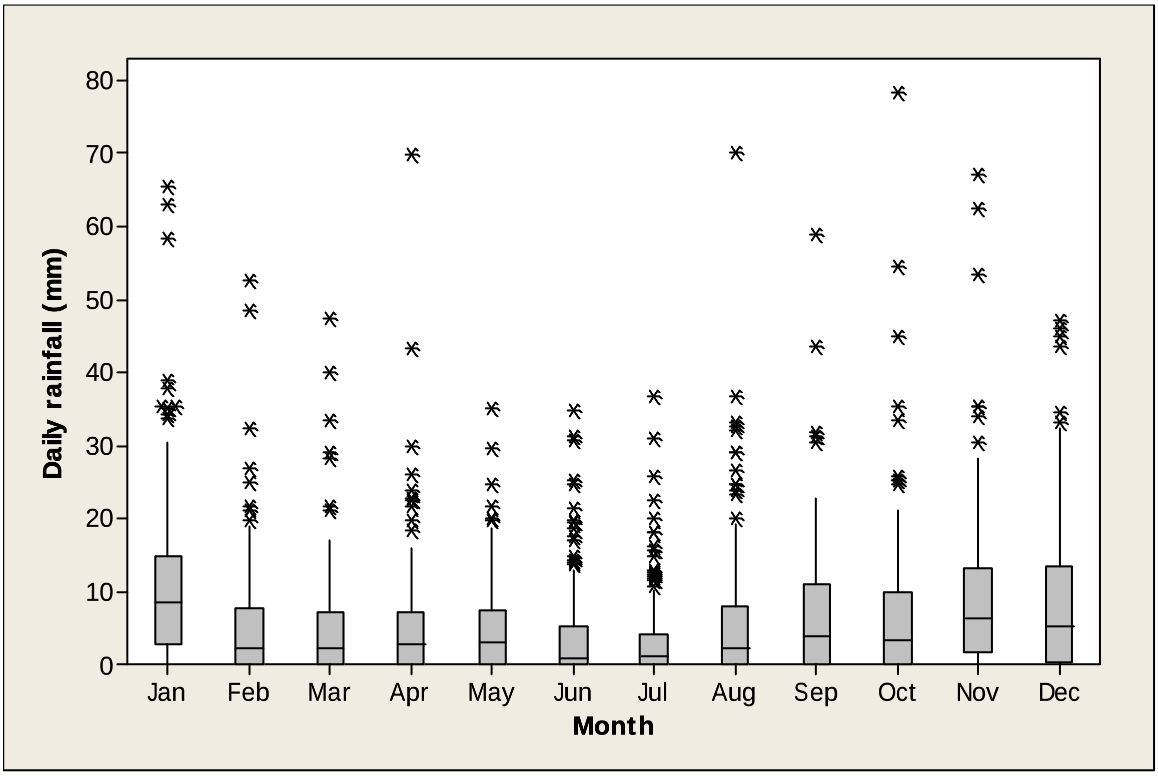

Figure 9.4 Boxplot of daily rainfall values by month, 2003-2007

For the period considered here 19.3% of days experienced no rainfall. 9.6% of days received only a 'trace', and 35.2% of days experienced rainfall of 1mm or less. The wettest months were November, December and January.

It can therefore be expected that levels of rainfall dependent faecal contamination entering the production area from these sources will be higher during the late autumn and winter months. It is possible that there is a build-up of faecal matter on pastures during the drier summer months when stock levels are at their highest which results in more significant faecal runoff in the autumn at the onset of the wetter months.

9.2 Wind

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

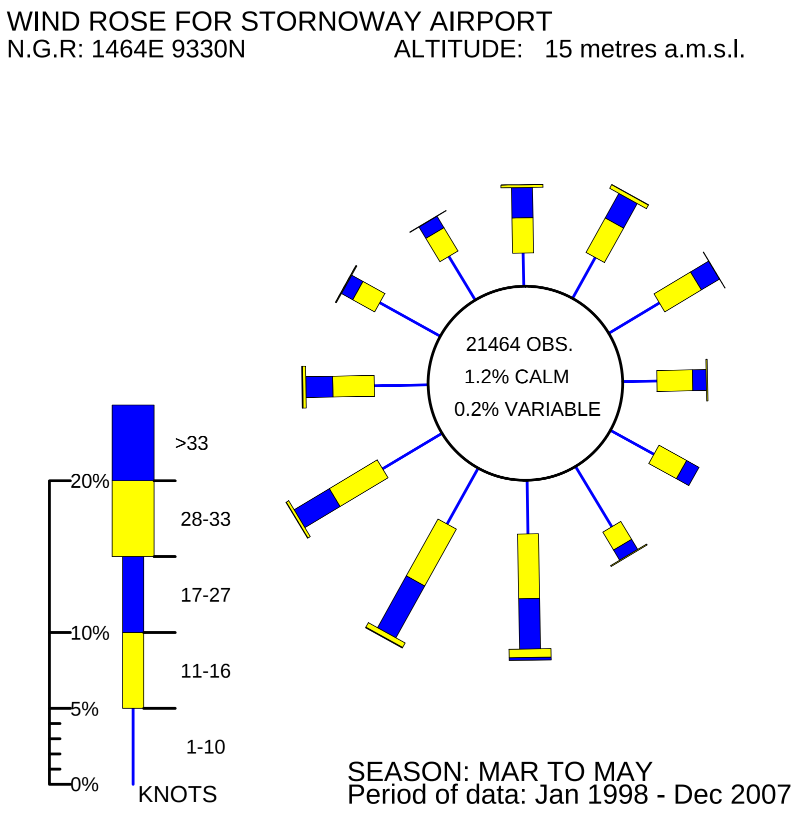

Figure 9.5 Wind rose for Stornoway (Spring)

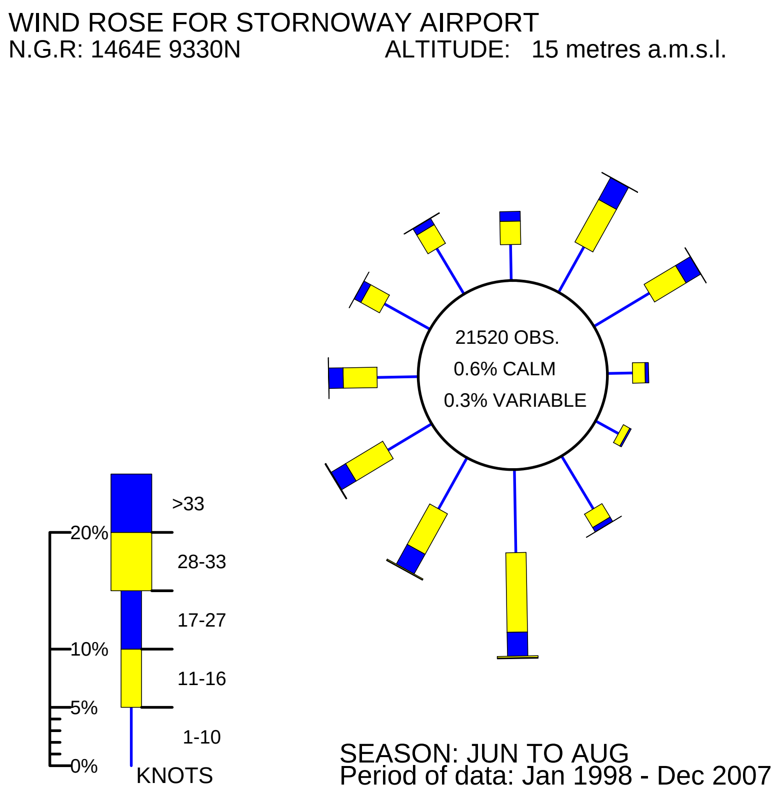

Figure 9.6 Wind rose for Stornoway (Summer)

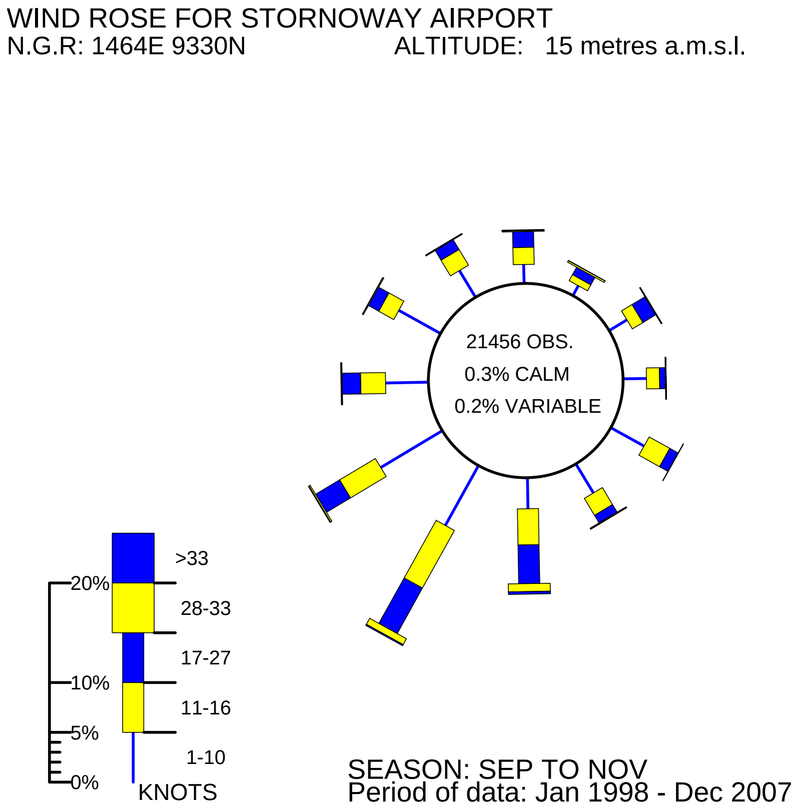

Figure 9.7 Wind rose for Stornoway (Autumn)

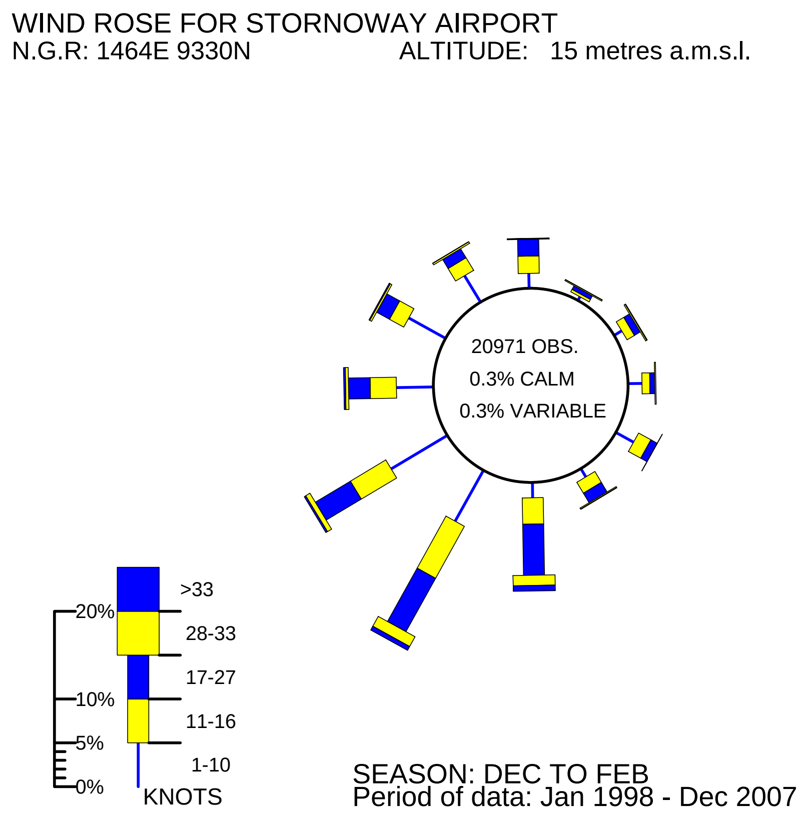

Figure 9.8 Wind rose for Stornoway (Winter)

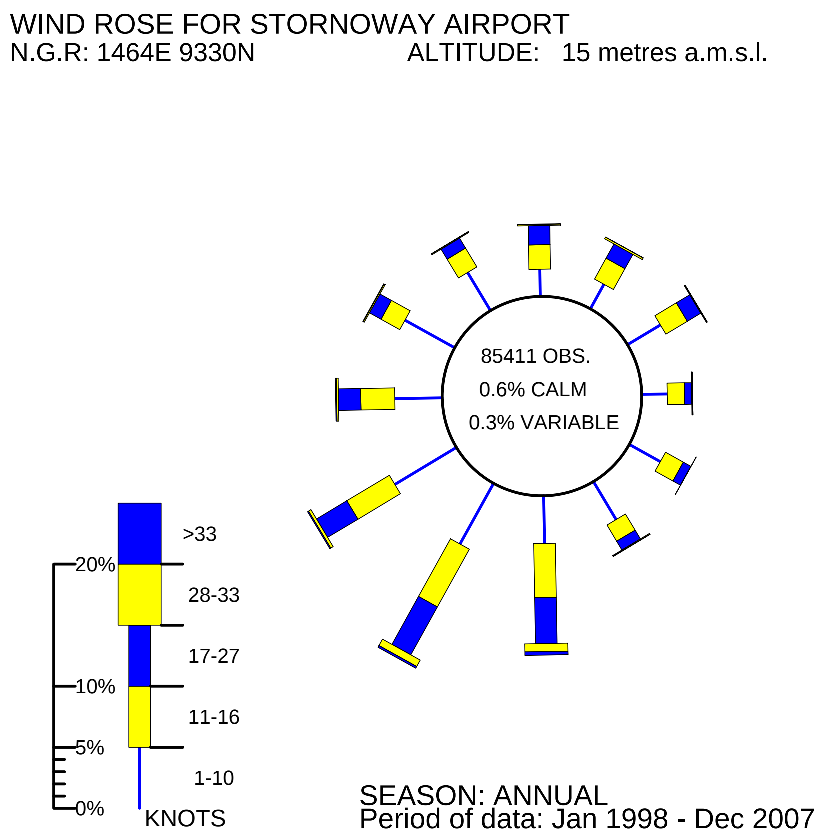

Figure 9.9 Wind rose for Stornoway (Annual)

Stornoway 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 the strongest winds come from this direction. Winds are generally lighter during the summer months and strongest in the winter.

Loch Inchard has a south east to north west aspect, facing the open Atlantic to the west. It is about 6.5 km long and about 0.5km wide, and is surrounded by low hills rising to about 150m with steep cliffs along its western shore. Thus the loch will receive shelter from winds from most directions, but is more open to a westerly or north westerly wind which would be funnelled up the loch by the surrounding hills.

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

Although tidally driven circulation of water in the loch is important due to its relatively large tidal range, wind effects are likely to cause significant changes in water circulation. 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 in the direction of the wind. These surface water currents create return currents, which may travel along the bottom or sides of the loch depending on bathymetry. Either way, strong winter winds will increase the circulation of water and hence dilution of contamination from point sources within the loch. There may be some instances where contamination from settlements may be carried to production sites by wind driven currents. An example may be a northerly wind carrying contamination from the settlement of Achriesgill towards the production site at Site 4 - D. Ross.

10. Current and Historical Classification Status

The area has been classified for mussel production since before 2001. The classification history since 2001 is presented in Table 10.1. Currently, the area is classified as a year seasonal A/B and has 5 active production sites. 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	A	A	B	A	A	A
2002	B	B	B	B	A	A	A	A	A	A	A	A
2003	A	A	A	A	A	A	A	A	A	A	A	A
2004	A	A	A	A	A	A	A	A	A	A	A	A
2005	A	A	A	A	A	B	B	B	B	A	A	A
2006	A	A	A	A	A	A	B	B	B	A	A	A
2007	A	A	A	A	A	A	B	B	A	A	A	A

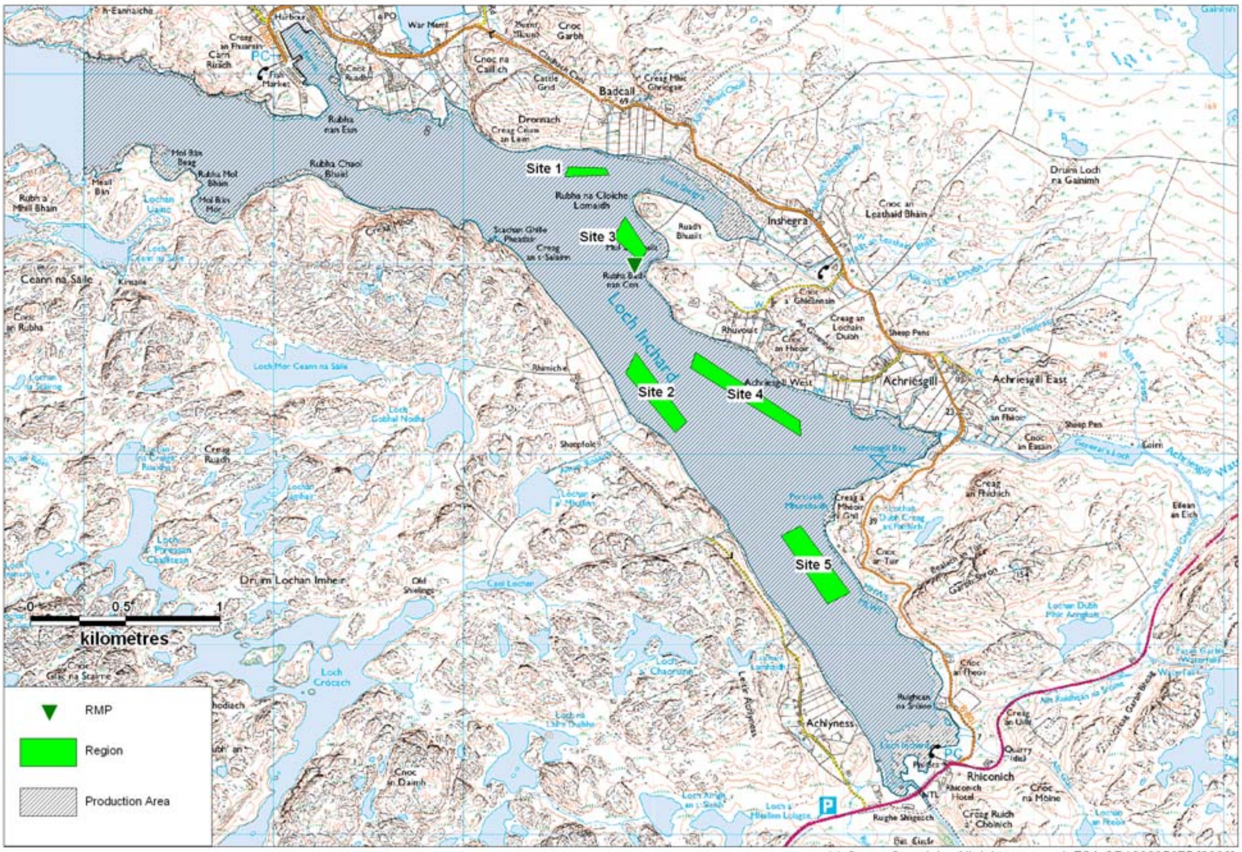

Figure 10.1 Loch Inchard production area

11. Historical *E. coli* data

11.1 Validation of historical data

All shellfish samples taken from Loch Inchard from the beginning of 2002 up to the end of 2007 were extracted from the database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data.

No samples were excluded due to either geographical or date discrepancies. 26 samples had the result reported as <20, and were assigned a nominal value of 10 for statistical assessment and graphical presentation. All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intravalvular fluid.

11.2 Summary of microbiological results by production area

A summary of all sampling and results by is presented by reported sampling location in Table 11.1.

Table 11.1 Summary of results from Loch Inchard

Sampling Summary									
Production area	Loch Inchard	Loch Inchard	Loch Inchard	Loch Inchard	Loch Inchard	Loch Inchard	Loch Inchard	Loch Inchard	Loch Inchard
Site	Loch Inchard (All sites)	Site 1 - D. Ross	Site 1 - D. Ross	Site 1 - D. Ross	Site 2 - D. Forbes & Site 1 - N Ross	Site 3 - Morrison	Site 3 - Morrison	Site 4 - J. Ross	Site 5 - N. Ross
Species	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels
SIN	HS162	HS16231108	HS16231108	HS16231108	HS16231208 and HS16231108	HS16231308	HS16231308	HS16231408	HS16231508
Location	All	NC235555	NC235554	NC236554	NC239542	NC239550 (RMP)	NC238552	NC246543	NC248534
Total no of samples	94	17	1	1	22	15	1	15	22
No. 2002	14	2	0	0	3	4	0	3	2
No. 2003	20	1	0	0	4	3	0	5	7
No. 2004	23	4	0	0	6	4	0	5	4
No. 2005	14	2	0	0	5	1	0	1	5
No. 2006	12	2	0	0	4	1	0	1	4
No. 2007	11	6	1	1	0	2	1	0	0
Results Summary (*E. coli* mpn/100g)									
Minimum	<20	<20	-	-	<20	<20	-	<20	<20
Maximum	5400	1700	-	-	3500	5400	-	430	310
Median	40	90	90	110	20	40	<20	40	20
Geometric mean	50.6	94.7	-	-	44.8	65.1	-	49.9	30.3
90 percentile	479	1180	-	-	475	1220	-	298	108
95 percentile	1170	1380	-	-	738	2810	-	416	110
No. exceeding 230/100g	16 (17%)	6 (35%)	-	-	4 (18%)	3 (20%)	-	2 (13%)	1 (5%)
No. exceeding 1000/100g	6 (6%)	3 (18%)	-	-	1 (5%)	2 (13%)	-	0 (0%)	0 (0%)
No. exceeding 4600/100g	1 (1%)	0 (0%)	-	-	0 (0%)	1 (7%)	-	0 (0%)	0 (0%)
No. exceeding 18000/100g	0 (0%)	0	-	-	0 (0%)	0 (0%)	-	0 (0%)	0 (0%)

11.3 Overall geographical pattern of results

Figure 11.1 presents a map showing geometric mean result by reported sampling location (with OS grid reference, site, number of samples and sampling dates). There is good agreement between the reported sampling location and the location of the sites to which they were attributed, aside from three samples collected from NC239542 (approximately at site 2) but attributed to Site 1.

A comparison of results from different locations within the production area indicates no significant difference in mean result between sampled location (One-way ANOVA, p=0.427, Appendix 4).

A total of 16 results of over 230 *E. coli* mpn/100g were reported. The proportion of samples exceeding 230 *E. coli* mpn/100g was highest at NC235555 (Site 1), intermediate at NC239542 and NC239550 (Sites 2 and 3), and lowest at NC246543 and NC248534 (Sites 4 and 5).

One-way ANOVA showed no significant difference between the mean log10-transformed *E. coli* data from the sites (Appendix 4). It should be noted that samples from the different sites were not necessarily taken on the same dates, or even the same date range, and this limited the extent to which the results could be compared.

Only one result of over 4600 *E. coli* mpn/100g was reported, and this originated from NC239550 (Site 3).

Due to the lack of any significant difference in results between the sampling locations, and the relatively low numbers of samples taken from each location, all data is considered together in the following analysis.

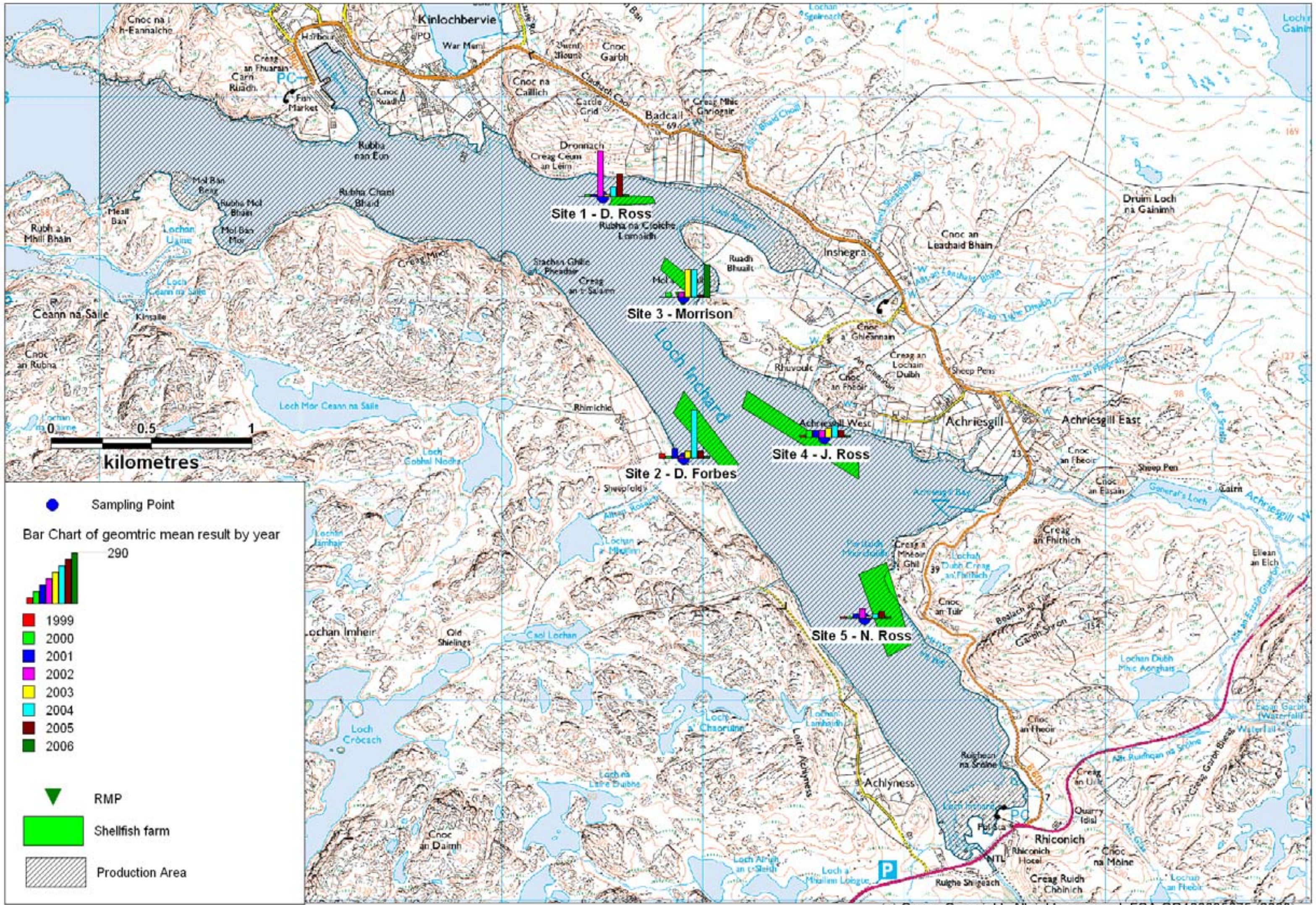

Figure 11.1 Map of sampling points and geometric mean result

11.4 Overall temporal pattern of results

Figure 11.2 and 11.3 present scatter plots of individual results against date for all mussel samples taken from Loch Inchard. Both are fitted with trend lines to help highlight any apparent underlying trends or cycles. Figure 11.2 is fitted with lines indicating the geometric mean of the previous 5 samples, the current sample and the following 6 samples. Figure 11.3 is fitted with loess smoothers, a regression based smoother line calculated by the Minitab statistical software.

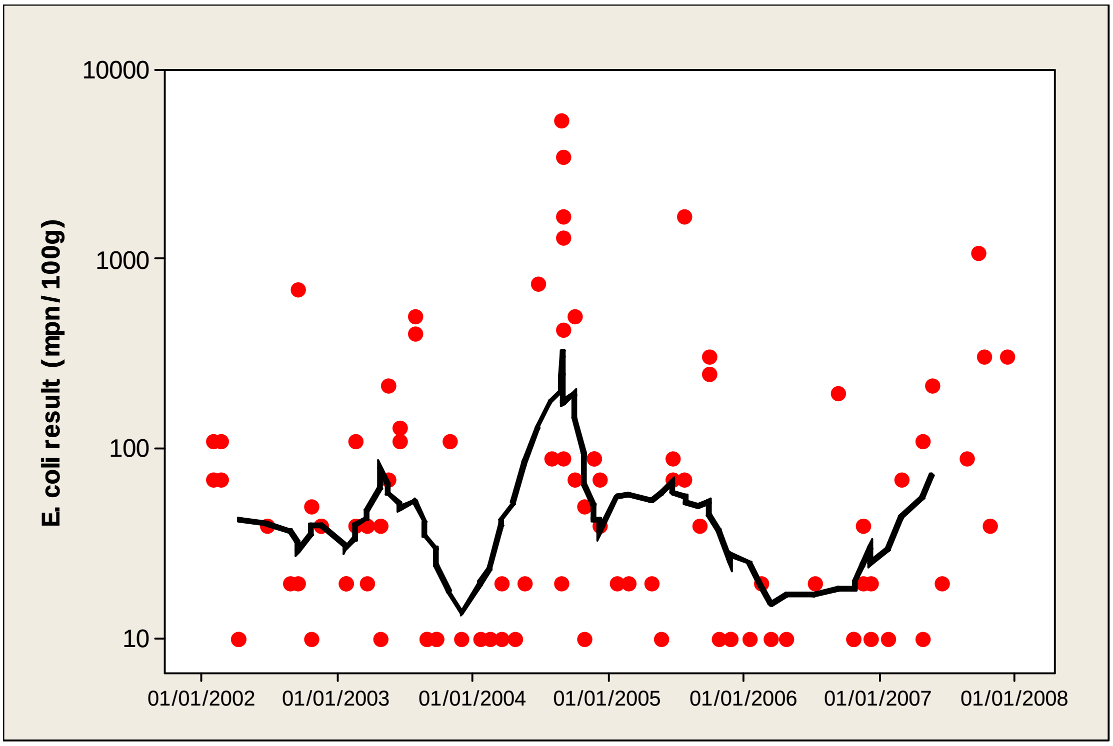

Figure 11.2 Scatterplot of results by date with rolling geometric mean

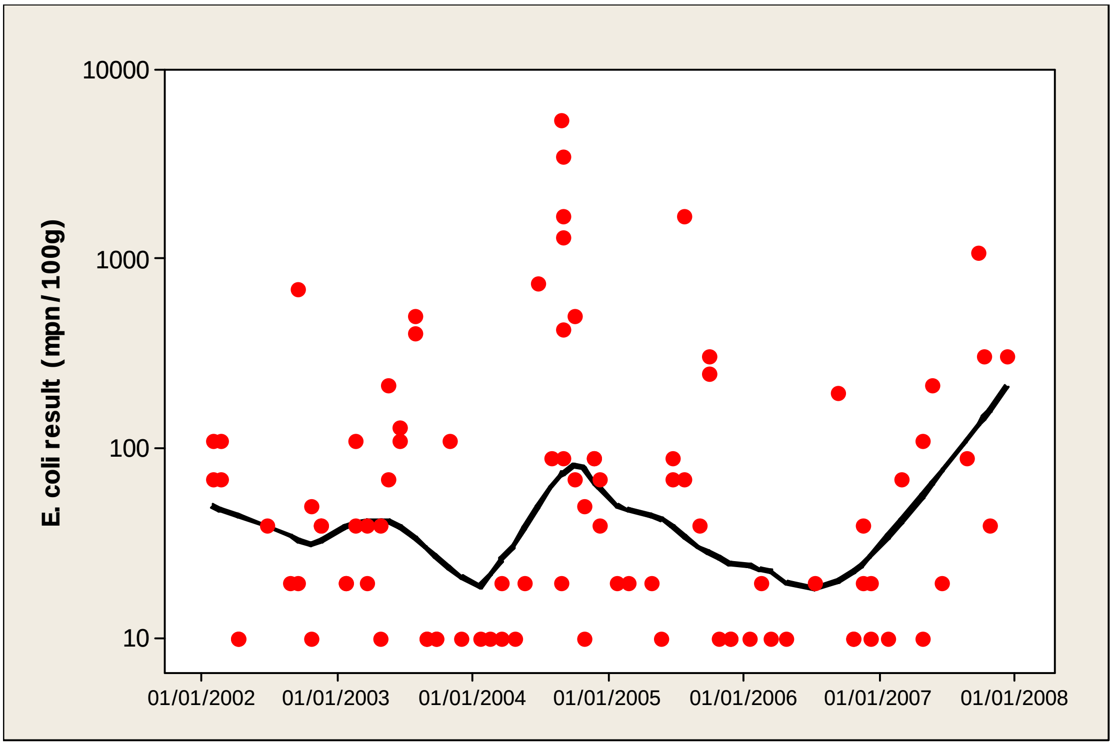

Figure 11.3 Scatterplot of results by date with loess smoother

Figures 11.2 and 11.3 show a peak in mid 2004. This may be attributed to a period of higher contamination and sampling intensity, when a total of 7 samples were taken in late August 2004. Also, Figures 11.2 and 11.3 suggest a deterioration in microbial quality during 2007.

11.5 Seasonal pattern of results

Season dictates not only weather patterns and water temperature, but livestock numbers and movements, presence of wild animals and patterns of human occupation. All of these can affect levels of microbial contamination, and cause seasonal patterns in results. Figure 11.4 presents the geometric mean *E. coli* result by month (+ 2 times the standard error) for Loch Inchard.

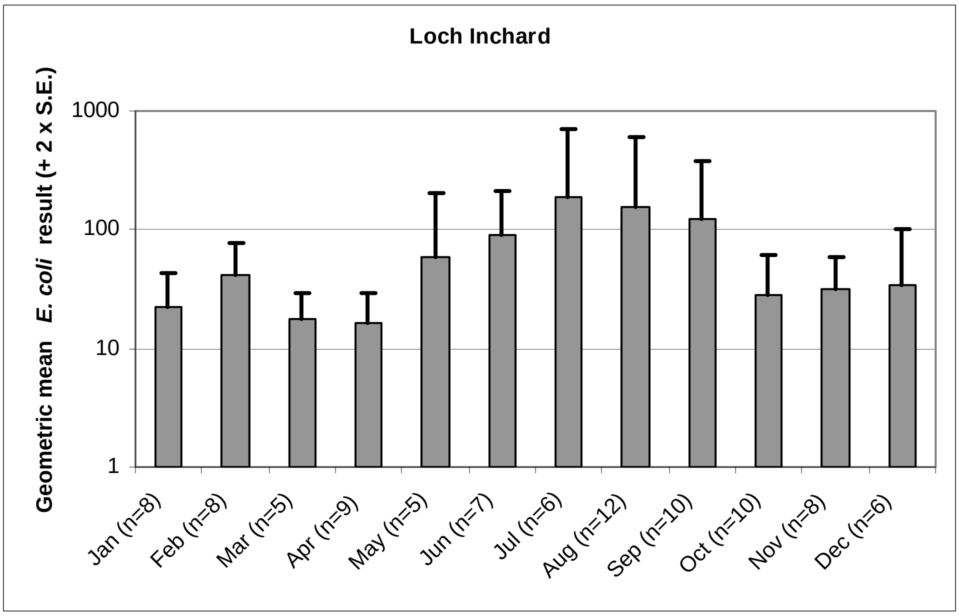

Figure 11.4 Geometric mean result by month

Highest mean results for occurred from May to September, peaking in August. For statistical evaluation, seasons were split into spring (March - May), summer (June - August), autumn (September - November) and winter (December - February).

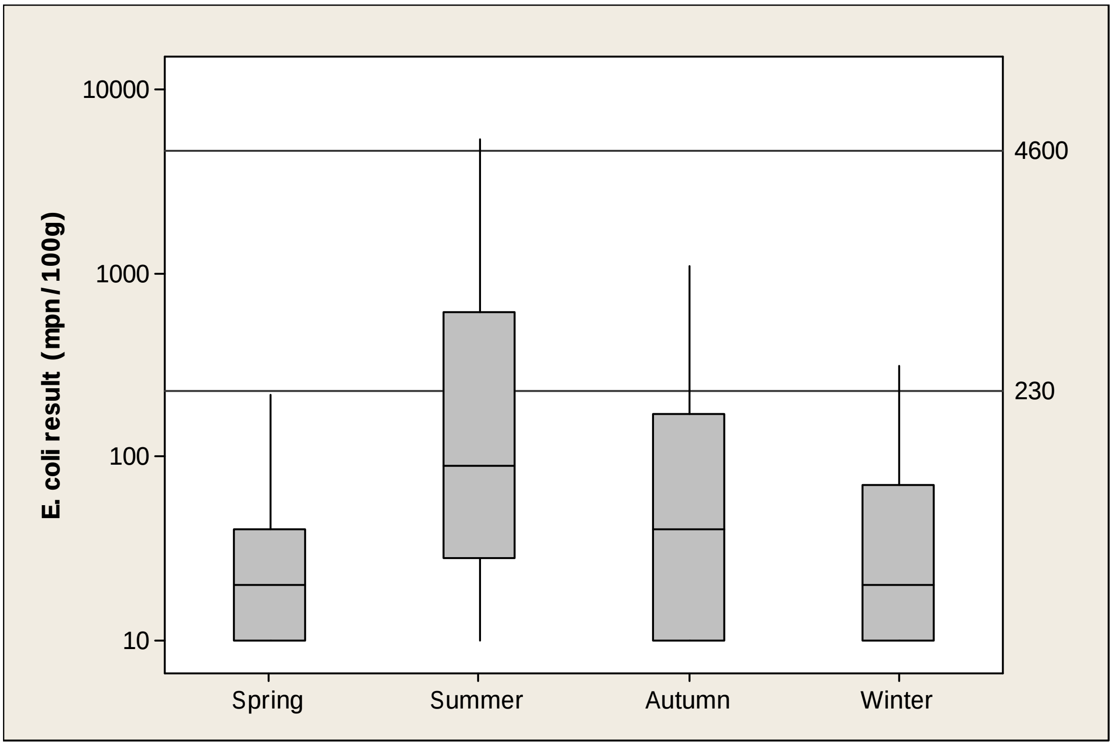

Figure 11.5 Boxplot of result by season

A significant difference was found between results by season (One-way ANOVA, p=0.000, Appendix 4). A post ANOVA test (Tukeys comparison, Appendix 4) indicates that results for the summer were significantly higher than those in the other three seasons.

Table 11.2 Proportion of historic *E. coli* sampling result over 230 mpn/100g by season

	Spring	Summer	Autumn	Winter
No. results > 230 mpn/100g	0 (0%)	9 (36%)	6 (27%)	1 (5%)
No. results < 230 mpn/100g	19	16	22	21
Total results	19	25	28	22

The proportion of results exceeding 230 *E. coli* mpn/100g was highest in the summer followed by autumn, with over a quarter of results still above the 230 threshold.

11.6 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.

11.6.1 Analysis of results by recent rainfall

The nearest weather station is Achfary, approximately 15 km to the south east of the production area. Rainfall data was purchased from the Meteorological Office for the period 1/1/2003 to 31/12/2007 (total daily rainfall in mm). The coefficient of determination was calculated for *E. coli* results and rainfall in the previous 2 days at Achfary. Figure 11.6 presents a scatterplot of *E. coli* results against rainfall for both production areas. Figure 11.7 presents a boxplot of results by previous 2 days rainfall quartile for both production areas (quartile 1 = 0 to 1.8 mm, quartile 2 = 1.8 to 8.2 mm, quartile 3 = 8.2 to 19.2 mm, quartile 4 = more than 19.2 mm).

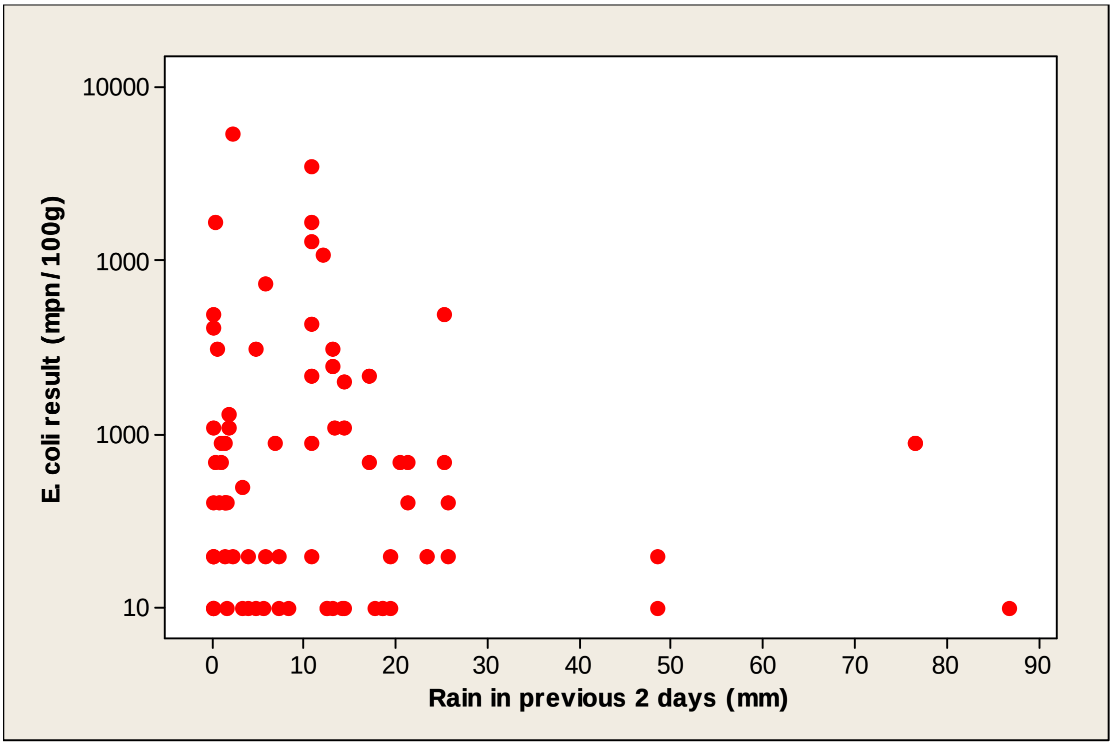

Figure 11.6 Scatterplot of result against rainfall in previous 2 days

The coefficient of determination indicates that there was no relationship between the *E. coli* result and the rainfall in the previous two days (Adjusted R-sq=0.0%, p=0.471, Appendix 4). The four samples with rainfall over 40 mm gave relatively low *E. coli* results, and this may have masked any weak relationship which may have otherwise been present if these points were excluded.

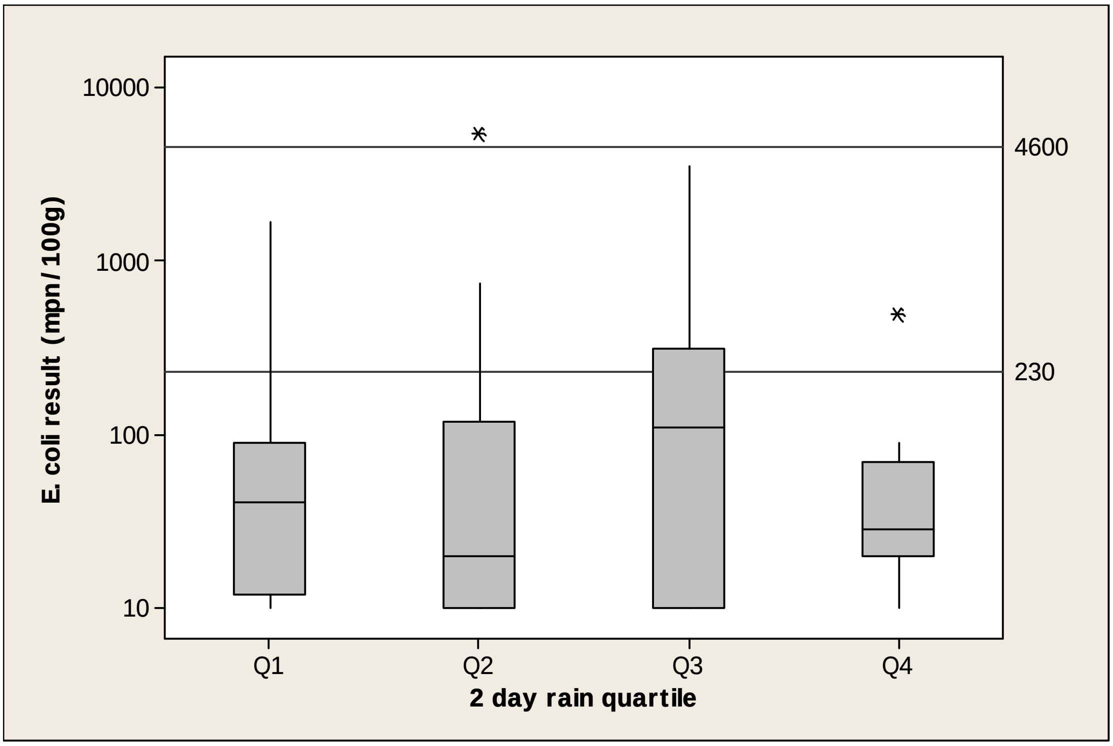

Figure 11.7 Boxplot of result by rainfall in previous 2 days quartile

No significant difference was found between the results for each 2-day rain quartile (One way ANOVA, p=0.333, 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 was investigated in an identical manner to the above. Interquartile ranges for 7 days rainfall were as follows; quartile 1 = 0 to 17.3 mm; quartile 2 = 17.3 to 37.0 mm; quartile 3 = 37.0 to 64.3 mm; quartile 4 = more than 64.3 mm.

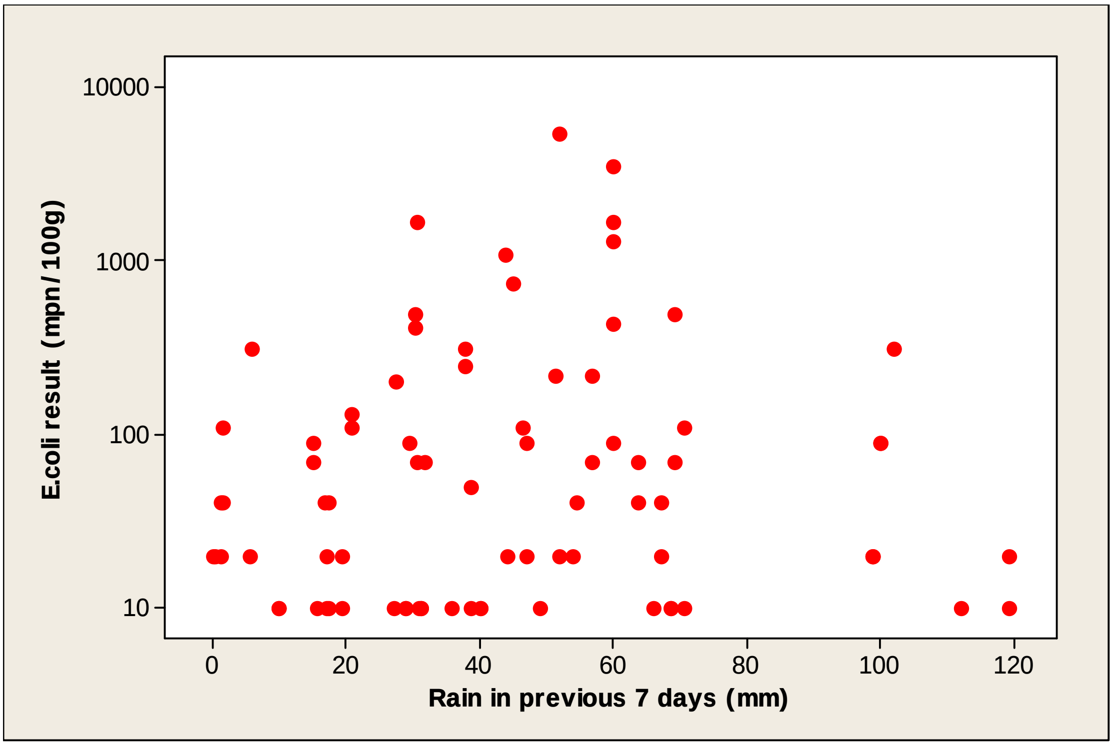

Figure 11.8 Scatterplot of result against rainfall in previous 7 days

The coefficient of determination indicates that there was no significant relationship between the *E. coli* result and the rainfall in the previous 7 days (Adjusted R-sq=0.0%, p=0.493, Appendix 4).

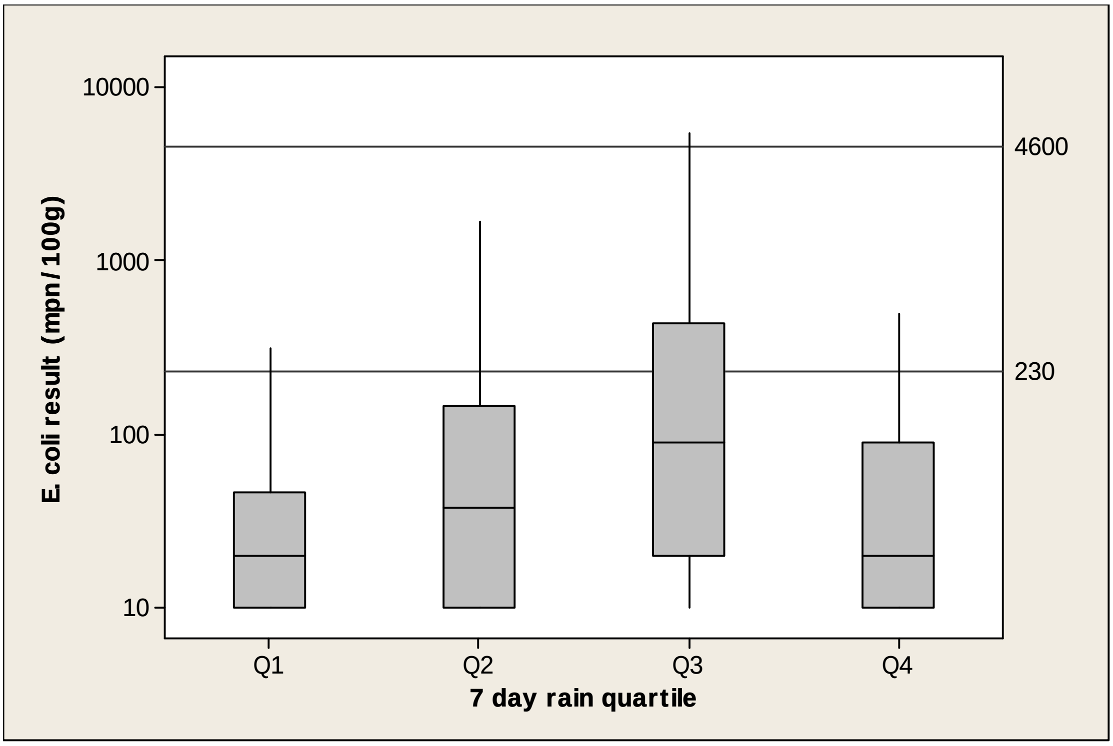

Figure 11.9 Boxplot of result by rainfall in previous 7 days quartile

A significant difference was found between the results for each 2-day rain quartile (One way ANOVA, p=0.015, Appendix 4). A post-ANOVA test (Tukeys comparison, Appendix 4) indicated that results were significantly higher for quartile 3 than for quartile 1. This suggests a tendency for higher results to follow higher recent rainfall, aside from in those 6 samples mentioned in the previous paragraph.

11.6.2 Analysis of results by tidal size and state

When the larger (spring) tides occur every two weeks, circulation of water and particle transport distances will increase, and more of the shoreline will be covered at high water, potentially washing more faecal contamination from livestock into the voe. Figure 11.10 presents a scatterplot of *E. coli* results by predicted height of the previous high water at Loch Bervie (predictions from Totaltide tidal prediction software). It should be noted that local meteorological conditions such as wind strength and direction can influence the height of tides and this is not taken into account.

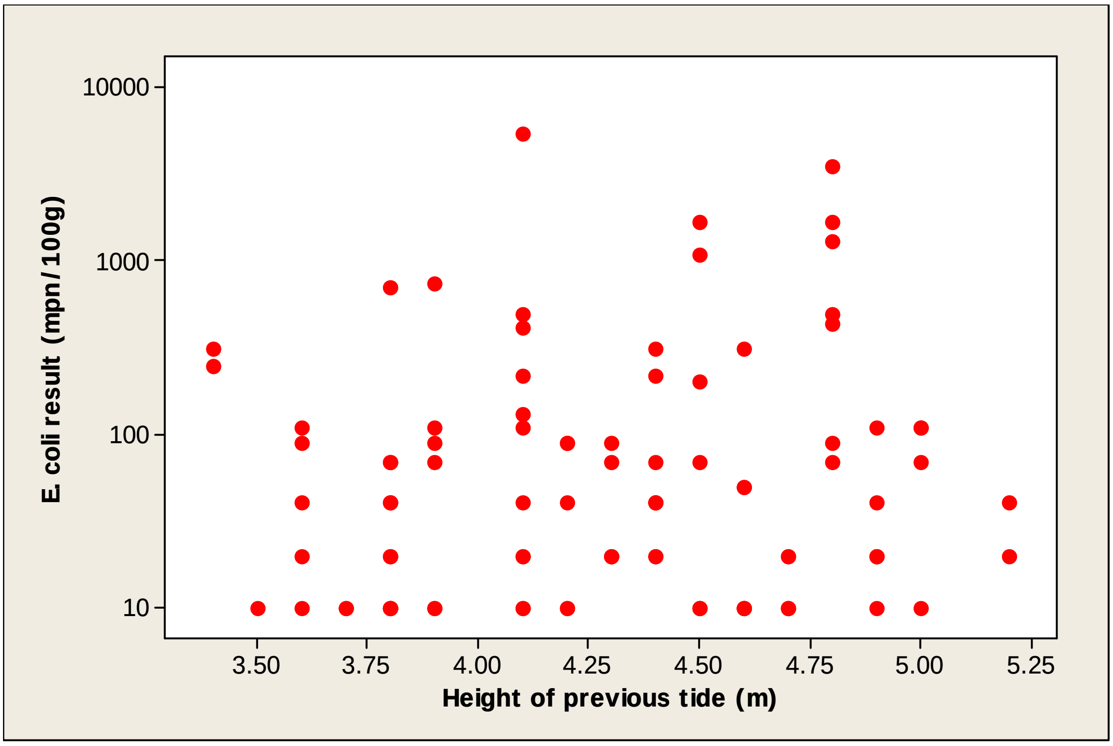

Figure 11.10 Scatterplot of result by tide size

The coefficient of determination indicates that there was no relationship between the *E. coli* result and predicted height of the previous tide (Adjusted R-sq=0.0%, p=0.557, Appendix 4).

Direction and strength of flow around the production area will change according to tidal state on the (twice daily) high/low cycle, and, depending on the location of sources of contamination, this may result in marked changes in water quality in the vicinity of the farms during this cycle. As *E. coli* levels in mussels can respond within a few hours or less to changes in *E. coli* levels in water, tidal state at time of sampling (hours post high water) was compared with *E. coli* results. As any effects are likely to be location specific, this was investigated for each sampling point from which 15 or more samples were taken.

Table 11.3 Circular-linear correlations between *E. coli* result and tidal state

Sampling location	Site	Number of samples	r	p
NC235555	Site 1	17	0.094	0.884
NC239542	Sites 2 & 1	22	0.067	0.917
NC239550	Site 3	15	0.51	0.041*
NC246543	Site 4	15	0.279	0.392
NC248534	Site 5	22	0.392	0.053

* Denotes significant correlation at 0.05 level.

The only significant correlation was found for NC239550 at Site 3, and here the highest results were obtained on the flood tide, but it must be noted that only 3 samples of 15 were taken on the flood tide at this location.

Overall, tide size does not appear to have an influence on result. Larger tides will result in increased particle transport distances so the shellfish may be exposed to contamination originating from sources which are further afield.

No significant correlation was found between tidal state at time of sampling for most locations, but at Site 3 results were higher on the flood tide.

11.6.3 Analysis of results by water temperature

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

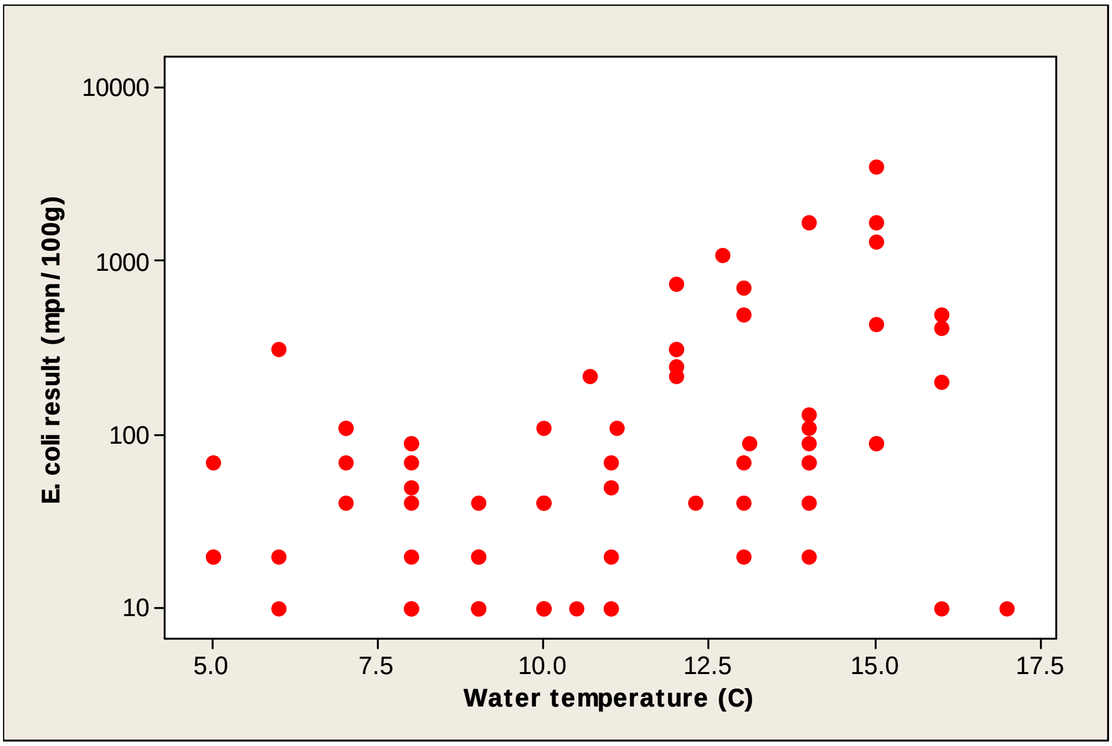

Figure 11.11 Scatterplot of result by water temperature

The coefficient of determination indicates that there was a weak positive relationship between the *E. coli* result and water temperature recorded at the time of sampling (Adjusted R-sq=19.4%, p=0.000, Appendix 4).

11.6.4 Analysis of results by wind direction

Wind speed and direction are likely to influence water circulation patterns in the production area. Mean wind direction for the 7 days prior to each sample being collected was calculated from wind data recorded at the Stornoway weather station, and mean result by mean wind direction in the previous 7 days is plotted in Figure 11.12.

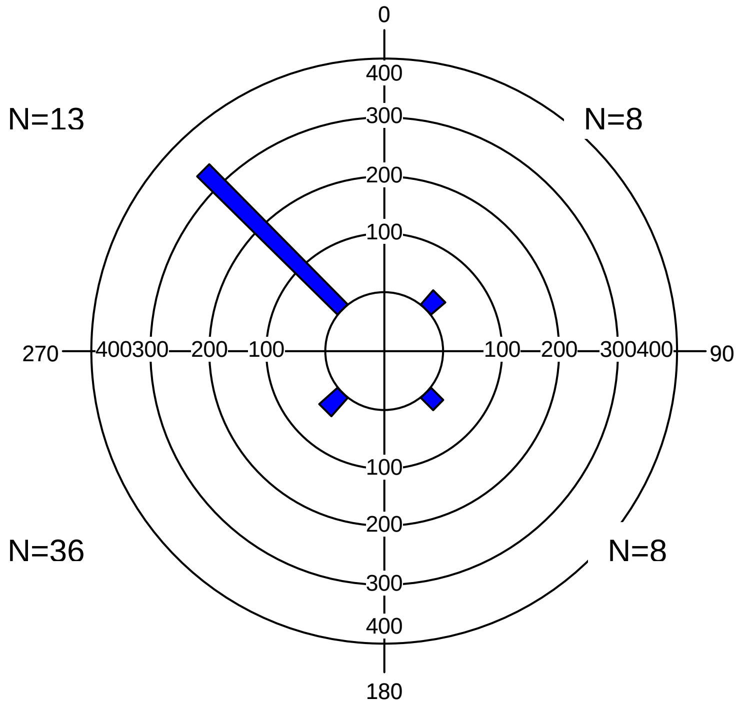

Figure 11.12 Circular histogram of geometric mean *E. coli* result by wind direction

A significant correlation was found between wind direction and *E. coli* result (circular-linear correlation, r=0.286, p=0.006, Appendix 4). Higher mean results occurred when the wind was in a north westerly direction, the direction which would push surface water towards the head of the loch. It must be noted that wind speeds are not taken into consideration.

11.7 Evaluation of results over 4600 *E. coli* mpn/100g

One result over 4600 *E. coli* mpn/100g were reported. It arose at approximately low water during medium sized tides following a relatively wet week with north easterly winds.

Table 11.4 Historic *E. coli* sampling results over 4600 mpn/100g

Collection date	*E. coli* result (mpn/100g)	Location sampled	Site	2 day rain quartile	7 day rain quartile	7 day wind direction	Previous tide height	Time since high water
23/8/2004	5400	NC239550	Site 3	Q2	Q3	24.7º	4.1 m	11h37mins

11.8 Summary and conclusions

No statistically significant geographical patterns were observed. Highest geometric mean result came from NC235555 (Site 1), as did the highest proportion of results over 230 *E. co*li mpn/100g. Highest overall result came from NC239550 (Site 3).

A seasonal effect was found, with mean results highest in the summer. This suggesting that either inputs are higher in summer and/or the uptake of bacteria by the shellfish is higher in warmer water.

The only statistically significant relationship found between recent rainfall and *E. coli* results was found when the 7 day rain quartiles were considered, where results for quartile 3 were higher than results for quartile 1. The reason for this may be an underlying tendency for higher results following periods of heavier rainfall, although the six samples collected during periods of the very highest rainfall returned relatively low results.

No significant influence of either tide size (i.e. spring or neap) was found. A weak correlation between tidal state (i.e. high/low/ebb/flood) was found at one sampling location at Site 3.

A positive relationship between water temperature and *E. coli* results was found. This is in agreement with the seasonal pattern.

A correlation was found between wind direction and magnitude of *E. coli* results, with highest results occurring during periods of north westerly winds. As the loch faces the north west, there would be less shelter from winds from this direction so they would be stronger, and they would probably have the effect of pushing surface waters towards the head of the loch.

It should be noted that the relatively small amount of data precluded the assessment of the effect of interactions between environmental factors on the *E. coli* concentrations in shellfish.

11.9 Sampling frequency

When a production area has held the same (non-seasonal) classification for 3 years, and the geometric mean of the results falls within a certain range it is recommended that the sampling frequency be decreased from monthly to bimonthly. This is not appropriate for this production area as it has held seasonal classifications for the last three years.

12. Designated Shellfish Growing Waters Data

The area considered in this report is also a shellfish growing water that has been monitored by SEPA since its designation in 2002. The extent of this and the location of the SEPA monitoring point are shown in Figure 12.1.

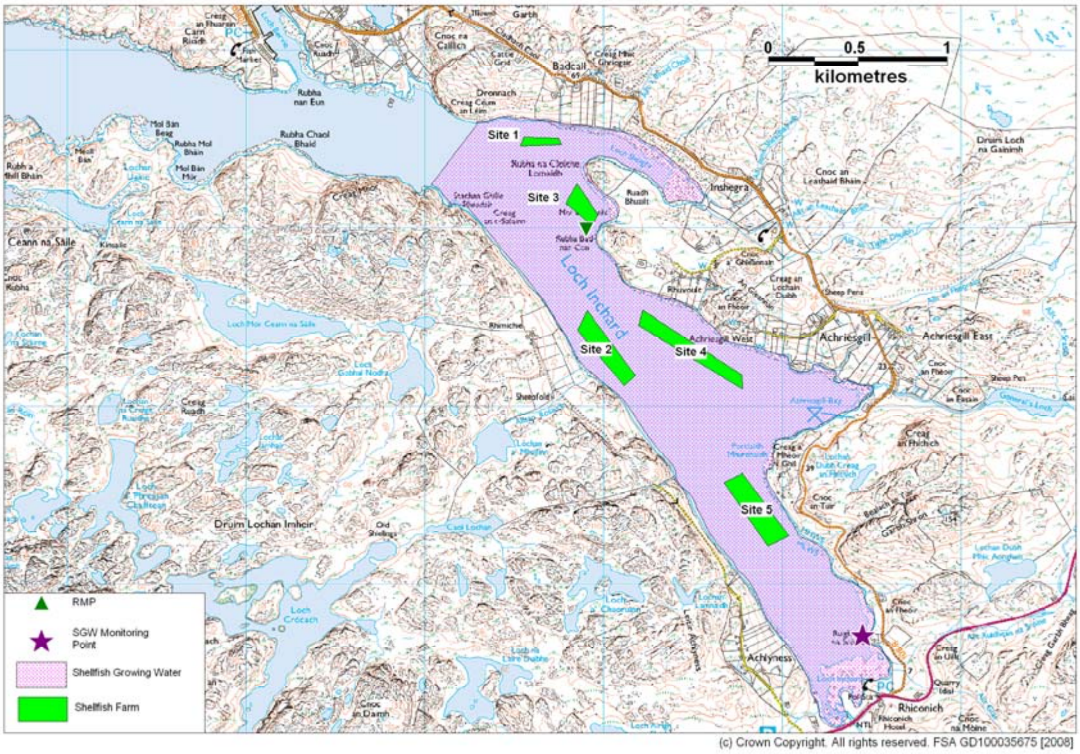

Figure 12.1 Designated Shellfish Growing Water and monitoring point

The monitoring 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 shore mussels
- Quarterly for faecal coliforms in shore mussels

Monitoring of the area started in the last quarter of 2002, and results to the end of 2006 have been provided by SEPA. Monitoring results for faecal coliforms are presented in Table 12.1.

Table 12.1. SEPA Faecal coliform results (faecal coliforms / 100g) for non-commercial shellfish gathered from Loch Inchard.

	Site	Loch Inchard	Loch Inchard
	OS Grid Ref.	NC 239 550	NC 25449 52714
	Q1	-	-
	Q2	-	-
	Q3	-	-
2002	Q4	20	-
	Q1	40	-
	Q2	-	-
	Q3	-	40
2003	Q4	-	20
	Q1	-	40
	Q2	-	40
	Q3	-	500
2004	Q4	-	130
	Q1	-	<20*
	Q2	-	310
	Q3	-	500
2005	Q4	-	40
	Q1	-	-
	Q2	-	<10**
	Q3	-	30
2006	Q4	-	10

* Assigned a nominal value of 10 for the purpose of calculating the geometric mean
** Assigned a nominal value of 5 for the purpose of calculating the geometric mean

The first two samples collected were taken from NC 239550, which is at the RMP. All other samples were taken from the SEPA monitoring point near the head of the loch, as shown in Figure 12.1. The geometric mean result of all SEPA mussel samples was 45.0 faecal coliforms / 100g. Results ranged from <10 to 500 faecal coliforms / 100g. The two highest results both occurred in quarter 3.

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. The geometric mean level of contamination in shore mussels taken as part of the SEPA monitoring point is very similar to the overall geometric mean of the rope mussel samples tested for *E. coli* (42.1 mpn/100g) presented in Table 11.1.

Results for the physical and chemical parameters monitored by SEPA are not presented in this report.

13. River Flow

Loch Inchard receives fresh water input from a large number of rivers, streams and other small watercourses. In many areas, these trickle down the cliff faces so it was not possible to either measure or sample. Due to the poor soil drainage, it is expected that much of water flowing into the loch carries a significant amount of land runoff, some of which will be contaminated with animal faeces. Some of the septic tanks in the area discharge to watercourses, such as those observed at Inshegra (River no. 7).

There are no river gauging stations on rivers or burns feeding into Loch Inchard.

The following burns were measured and sampled during the shoreline survey. These represented the largest freshwater inputs into Loch Inchard. The overall input of these is approximately 2 million m^3 per day compared to a total low water loch volume of 88 million m^3. Measurements taken on the day of survey may not be representative of flow conditions at all times of the year.

Table 13.1 River flows and loadings – Loch Inchard

No	Grid Ref	Description	Width (m)	Depth (m)	Meas. Flow (m/s)	Flow in m3/day	*E.coli* (cfu/ 100ml)	Loading (*E.coli* per m3)
1	NC 22334 56073	Stream	0.3	0.027	0.02	14	<100*	7E+06
2	NC 22926 55837	Stream running from Loch Innis na Ba Buidhe	9.1	0.26	0.7	143096	500	7.2E+11
3	NC 25616 54057	Achriesgill Water	39.0	0.2	0.9	606528	<100*	3E+11
4	NC 25386 52221	Rhiconich River	17.0	1.0	0.8	1175040	<100*	5.9E+11
5	NC 25522 54514	Allt an Fheorain	2.0	0.8	0.4	55296	<100*	2.8E+10
6	NC 24933 55010	Allt an Leathaid Bhain	1.2	0.3	0.1	3110	400	1.2E+10
7	NC 24854 55221	Allt Innis Shreadhairidh	1.0	0.05	0.4	1728	800	1.4E+10
8	NC 23915 54161	Allt an Rosaich	0.93	0.19	0.2	3053	<100*	1.5E+09
9	NC 24338 53562	Stream	0.66	0.17	0.02	194	<100*	9.7E+07

* Assigned a nominal value of 50 for the calculation of loading

Of the above streams, number 8 Allt an Rosaich discharges into the loch at a point closest to the shellfish farms, as shown on the map in Figure 14.1.

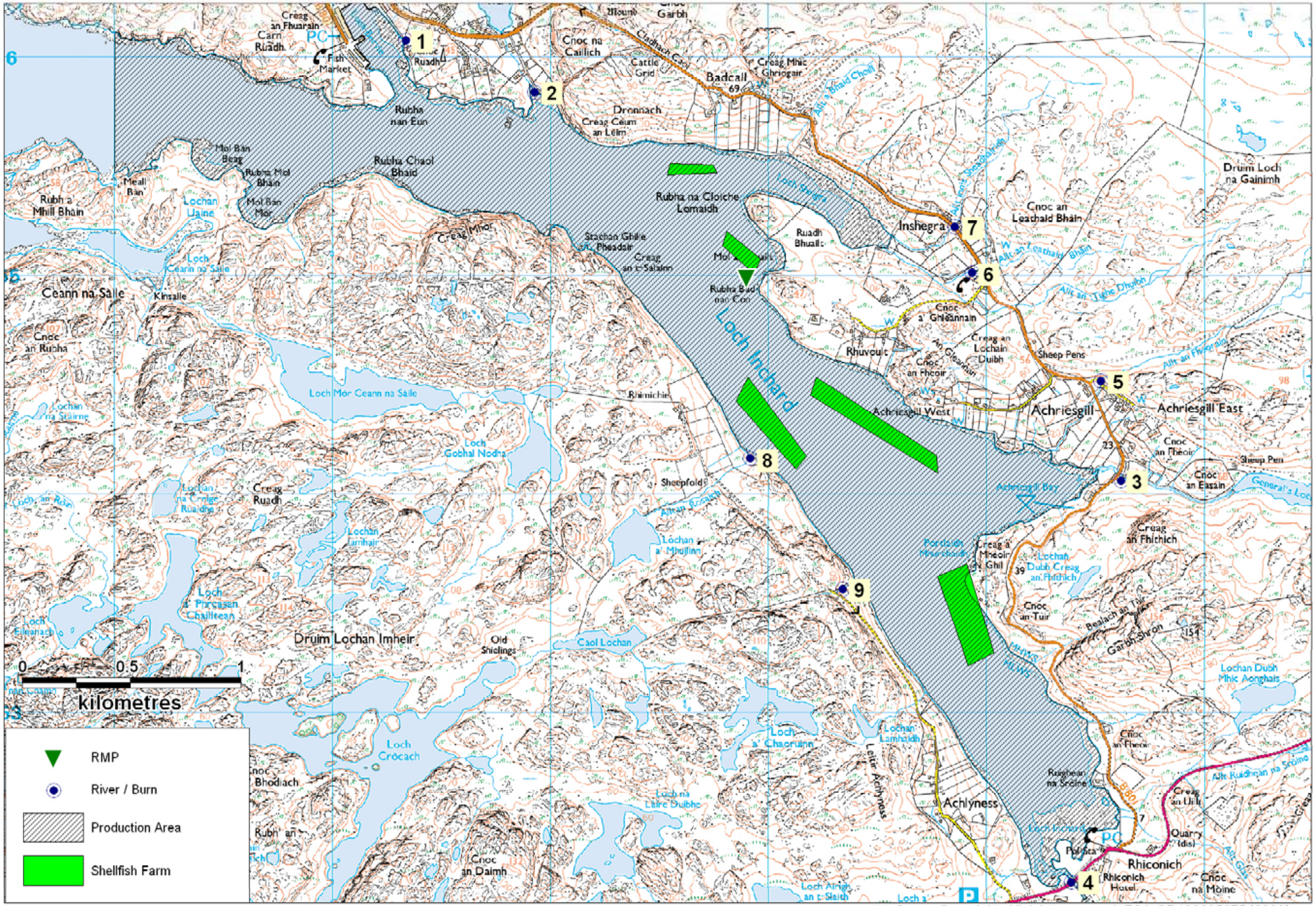

Figure 13.1 Significant streams and loadings

14. Hydrography

This site was chosen for an extended hydrographic assessment but without application of a computer model. It is recommended that the Hydrography Methods Document be consulted for background information on the methods applied.

14.1 Physical Characteristics

Primary data comes from the Sea Loch Catalogue (SLC) produced by the SMBA. Loch Inchard (OS reference NC200550) is a tidal fjordic sea loch on the North west coast of Scotland (Figure 14.1). The loch connects to the open sea and has a single sill approximately 1/4 along the loch from the mouth. The loch is 6.6 km long; the average depth at low water is 22 m. The loch contains two basins where depths exceed 35m. The maximum depth in the inner basin is 61m. The average sill depth at 16 m is quite deep compared to the mean depth (22m) of the loch.

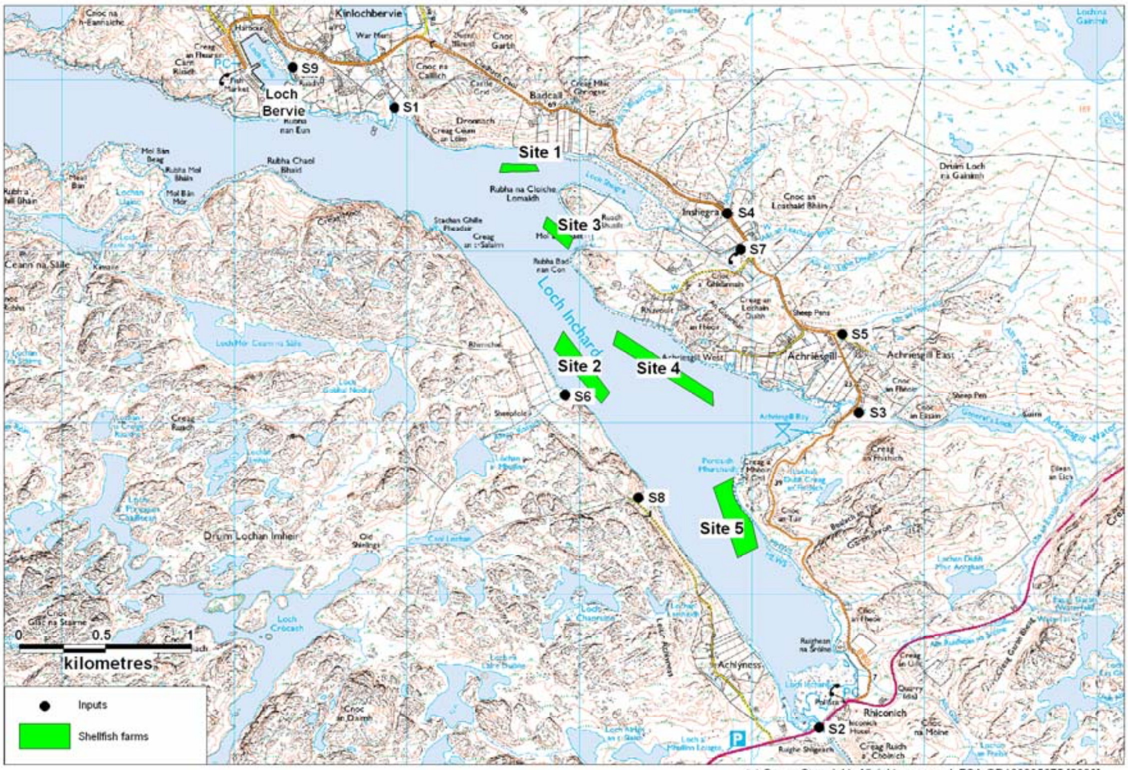

Figure 14.1 Leased sites together with potential sources identified by shoreline survey and ranked by magnitude (*E. coli* per day) with S1 the largest. Also marked is the approximate location of the only sill (black line).

<u>Tides</u>

The spring tidal range is stated in the SLC as 4.2 m, with the high water area of the loch being 4.1 km^2 and the low water area being 4.0 km^2. The low water volume of the loch is given as 88 M m^3. The volume of water that passes by tidal action across the sill can be estimated to give a mean speed of 8 cm/s (very weak) giving an effective transport distance of 1 km over a tidal cycle. Unlike other sea lochs where tidal flow over sills is more vigorous, flow over the sill in Loch Inchard is unlikely to lead to significantly enhanced mixing and dilution for contaminants. Average tidal velocities in the loch are likely to be lower still. Information for ship navigation (Clyde Cruising Club, 1997) states that tidal streams are ‘negligible’ within the loch. Nevertheless, assuming a peak tidal flow of 5 cm/s, tidal transport distances over a 6.2 hour (half) tidal period are around 0.7 km.

Flushing time is defined in the SLC as the time for 60% of the original water of the loch to be exchanged by tidal action. For Loch Inchard, the SLC gives a flushing time of 4 days, which is reasonably short. However this assumes complete replacement of the tidally exchanged water with new water on each tide. Studies at Loch Etive (Edwards and Edelsten, 1976) indicated a 50% exchange efficiency for that loch. Applying this to Inchard gives 7.5 days for the tidal flushing time, which may be a more realistic value. Some water in the deeper basins will remain isolated for longer than this but the surface waters will generally be exchanged more rapidly. Wind effects will modify the flushing time in a manner difficult to quantify without detailed hydrodynamic modelling.

<u>Wind driven flows</u>
Figure 14.2 gives the wind rose at Tiree in the outer Hebrides. While being a more exposed location than Loch Inchard, this station is likely to be broadly representative of the wind directions experienced at the loch.

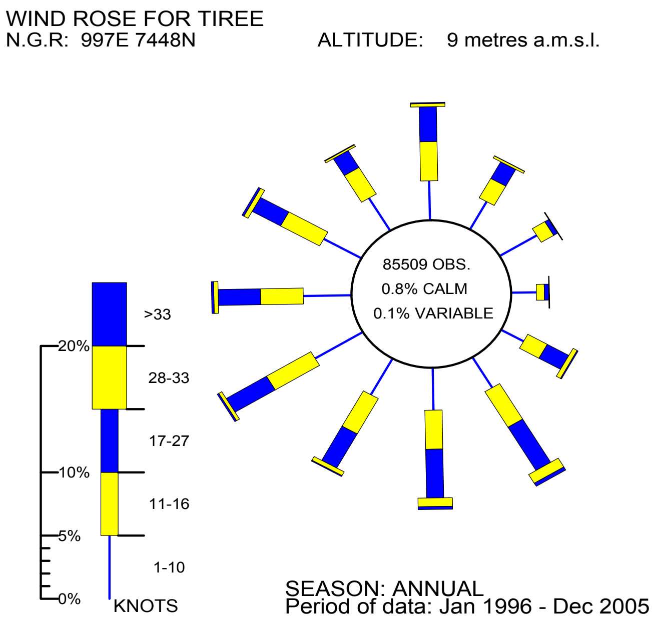

Figure 14.2 Annual wind rose for Tiree.

The information is summarised in tabular form below.

Table 14.1 Summary of Tiree wind rose data. Wind speeds converted to surface current speeds and associated transport distances. Surface winds assumed to be 3% of wind speed

Wind Speed (knots)	Surface current (cm/ s) average	% time	Distance transported in an hour (km)
>33	72	1.2%	2.6
28 –33	51	3.8%	1.8
17 - 27	42	28.1%	1.5
11 - 16	25	30.3%	0.9
0 -10	15	36.6%	0.56

Wind speeds greater than 10 knots occur 63% of the time. Assuming the wind driven surface layer moves at about 3% of the wind speed, this equates to a surface transport distance of around 0.5 km/h. Over a 12-hour period this could in theory move material the entire length of the loch. Approximately 33% of the time the wind direction comes from 300^o – 330^o or 120^o – 150^o (measured from the north), thus broadly aligned with the major axis of the loch and likely to lead to the formation of wind rows. Wind rows would act to transport material from near shore to offshore and to increase the potential for dilution of contaminants.

Density driven flows

Annual rainfall is given as 1250 mm per year with a runoff of 137 M m^3/year from a watershed of 137 km^2. The annual average ratio of freshwater input volume to tidal prism is estimated as 1:66 (SLC). Loch Inchard has a relatively large freshwater input compared to the exchange of water due to the tide (26 out of a list of 109 sealochs). No information concerning the lateral (cross-loch) distribution of salinity was identified. Freshwater inputs will create a persistent, generally seaward movement of water at the surface.

Related studies

No existing modelling studies or hydrographic survey data have been identified. A study of the ecology of the loch (Holt, 1991) describes some aspects of the hydrography drawn from existing sources. Descriptive hydrography mainly derived from the Sea loch catalogue appears in a sailing guide (Clyde Cruising Club, 1997) document and the Loch Inchard Aquaculture Framework Plan (2001).

14.2 Transport and dilution with respect to known sources.

Sources

For sources identified by the shoreline survey, the measured *E. coli* concentrations and flow rates were multiplied to give loadings. Note that water samples collected near the marina (Loch Bervie) showed the highest *E. coli* concentrations (4 times the next highest water sample concentration, see Table 14.4) but flow rates were not easily estimated to enable a loading to be derived. Nevertheless, if the measured water concentrations are representative it is likely that the marina at Loch Bervie represents a significant input.

Sources for which estimates of loadings were availabe from the shoreline survey were ordered according to magnitude. The largest source was designated source 1 (S1), the next source 2 (S2) etc. Clearly sources 1 to 3 are significantly larger than others (Figure 14.3). Source 1 is a stream leading from Kinlochbervie and had the highest loadings. Source 2 is the Rhiconich river at the head of the loch and source 3 is the Achriesgill river also near the head of the loch. Other sources, although much smaller, may have an impact if discharging onto or very close to a production area.

Note, the flow rates and hence loadings are estimated and occurred only to the day of the survey and so may be unrepresentative. The following assessment is based on the values measured on the day of the shoreline survey.

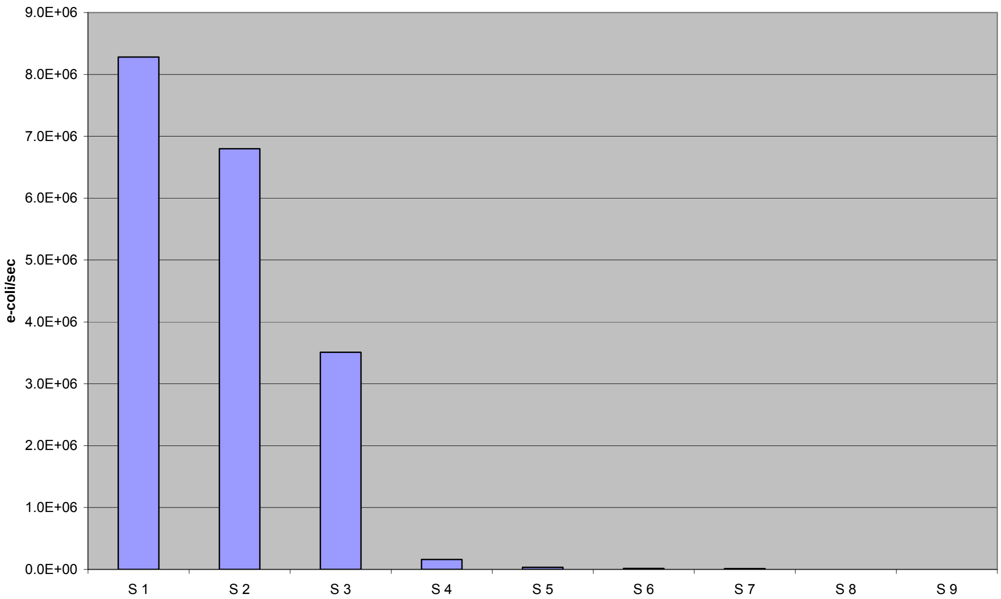

Figure 14.3 Loch Inchard loadings (*E. coli* /s) ordered by magnitude measured during shoreline survey. Refer to figure 14.1 for source locations.

Table 14.2 Measured water *E. coli* concentrations and estimated loadings by source.

Name	Grid Ref	*E. Coli* (cfu/100ml)	Loading (*E. coli*/day)
S1 Stream 2	NC 22926 55837	500	7.2E+11
S3 Achriesgill River	NC 25616 54057	50	3.0E+11
S2 Rhiconich River	NC 25386 52221	50	5.9E+11
S5 Achriesgill East burn	NC 25522 54514	50	2.8E+09
S7 Stream 6	NC 24933 55010	400	1.2E+09
S4 Stream 7	NC 24854 55221	800	1.4E+10
S6 Stream 8	NC 23915 54161	50	1.5E+09
S8 Stream 9	NC 24338 53562	50	9.7E+07
S9 Stream 1	NC 22334 56073	50	7.8E+06
Marina	NC 22168 56208	3200	NA

Dilution

A crude estimate of the *E. coli* concentration averaged over the entire loch can be derived by summing all inputs, multiplying by the estimated flushing time of the entire loch and dividing by the loch volume. Using the relatively short flushing time from the SLC of 4 days gives a loch averaged concentration of 5.3 x10^4 *E. coli* /m. This concentration lies between the requirements for potential class A status (i.e. 1 x10^4 *E. coli*/m or 1 *E. coli per 100 ml*) and potential class B status (i.e. 1 x10^6 *E. coli*/m or 100 *E. coli per 100 ml*). Thus, even at this broad level it seems that measured inputs are sufficient to compromise the attainment of class A classification over regions of the loch at certain times.

Now a more detailed assessment of the effect of diffusion and dilution is considered with respect to the three largest identified sources. Broadly dilution is calculated based on an assumed current speed, diffusion rate and a representative depth. Mixing to the representative depth is assumed to occur instantaneously. Thereafter the contaminating material is taken to move with flow parallel to the shoreline and to undergo diffusion and dilution in the offshore direction. Turbulence and small scale flows features act to diffuse and dilute material away from the shore (see the hydrography methods document for more details of the approach). Since flow may move either clockwise or anticlockwise around the loch, movement of material in both directions away from a source is considered. With these assumptions, an approximate mathematical relationship can be used to calculate zones where *E.coli* concentrations in the water column make it likely production areas will fail class A or class B classification.

Table 14.3 Parameters used in the dilution calculation.

Parameter	Representative depth	Horizontal diffusion coefficient	Current velocity
Value	5 m	0.1 m^2/s	0.1 m/s
Note	Compromise between a surface fresh water layer thickness (<2m) and an estimate of average loch depth along the shoreline.	Typical value used by SEPA and others in non-tidally dominated semi enclosed regions.	Representative of relatively weak tidal, wind or density driven flows.

Calculations for sources S4 to S9 indicate that dilution is sufficient to prevent these inputs having a wide scale impact. However, both S6 and S8 discharge very near to shellfish farms and certainly have the potential to cause problems. The measured water concentrations (Table 14.2) from S6 and S8 exceed those likely to cause class A failure if directly impacting a production area. Concentrations associated with S6 are high enough to indicate potential class B failure if directly impacting a production area.

Calculations for the three largest sources (Figures 14.4, 14.5, 14.6) suggest transport and diffusion can potentially cause large areas of the loch to fail class A classification. Potential class B failure is only predicted in the immediate vicinity of the sources (50-100 m) and is not shown. However, it is emphasised that the area shown for potential non-compliance for class A shown is indicative only as it assumes a continuous alongshore flow from the source around the perimeter of the loch. Although useful for visualising the effect of transport and dilution it is unlikely that the flow will in reality be so simple. For enclosed water bodies such as sea lochs, modelling studies (e.g. Yang et al. 2007, Cefas 2007) suggest that both tide and wind driven residual currents tend to form basin-wide gyre or eddy circulation patterns rather than purely alongshore flow. In addition, offshore movement of water will occur if wind rows form. . Nevertheless, the results indicate that dilution is probably not sufficient to reduce water concentrations below the level likely to give class A classification and that diffusion actually has the undesirable effect of increasing the area over which failure may occur. However, dilution to concentrations below that likely to cause class B failure is readily achieved for all sources and only those discharging directly onto production areas are likely to cause problems with class B failure.

The marina (Loch Bervie) may also be a significant source although as noted above an actual loading estimate could not be made due to difficulty in assessing exchange rates between the Marina and the main body of the Loch.

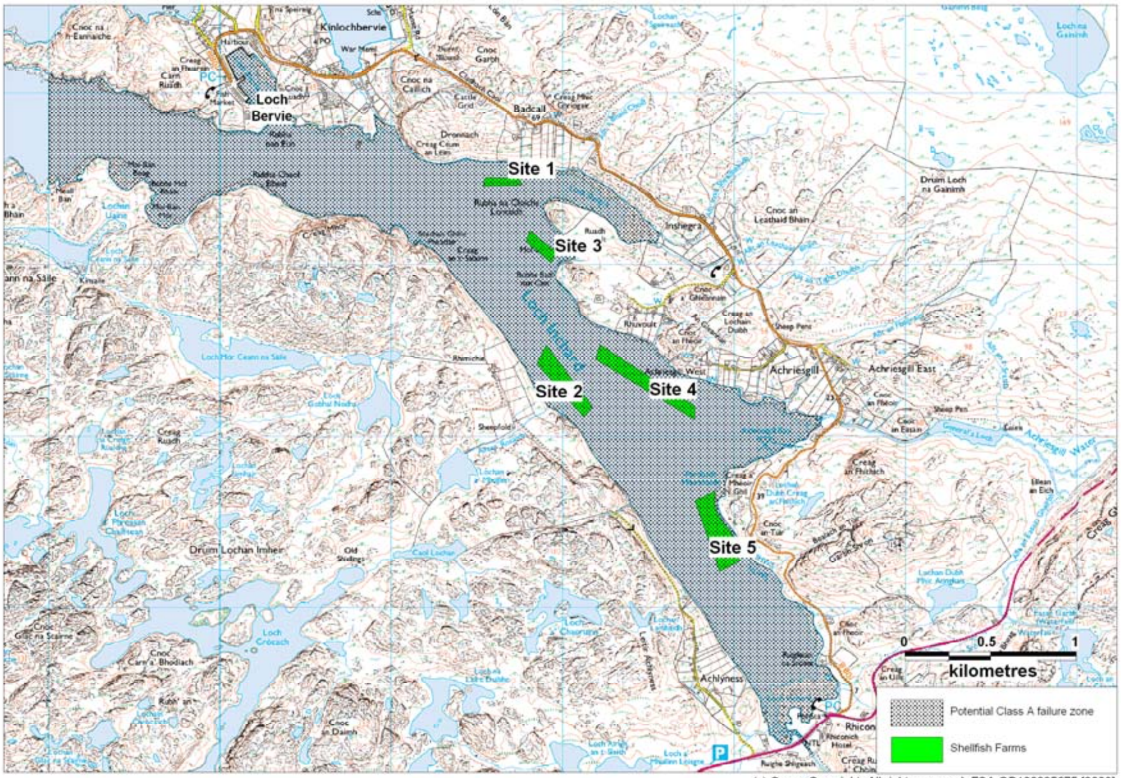

Figure 14.4 Potential Zone A failure (shaded in grey) for all sources. Assumes continuous circulation path around loch.

Transport paths

Consideration is now given to individual production areas in relation to the sources identified by the shoreline survey. Without extensive observations or numerical modelling the discussion that follows is necessarily reliant on expert judgement and is a subjective assessment.

The results shown in Figures 14.4 to 14.6 suggest that dilution in the loch is not sufficient to mitigate the impact of the three largest sources (as identified by the shoreline survey) on any of the designated productions areas at class A. As noted above, the areas shown as potentially failing class A and B classification are based on assuming a continuous alongshore flow around the perimeter of the loch. Such a simple continuous flow, although useful for indicating the effect of diffusion and dilution, is unlikely to exist in reality. Based on modelling work in other sea lochs (e.g. Loch Fyne) we suggest that the water circulation pattern under both tidal and persistent winds will form a series of gyres. A tentative pattern of circulation derived from experience in other sea lochs and a consideration of the bathymetry is given in Figure 14.7. However, it is emphasised that this is an estimate only.

Assuming this sort of circulation pattern it is possible to conclude the following. Inputs from S1 are more likely to impact production areas D. Ross and C. Morrison; inputs from S2 are more likely to impact D. Forbes; inputs from S3 are more likely to impact production areas N. Ross and D Ross. Circulation under dynamically varying winds will be more complex and difficult to predict. Nevertheless as common sense would suggest, production areas are more likely to be impacted by local rather than far away sources.

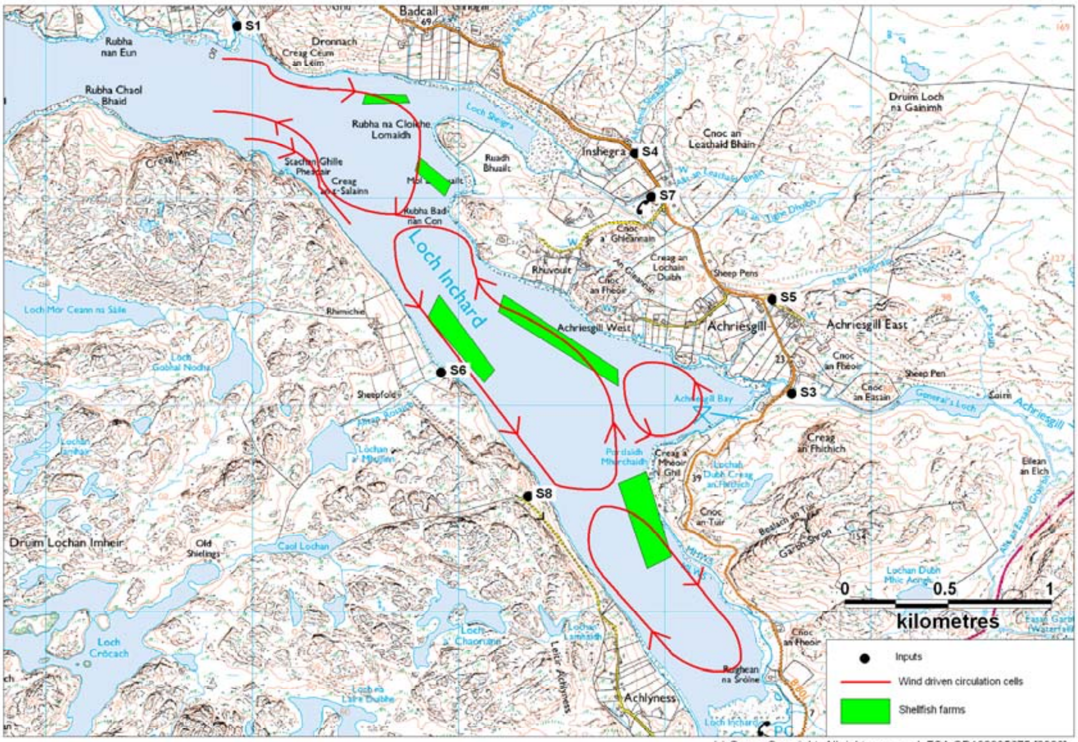

Figure 14.5 Hypothesised wind driven circulation cells. Direction of circulation can be either with or opposite to the direction indicated by arrows, depending on wind direction.

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14.3 Summary

Tidal velocities in the loch are weak so that wind and density driven flows are likely to be more important for moving contaminated water. Given the relatively high freshwater inputs it is expected that a near surface freshwater layer will form. Since *E. coli* inputs are associated with fresh water, it is likely that this layer will be contaminated. Contaminant input rates are rather high relative to the rate at which water is estimated to be flushed out and crude estimates suggest that average levels of *E. coli* calculated from the ratio of input rates to flushing rates could cause failure for class A status. An assessment relating known sources, production areas, hydrography and dilution concluded that all sites are potentially impacted by *E. coli* concentrations probably sufficient to fail class A classification. Regions where water concentrations are high enough to cause likely class B failure are limited to the immediate vicinity of sources.

15. Shoreline Survey Overview

Loch Inchard is a narrow and somewhat constricted fishery, with less than 200 metres between mussel farms Site 2 and Site 4 in the centre of the loch.

There is a relatively small population in the area with only two settlements consisting of more than just a few homes: Kinlochbervie and Rhiconich.

In addition to septic tanks and overflows operated in the area by Scottish Water, additional private septic tanks were observed at the head of the loch in Rhiconich and in a smaller settlement along the eastern shore of the loch at Inshegra. Of water samples collected from freshwater sources around the loch, the majority (75%) showed results of $\leq$100 *E. coli* cfu/100 ml. The highest freshwater result (800 *E. coli* cfu/100 ml) came from the sample taken downstream of the three private septic tank discharges at Inshegra.

Seawater samples showed salinities more consistent with fresh or brackish water (0.7-11.5 ppt, where normal seawater has a salinity of 35 ppt.) This was consistent with observations on the day as the water churned up by the propeller wash of the survey boat had the same tea-stained appearance of the water seen in the rivers. Analysis for *E. coli* showed a range of concentrations between 7 and 25 cfu/100 ml, though the water sample taken from the small marina in Kinlochbervie Harbour contained 3200 cfu/100ml.

Kinlochbervie is a deep sea fishing port and there appeared to be a discharge from the toilets at the Fisherman's Mission, however this could not be verified. No fishing boats were observed on the day of the survey, only a few small fishing boats. There was a small marina with pontoon berths in the northeast corner of the harbour. This was fully occupied with 11 boats on the day of survey.

The land around the loch was rugged and rocky, with steep cliffs and virtually no foreshore. Approximately 180 sheep in total were counted around the entire loch, though reportedly numbers had been significantly higher in the weeks prior to the survey as a large number of lambs had already been shipped to market. The harvester's representative estimated that there were normally in excess of 300 animals on the farm along the western shore of the loch alone.

Shellfish samples collected from each of the mussel farms in the loch showed E. coli concentrations ranging from 100 mpn/100 g to >18000/100 g. Highest results were seen toward the mid section of the loch, where results were also higher for samples taken at 5 metres depth than for those collected from just below the surface. Results for the most northerly and southerly shellfish samples showed the reverse trend, with samples collected just below the surface showing higher results than those at greater depth and concentrations ranging from110 to 2200 mpn/100 g. Highest results were found on Site 4, nearest Achriesgill Bay.

The map in Figure 15.1 shows relative locations of the most significant of the shoreline survey findings.

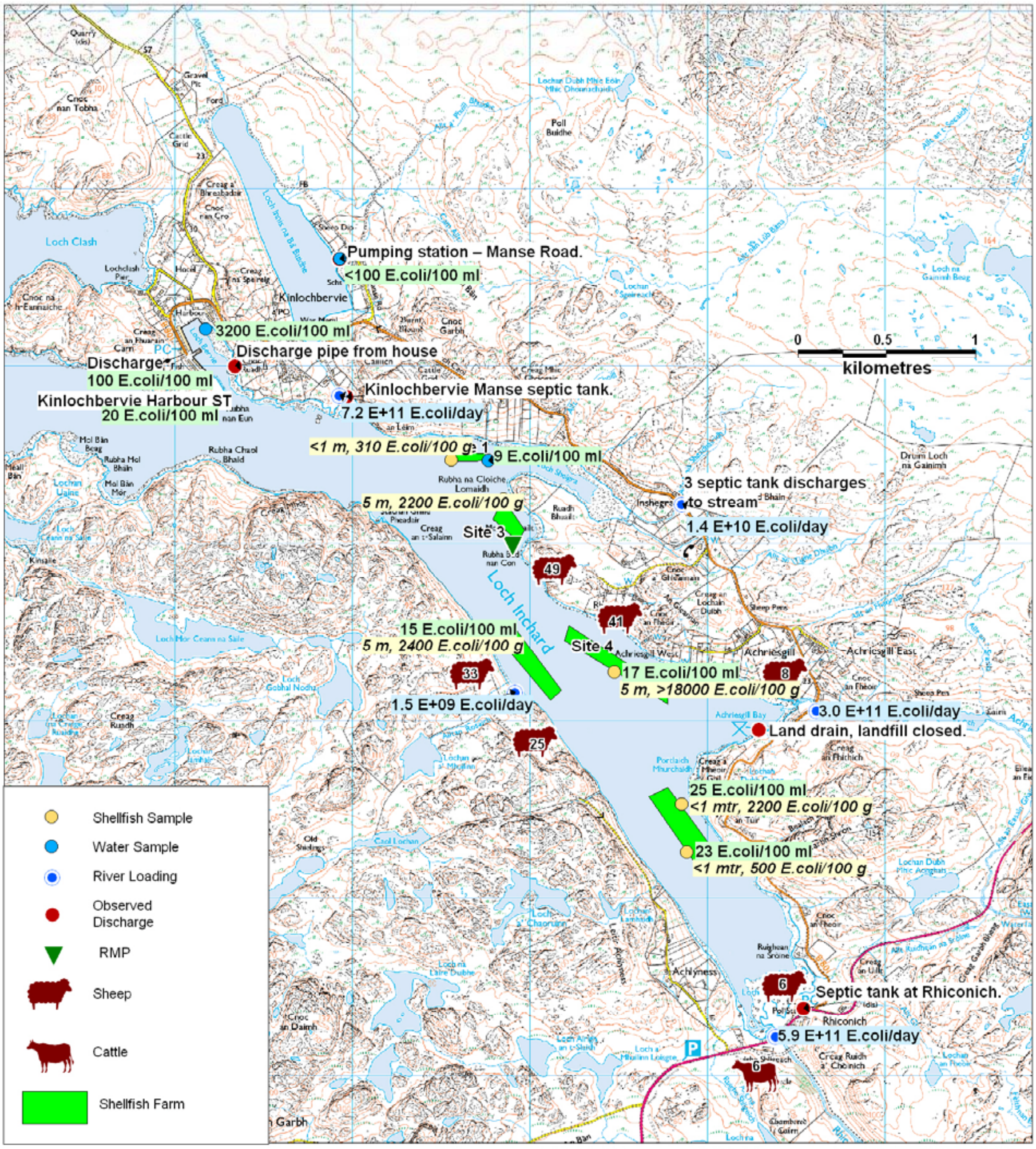

Figure 15.1 Loch Inchard shoreline survey findings

16. Overall Assessment

Human Sewage Inputs

Input of human sewage to Loch Inchard is through two community septic tanks, an unspecified number of private septic tanks and three pumping station emergency overflows. The consented design population equivalent for the community tanks is 384. Both of these are located on the eastern side of the loch between Inshegra and Kinlochbervie Harbour. The larger outfall is located at the outside of Kinlochbervie Harbour. Within the harbour there is additional potential for human sewage contamination from boats.

There are a number of private septic tanks in the area most notable of which were those serving the hotel, police station and public toilets at Rhiconich and those found to be discharging to the stream at Inshegra. It is anticipated that a further discharge may be associated with the farm on the western shore, though this was not confirmed.

Overall, for the size of area human sewage input was relatively low. The effect of seasonal tourism would be to potentially increase the human population in the area (447) by up to 100 people.

The human sewage impacts are primarily restricted to the eastern shore of the loch and would most acutely impact fisheries located nearer the discharges, in particular Sites 1 and 3.

Agricultural Impacts

No arable agriculture is undertaken in the vicinity of the loch as the land is unsuitably rocky and steep.

Livestock grazing is undertaken in the area, with both sheep and cattle being grazed. On the day of survey approximately 160 sheep were observed, though the prior to shipment to market there had been over double that number present. Further, local information indicated that the farm on the west side of the loch had 200-300 sheep as opposed to approximately 100 on the east side. This it is likely that the more significant agricultural impact will be to Site 2 nearest the western shore.

When considered in combination with the poorly drained soils present on the western side of the loch, the potential for runoff contaminated with livestock waste is high on this side of the loch.

It was noted that there is significant seasonal variation in the numbers of livestock present as lambs and calved are sent to the mainland for finishing in early autumn.

Wildlife Impacts

The only significant wildlife observed during the survey were two seals seen in Kinlochbervie Harbour. There are significant seabird and seal populations located just outside Loch Inchard, especially at Handa Island. While it is likely that these animals may hunt or pass by the mussel farms, their impact from the standpoint of faecal pollution is likely to be spatially and temporally unpredictable and therefore will not be considered in establishment of an RPM.

Rivers and Streams

Of the large number of streams and small freshwater courses that feed into Loch Inchard, the nine largest were measured and sampled as part of the shoreline survey. Collectively, they represent an input of approximately 2 million m^3 per day into the total low water loch volume of 88 million m^3. This calculation is based on recorded flows and measurements on the date of shoreline survey and so may not be fully representative of conditions on site.

Streams with the highest *E. coli* levels were those feeding into Loch Sheigra and one discharging just to the east of Loch Bervie. These contained 400, 800 and 500 cfu *E. coli*/100 ml.

Calculated loadings ranged from 7.2×10^{11} for the stream discharging east of Loch Bervie, as mentioned above, to 7×10^6 for the smallest stream measured.

All of these streams discharge into the production area as currently defined, though only one, the Allt an Rosaich (loading 1.5×10^9 *E. coli*/day) discharges directly adjacent to one of the mussel farms (Site 2, along the western shore). It is expected that this discharge would significantly impact water quality at this site.

Meteorology and Movement of Contaminants

Analysis of the hydrography of Loch Inchard in relation to inputs and mussel farm locations shows that contamination entering the loch from the various stream inputs is capable of causing failure of class A status for the entire loch.

Flushing time is likely to be longer than the 4 days given in the Scottish Sea Loch Catalog, with current speeds predicted to be low. Wind driven movements cells and density driven flow of fresh water out of the loch are more likely to dominate the movement of contaminants within the loch than tidal regimes.

Predicted movement cells would carry contamination from discharge sources around the sides of the loch and through the shellfish farms. Where the cells converge, greater mixing at depth may occur and shellfish *E. coli* results from the shoreline survey appear to indicate this may be happening in Sites 2, 3 and 4.

Analysis of Results

Historical monitoring results for the production area show Site 5 had the both the lowest geometric mean and the lowest maximum *E.coli* results where Site 3 had both the highest geometric mean and the highest maximum.

Substantially higher *E.coli* concentrations were found during the shoreline survey than had been obtained during previous monitoring. A sufficiently representative number of samples was obtained from each site, with n ranging between 15 and 28. Site 5 had the largest number of samples represented (n=28) and Site 3 the fewest (n=15). Statistical analysis found no significant differences between results for any of the sites. Further, no significant deterioration in apparent quality of shellfish was observed over time, indicating that contamination levels in the loch have neither improved nor deteriorated.

There was significant correlation between season and *E. coli* result, with significantly higher results observed in summer. Highest mean results were observed in July and August. This did not appear to correlate with rainfall and in fact, mean monthly rainfall at Achfary was lowest in July.

A positive correlation was observed between temperature and *E. coli* result, though it is not clear whether this was coincidental to the seasonal effect or the cause of it.

17. Recommendations

Current production area boundaries are given as being the area bounded by a line drawn between NC 2100 5611 and NC 2100 5547 extending inshore to MHWS.

It is recommended that the production area boundaries be redrawn to encompass only the area in use and to exclude areas closest to major discharges. It is proposed that the southern boundary be drawn to exclude the head of the loch where there is a septic tank discharge as well as the Rhiconich River. Likewise, Loch Sheigra and Achriesgill Bay have been excluded from the production area as they are likely to be more highly contaminated due to the river discharges there.

The proposed new production area is the area bounded by lines drawn between NC2317 5562 and NC 2306 5522 and between NC 2400 5553 and NC 2400 5538 and between NC 2500 5428 and NC 2500 5381 and between NC 2482 5298 and NC 2525 5318 and extending to MHWS.

As there is evidence to suggest that levels of contamination may be widespread throughout the loch and there was statistically little difference between monitoring results collected at each of the farms over time, it has not been recommended that the production area be split.

The existing RMP is located at NC 239 550. It is suggested that the RMP be moved to NC 2482 5298 on Site 4 near Achriesgill Bay. This area was shown from shoreline survey sampling results to have higher levels of contamination than were observed in samples taken from the vicinity of the RMP. It is further recommended that samples be collected from a depth of 5 metres as higher levels of contamination were observed at this depth that near the surface. A tolerance of 20 metres is suggested for sampling to allow for natural movement of the lines with the wind and tide.

As the site has a seasonal classification, it is recommended that monthly monitoring be continued.

Figure 17.1 illustrates the proposed production area boundaries and RMP.

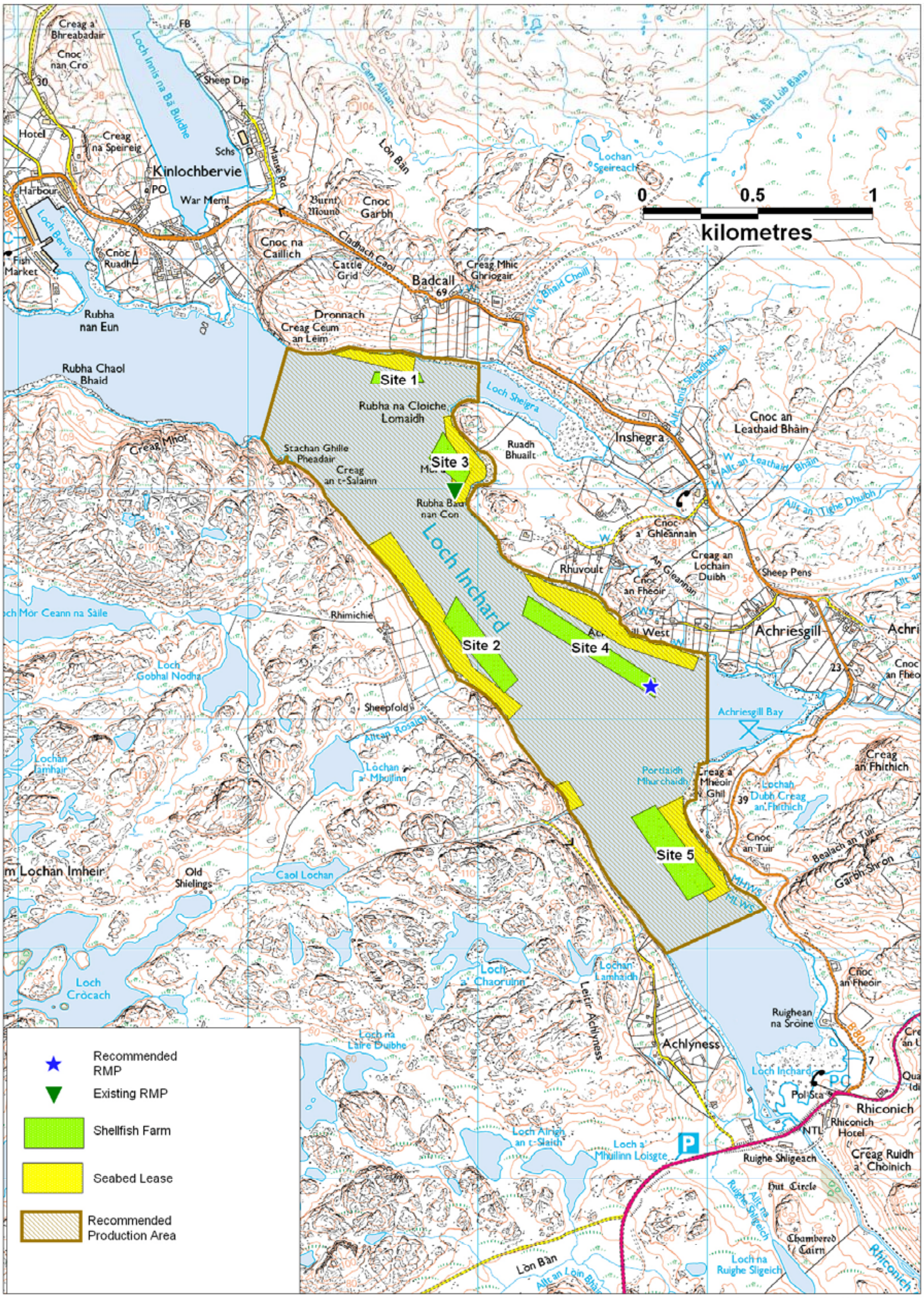

Figure 17.1 Loch Inchard recommendations

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2. Sampling Plan
3. Table of Typical Faecal Bacteria Concentrations
4. Statistical Data
5. Hydrographic Methods

Shoreline Survey Report

Loch Inchard
HS 162

Scottish Sanitary Survey Project

Shoreline Survey Report

Production area: Loch Inchard
Site names:

Site Name	SIN	Species
Site 1 – D. Ross	HS 162 311 08	Common Mussels
Site 2 – D. Forbes	HS 162 312 08	Common Mussels
Site 3 –C.Morrison	HS 162 313 08	Common Mussels
Site 4 – J. Ross	HS 162 314 08	Common Mussels
Site 5 – N. Ross	HS 162 315 08	Common Mussels

Species: Common mussels
Harvester: D. Ross, D. Forbes, J. Ross, N. Ross and C. Morrison
Local Authority: Highlands Council - Sutherland
Status: Currently classified B in Jul-Aug, A remainder of year.

Date Surveyed: 11-12 September 2007
Surveyed by: M. Price-Hayward, G. Askew
Existing RMP: NC239550
Area Surveyed: See Map in Figure 1

Weather observations

11 September: Overcast. Dry in a.m., mist turning to showers during p.m. Winds WNW Force 5. Temperature 13C. No precipitation for the previous 48 hours.

12 September: Overcast early, brightening by mid day. Dry. Temp 15-16. Winds calm to Force 3.

Site Observations

Fishery

Boat and skipper Jaime Dawson were available to assist on both days courtesy of harvester John Ross.

Water churned up by the boat's outboards was tea-coloured, indicating strong fresh water influence. The local burns and streams drain areas with peat soils and so are tinted a light brown (see photo in Figure 31).

The loch is narrow and the fisheries located within close proximity in some cases. Sites 4 and 5 are separated by 183 metres at their closest point. The actual locations of the farms are illustrated on the map in Figure 1.

All the sites produce rope-grown mussels on double headed long lines with 5 metre pegged droppers.

Tackle on site as observed on the day of survey:

Site 1, D. Ross – 3 lines
Site 2, D. Forbes – 3 lines
Site 3, C. Morrison – 4 lines
Site 4, J. Ross – 3 lines
Site 5, N. Ross – 4 lines

<u>Sewage/Faecal Sources</u>

The following table lists discharges identified by Scottish Water prior to conducting the shoreline survey.

NGR of discharge	Discharge Name	Easting	Northing	Discharge Type	Level of Treatment	Consented flow (DWF) m3/d
NC 22105570	Kinlochbervie Harbour	222100	955700	continuous	Septic Tank	254
NC 23905580	Kinlochbervie Innis Place	223900	955800	continuous	Septic Tank	130
NC 22005620	Kinlochbervie Bervie PS EO	222000	956200	intermittent	6mm screen on overflow	
NC 21805640	Kinlochbervie Clash PS EO	221800	956400	intermittent	6mm screen on overflow	
NC 22905658	Kinlochbervie Manse Rd PS EO	222900	956580	intermittent	6mm screen on overflow	

The following were identified during the shoreline survey:
Kinlochbervie Manse Septic Tank was recorded at NC 22965 55830.
Kinlochbervie Harbour Septic Tank was recorded at NC 22169 55800.
Kinlochbervie Manse Rd Pumping Station was recorded at NC 22926 56605.

The Loch Clash pumping station was not located, however a distinct odour of sewage was noted in the area of the seawall. The Kinlochbervie Bervie PS was also not directly observed, but would have been located somewhere on the fishing quay. Outfalls were observed at the base of the pier, however these were inaccessible. The Innis Place septic tank was presumably observed at NC 23552 55980, however as this was not labelled in any way this could not be confirmed visually.

A septic tank was observed at Rhiconich, with discharge pipe not confirmed but a drain cover was located on the shoreline below the inspection hatches and the sound of running water was audible from above the cover (see photo in Figure 33.) Additional septic tanks were observed for the homes and B&B located near Inshegra. Three pipes discharge to the same stream adjacent to the main road.

<u>Seasonal Population</u>

There are two settlements near the loch: Kinlochbervie and Rhiconich. There is a hotel with accommodation for 19 people at Rhiconich, which is situated at the head of the loch. In Kinlochbervie, there is a hotel with accommodation for 30, in addition to B&B and self catering accommodation in the area for up to 40 people. At Kinlochbervie, there is fisherman’s mission, a small post office and shop, as well as a small shop along the road between Kinlochbervie and Rhiconich.

High season for visitors is June to August and over the Christmas holiday based on the schedule of rates charged by the hotels.

No campsites were observed during the shoreline survey.

Boats/Shipping

Kinlochbervie is a deep sea fishing port with a quay for offloading and transfer of fish to trucks for delivery to market. On the day of survey, 3 small work boats were observed in port and no large fishing boats. A small number of pontoon berths were fully occupied (11 boats plus 1 barge) in the north east corner of the harbour.

Small, open workboats were observed on Loch Inchard itself during the survey, and these were moored and not in use.

Land Use

The land around the loch is rugged and rocky, with no arable agriculture apparent. There is a farm on the south side of the loch that raises sheep. According to both the skipper and the sampling officer, sheep had been sent to market the week before and numbers present on the day were a fraction of what they had been. They estimated there had been approximately 200-300 sheep present on the south side of the loch and 100 sheep on the north side.

Wildlife/Birds

Cormorants and gulls were observed during the survey, though not in large numbers. Eider Ducks were reported to be present on the loch though none were observed on the dates of survey. There is reportedly a colony of seals resident outside the loch itself. Two grey seals were observed around the base of the quay at Kinlochbervie harbour and it is expected that seals will hunt within the loch.

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

Figure 1.

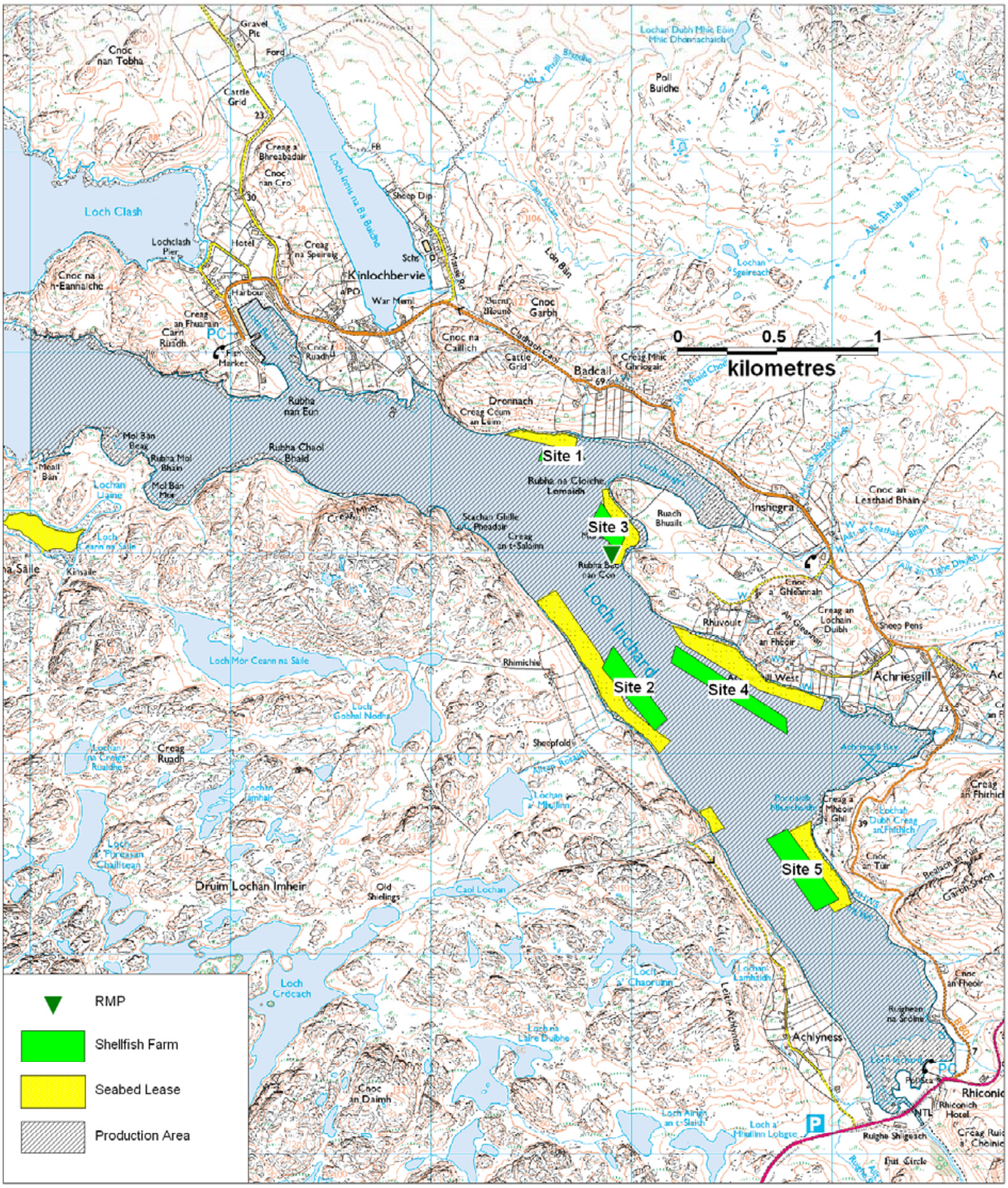

Site 1
Site 2
Site 3
Site 4
Site 5
Loch Inchard
Kinlochbervie
Loch Clash
Badcall
Inshegra
Achriesgill
Achlyness
Rhiconich
0
0.5
1
kilometres
RMP
Shellfish Farm
Seabed Lease
Production Area

Figure 2.

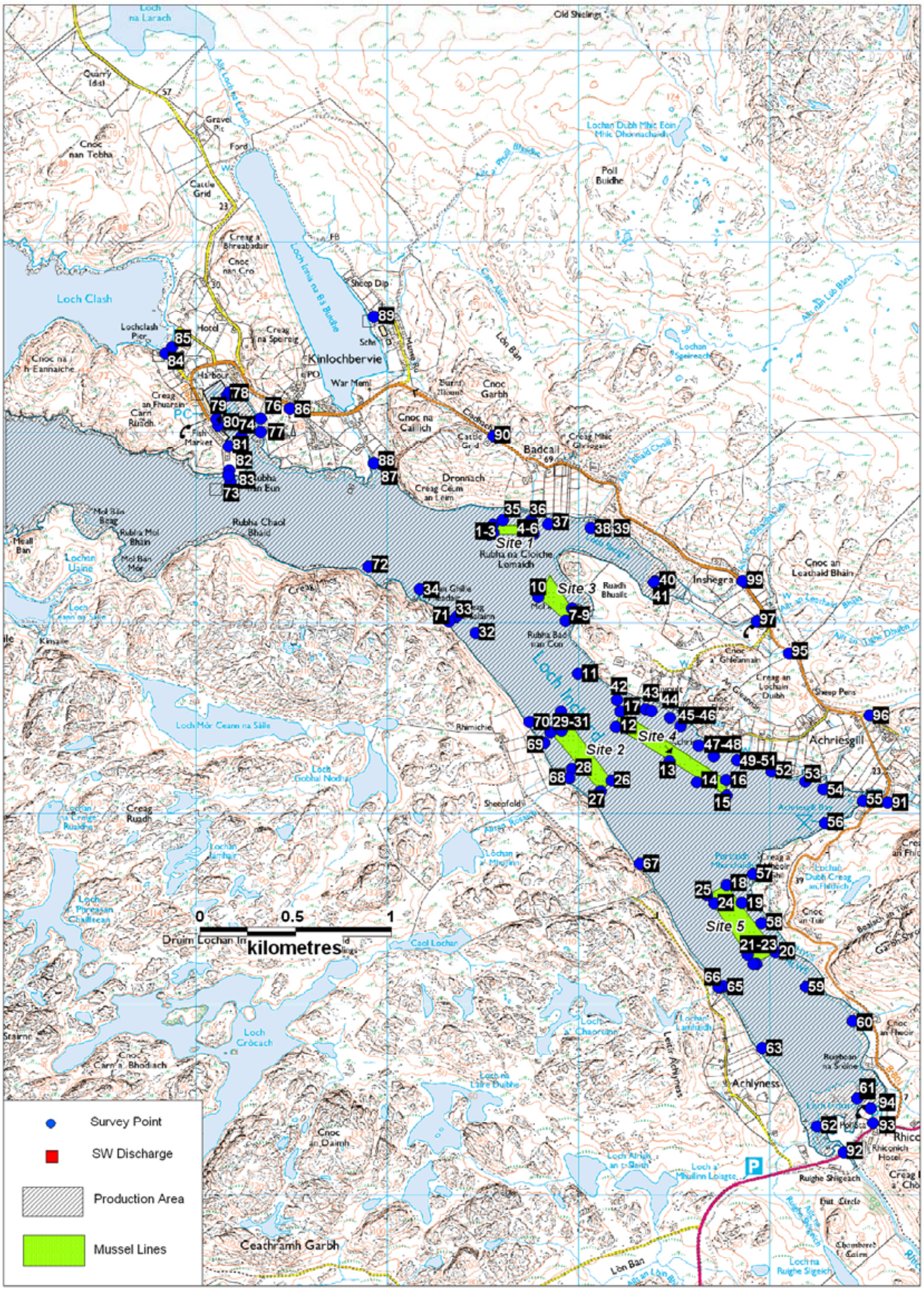

Survey Point
SW Discharge
Production Area
Mussel Lines
0
0.5
1
kilometres
Site 1
Site 2
Site 3
Site 4
Site 5
Loch Inchard
Kinlochbervie
Achriesgill
Achlyness

Table 1. Shoreline Observations

No.	Date	Time	NGR	Description	Photograph of Area
1	11-Sep-07	09:36:27	NC 23532 55460	Corner of mussel lines, Site 1 D.Ross.	
2	11-Sep-07	09:40:51	NC 23553 55471	Inchard water sample no.1, mussel sample nos. 1 (surface) and 2 (bottom). 3 lines, 5 m droppers. Temp 12.8C, salinity 17.3 (surface). Harvest 1 line per year in 3 year cycle.	
3	11-Sep-07	10:00:37	NC 23549 55512	NW corner of mussel lines, Site 1 D. Ross. 3 cormorants, 2 houses on hill, on north side no pipes seen.	
4	11-Sep-07	10:02:34	NC 23678 55512	No observation recorded.	
5	11-Sep-07	10:03:13	NC 23745 55506	Corner of mussel lines, Site 1 D.Ross.	
6	11-Sep-07	10:03:27	NC 23752 55501	Additional 6 houses up the hill.	
7	11-Sep-07	10:04:10	NC 23763 55468	C.Morrison. 4 lines, corner of site. Inchard water sample no. 2, mussel sample nos. 3 and 4. Temp 12.8C and salinity 5.4 ppt. 3 photos - rocky shore, improved pasture with sheep (5 sheep). Harvester said most went off to market last week. 200-300 on south side and 100 on north side, 1 cormorant and 1 gull on floats.	
8	11-Sep-07	10:07:06	NC 23848 55250	No observation recorded.	
9	11-Sep-07	10:28:24	NC 23963 55076	Corner of mussel lines.	
10	11-Sep-07	10:29:17	NC 23987 55054	Inchard water sample no. 3.	
11	11-Sep-07	10:30:00	NC 23932 55011	Corner of mussel lines.	
12	11-Sep-07	10:31:40	NC 23787 55139	Corner of mussel lines.	
13	11-Sep-07	10:34:48	NC 23995 54735	Site J.Ross. 3 long lines. to the south of this mark – on shore farm with 49 sheep. to the north is a house.	
14	11-Sep-07	10:36:58	NC 24192 54453	Corner of outer mussel line. on south shore, 5 houses, 5 fields, 33 sheep.	
15	11-Sep-07	10:39:24	NC 24473 54273	Inchard water sample no. 4, temp 12.8, salinity 2.9. mussel sample nos. 5 and 6.	
16	11-Sep-07	10:54:02	NC 24616 54164	On south shore, 2 houses, 1 sheep	
17	11-Sep-07	10:55:13	NC 24773 54095	Corner of mussel lines, on south.shore. are 24 sheep in 3 small fields	
18	11-Sep-07	10:56:23	NC 24771 54175	Corner of mussel lines, water very brown.	
19	11-Sep-07	11:00:40	NC 24217 54537	Corner of mussel lines. N.Ross, 4 lines.	
20	11-Sep-07	11:08:27	NC 24773 53624	Corner of mussel lines.	
21	11-Sep-07	11:10:45	NC 24853 53531	Inchard water sample no. 5, mussel sample nos. 7 and 8. Temp 13C, salinity 2.3.	
22	11-Sep-07	11:31:34	NC 25031 53272	Corner of mussel lines, cormorants on inner line floats, 1 shag.	
23	11-Sep-07	11:31:34	NC 25032 53272	No observation recorded.	

No.	Date	Time	NGR	Description	Photograph of Area
24	11-Sep-07	11:32:54	NC 24930 53210	Corner of mussel lines.	
25	11-Sep-07	11:35:31	NC 24882 53261	Feed store shed on shore. Inchard water sample no. 6, mussel sample nos. 9 and 10. Temp 13C, salinity 3.	Figure 13
26	11-Sep-07	11:47:08	NC 24915 53212	Corner of mussel lines. on south shore a road cuts inside of hill, houses seen toward head of loch.	
27	11-Sep-07	11:49:45	NC 24708 53530	Shore, no habitation, no stock	
28	11-Sep-07	11:50:07	NC 24669 53572	Corner of D.Forbes mussel lines, 3 long lines.	
29	11-Sep-07	11:55:27	NC 24173 54172	Corner of mussel lines.	
30	11-Sep-07	11:56:43	NC 24113 54114	Corner of mussel lines.	
31	11-Sep-07	11:58:19	NC 23965 54233	Small skiff.	
32	11-Sep-07	11:59:50	NC 23850 54426	Corner of mussel lines, 2 cormorants.	
33	11-Sep-07	12:00:56	NC 23905 54535	Corner of mussel lines, a navigation mark on shore that flashes at night, farm above site belongs to owner of lease.	
34	11-Sep-07	12:03:31	NC 23909 54435	Inchard water sample no. 7, mussel sample nos. 11 and 12. Temp 13C, salinity at surface 37, at 1m 27. last few readings at 1m, depth reading fluctuated by up to 5 .	
35	11-Sep-07	12:27:41	NC 23459 54949	On south shore cliffs, no access to shoreline.	Figure 14
36	11-Sep-07	12:28:37	NC 23359 55034	Inchard water sample no. 8.	
37	11-Sep-07	12:30:05	NC 23168 55177	3 service pontoons. Vegetation - bracken, heather, some grass, very rocky.	Figure 15
38	12-Sep-07	09:06:58	NC 23600 55538	Burn, 6 cattle. House up hill, no apparent pipe.	
39	12-Sep-07	09:07:49	NC 23750 55534	House with no apparent pipe. Shoreline consists of small-medium boulders.	
40	12-Sep-07	09:08:20	NC 23839 55516	4 houses with improved or semi-improved pasture.	
41	12-Sep-07	09:09:36	NC 24062 55497	House up hill.	
42	12-Sep-07	09:09:56	NC 24117 55482	Closer to loch side there is another house, still no apparent pipes. Roads run along the loch shore here. Fishing debris along the shore - plastic boxes, nets and floats.	
43	12-Sep-07	09:12:46	NC 24397 55219	Very small stream at end of bay.	
44	12-Sep-07	09:17:17	NC 24391 55214	Inchard water sample no. 10. Seawater. Headland with nothing but rocks, grass and heather.	
45	12-Sep-07	09:25:06	NC 24053 55042	No observation recorded.	
46	12-Sep-07	09:29:31	NC 24198 54597	Steep shingle beach with fishing debris. Sheep kept up in the hills can access the shore here.	
47	12-Sep-07	09:30:32	NC 24350 54548	House, grass.	
48	12-Sep-07	09:30:43	NC 24379 54540	Unimproved pasture with bracken.	

No.	Date	Time	NGR	Description	Photograph of Area
49	12-Sep-07	09:31:23	NC 24476 54504	Improved pasture, 30 sheep	
50	12-Sep-07	09:31:50	NC 24531 54458	11 sheep, 2 houses	
51	12-Sep-07	09:32:44	NC 24627 54355	Some trees, bracken, steep slope, rocky.	
52	12-Sep-07	09:33:21	NC 24705 54300	1 Heron.	
53	12-Sep-07	09:34:09	NC 24828 54280	House, no pipe, 1 sheep.	
54	12-Sep-07	09:34:29	NC 24880 54268	House, barn, field of bracken.	
55	12-Sep-07	09:34:38	NC 24904 54262	Unimproved pasture.	
56	12-Sep-07	09:35:33	NC 25008 54221	8 sheep on shore.	
57	12-Sep-07	09:37:08	NC 25185 54166	Workboat, small stream.	
58	12-Sep-07	09:38:23	NC 25281 54126	4 dwellings west of burn, 8 east. Homes and pasture set back. 5 sheep. Quite a lot of scum on water around the river. Dam forming a small fresh water loch was removed by land owner using a digger this summer.	
59	12-Sep-07	09:43:09	NC 25488 54065	Inchard water sample no. 11.	
60	12-Sep-07	09:45:13	NC 25289 53949	Land drain, landfill closed several years ago.	
61	12-Sep-07	09:49:02	NC 24910 53681	Small shingle beach with fishing debris.	
62	12-Sep-07	09:50:55	NC 24956 53426	Shed.	
63	12-Sep-07	09:53:38	NC 25187 53091	Road skirts close to the edge of the loch.	
64	12-Sep-07	09:55:42	NC 25432 52911	Power substation.	
65	12-Sep-07	09:58:43	NC 25457 52507	Point @ PC, police station, Rhiconich Hotel, 6 sheep on shore.	
66	12-Sep-07	10:02:01	NC 25246 52359	Rhiconich River, 3 houses on east river bank. no apparent pipes.	
67	12-Sep-07	10:05:52	NC 24960 52771	Improved pasture, 1 sheep.	
68	12-Sep-07	10:08:30	NC 24759 53092	Stream.	
69	12-Sep-07	10:08:32	NC 24755 53095	Stream.	
70	12-Sep-07	10:10:12	NC 24731 53089	Inchard water sample no.12.	
71	12-Sep-07	10:15:55	NC 24319 53738	Cliffs.	
72	12-Sep-07	10:19:43	NC 23949 54188	Another small burn.	
73	12-Sep-07	10:21:10	NC 23818 54371	Farm up on hill.	
74	12-Sep-07	10:22:16	NC 23740 54480	Home made navigation light.	
75	12-Sep-07	10:26:34	NC 23320 55009	Small trickle into loch, steep cliffs.	
76	12-Sep-07	10:29:48	NC 22900 55297	Small trickle down loch face into loch.	
77	12-Sep-07	10:39:33	NC 22174 55739	Near where outfall should be. Inchard water sample no13.	Figure 16

No.	Date	Time	NGR	Description	Photograph of Area
78	12-Sep-07	10:44:52	NC 22232 55980	House, 7 sheep,	
79	12-Sep-07	10:46:47	NC 22158 56192	Marina, 11 boats and a barge.	Figure 19
80	12-Sep-07	11:08:27	NC 22334 56073	Small stream draining from road. Field with four sheep. Inchard water sample no 17. 30cmx2.7 deep. Flow 1m - 55 seconds. Weather - overcast, light rain, calm wind. Temp 14C	
81	12-Sep-07	11:28:10	NC 22334 56000	Discharge pipe from house doesn't appear to be flowing.	Figure 19
82	12-Sep-07	11:43:13	NC 22168 56208	Water sample 14, 2 vials, marina.	
83	12-Sep-07	11:51:04	NC 22110 56034	2 grey seals. Discharge at base of quay.	Figure 20
84	12-Sep-07	11:57:22	NC 22103 56068	Discharge (septic?) out from fisherman's mission PC. No sample possible.	Figure 21
85	12-Sep-07	12:02:00	NC 22167 55924	Unkown discharge, near corner of pier. Sample 15. Flow 1L - 3.5 seconds. Storm water overflow from around storage tanks - diesel.	Figure 22
86	12-Sep-07	12:11:27	NC 22169 55800	Kinlochbervie Harbour ST, photo	Figure 23
87	12-Sep-07	12:14:24	NC 22165 55772	Outfall, old harbour. Loch Clash, 1 work boat, smell of sewage.	
88	12-Sep-07	12:27:39	NC 21836 56414	Photo - blocked area of seawalll. Sample 16. Small flow across sand, from front sides, odorous, broken bit of pipe.	Figure 24
89	12-Sep-07	12:34:44	NC 21871 56446	Old pipe (photo), no longer connected to anything.	Figure 25
90	12-Sep-07	13:32:30	NC 22486 56123	Kinlochbervie hotel - empty horse sheds. 7 occupied homes.	
91	12-Sep-07	13:53:28	NC 22965 55830	Kinlochbervie Manse septic tank.	Figures 26-27
92	12-Sep-07	13:59:26	NC 22926 55837	Burn adjacent septic tank, water sample no 18, 9.1m wide, ave 26cm deep, 0.7m/s flow. No apparent discharge pipes. 6 cattle on field across burn. Sheep droppings scattered but evident. 5 sheep observed in field back toward road from septic tank.	Figure 28
93	12-Sep-07	14:32:02	NC 22926 56605	Pumping station – Manse Road.	Figure 29
94	12-Sep-07	14:47:45	NC 23552 55980	Pumping station, ST? at Badcall – possibly Innis Place.	Figure 30
95	12-Sep-07	15:31:18	NC 25616 54057	Achriesgill River, 39m wide by 20cm ave depth, flow 0.9m/s, Inchard water sample no. 19.	Figure 31
96	12-Sep-07	16:08:46	NC 25386 52221	Rhiconich River, 17m x 1m x 0.8m/s, Inchard water sample no. 20.	Figure 32
97	12-Sep-07	16:50:03	NC 25540 52379	Inspection hatch for septic tank at Rhiconich.	
98	12-Sep-07	16:56:43	NC 25528 52455	Discharge to loch not flowing, old broken pipe adjacent. Audible sound of flowing water inside covered pipe at high tide line.	Figure 33
99	12-Sep-07	17:19:00	NC 25100 54843	Very small stream, observed well above loch.	
100	12-Sep-07	17:26:49	NC 25522 54514	Burn at Achriesgill East. 2m x 80cm (ave) x 0.4 m/s, Inchard water sample no 21.	Figure 34
101	12-Sep-07	17:41:52	NC 24933 55010	Small stream 1.2m x 30cm x 0.1m/s (not rigorous), Inchard water sample no 22.	

No.	Date	Time	NGR	Description	Photograph of Area
102	12-Sep-07	18:03:31	NC 24865 55214	Septic tank at Old School Rooms B&B. End of pipe dripping. Additional ST outfall downstream and from opposite bank (photo).	Figure 35
103	12-Sep-07	18:23:19	NC 24854 55221	Inchard water sample no. 23 taken from downstream of 3 septic tank outfalls, two were dripping, the other end of pipe was in flow of stream. 1m x 5 cm x 0.4m/s.	
104	02-Oct-07		NC 23915 54161	Stream 93cm x 19cm ave depth x 0.2m/s, Inchard water sample no. 24. 24 sheep grazing in fields on either side of stream.	
105	02-Oct-07		NC 24338 53562	Stream sampled appr 100m from where it joins loch. 66cm x 17cm ave depth x 0.02m/s. Inchard water sample no. 25.Animal faeces present in immediate vicinity of stream.	
106	02-Oct-07		NC24703 53058	Stream sampled appr 100m away from loch, 74cm x 18cm x 0.2m/s. no livestock observed at time of sampling but faeces present in surrounding area.	

Photographs referenced in the table can be found attached as Figures 5-35.

General Observations Relevant to Site

As in other parts of Scotland where crofting and sheep husbandry are the predominant agricultural activity of the area, sheep populations generally double during lambing. Ewes and lambs are grazed through the summer and in September the lambs are shipped to the mainland for finishing.

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

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

Sample Results

Water and mussel samples were collected at sites marked on the maps in Figures 3 and 4. Samples were packed in cool boxes and posted to the laboratory via Royal Mail next day service. Both water and shellfish samples were analysed for *E. coli* content. Bacteriology results follow in Tables 2 and 3. Table 4 lists results for measured watercourses and discharges.

Water sampled at the site was tested for salinity using a hand-held refractometer or a battery powered salinity meter. These readings are recorded in Table 1 as salinity in parts per thousand (ppt).

Samples were also tested for salinity by the laboratory under more controlled conditions. These results are more precise than the field measurements and are shown in Table 3, given in units of grams chloride per litre of water. In sea water, six ions contribute over 99% of the dissolved salts and are present in essentially constant proportions. Of these six, chloride is the most easily measured. The following formula is used to convert lab readings in milligrams chloride ion per litre to salinity in parts per thousand (ppt): g Cl/1000 * 1.80655.

Table 2. Water Sample Results

No.	Date	Sample	Type	NGR	*E. coli* (cfu /100ml)	Salinity (ppt)
1	11/09/07	Inchard 1	Seawater	NC23553 55471	7	7.0
2	11/09/07	Inchard 2	Seawater	NC23763 55468	9	4.6
3	11/09/07	Inchard 4	Seawater	NC24473 54273	17	3.0
4	11/09/07	Inchard 5	Seawater	NC24853 53531	25	2.6
5	11/09/07	Inchard 6	Seawater	NC24882 53261	23	3.0
6	11/09/07	Inchard 7	Seawater	NC23909 54435	15	3.8
7	11/09/07	Inchard 8	Seawater	NC23359 55034	7	5.0
8	12/09/07	Inchard10	Seawater	NC24391 55214	7	4.7
9	12/09/07	Inchard 11	Seawater	NC25488 54065	9	2.2
10	12/09/07	Inchard 12	Seawater	NC24731 53089	12	0.7
11	12/09/07	Inchard 13	Seawater	NC22174 55739	20	11.1
12	12/09/07	Inchard 14	Seawater	NC22168 56208	3200	11.5
13	12/09/07	Inchard 15	Freshwater	NC22167 55924	100	-
14	12/09/07	Inchard 16	Freshwater	NC21836 56414	<100	-
15	12/09/07	Inchard 17	Freshwater	NC 22334 56073	<100	-
16	12/09/07	Inchard 18	Freshwater	NC22926 55837	500	-
17	12/09/07	Inchard 19	Freshwater	NC25616 54057	<100	-
18	12/09/07	Inchard 20	Freshwater	NC25386 52221	<100	-
19	12/09/07	Inchard 21	Freshwater	NC25522 54514	<100	-
20	12/09/07	Inchard 22	Freshwater	NC24933 55010	400	-
21	12/09/07	Inchard 23	Freshwater	NC24854 55221	800	-
22	02/10/07	Inchard 24	Freshwater	NC23915 54161	<100	-
23	02/10/07	Inchard 25	Freshwater	NC24338 53562	<100	-
24	02/10/07	Inchard 26	Freshwater	NC24703 53058	<100	-

Table 3. Shellfish Sample Results

No.	Date	Sample	Type	NGR	E. coli (mpn/ 100g)	Depth (m)
1	11/9/07	Inchard 1	Mussel	NC23553 55471	310	<1
2	11/9/07	Inchard 2	Mussel	NC23553 55471	110	5
3	11/9/07	Inchard 3	Mussel	NC23848 55250	1300	<1
4	11/9/07	Inchard 4	Mussel	NC23848 55250	2200	5
5	11/9/07	Inchard 5	Mussel	NC24473 54273	16000	<1
6	11/9/07	Inchard 6	Mussel	NC24473 54273	>18000	5
7	11/9/07	Inchard 7	Mussel	NC24853 53531	2200	<1
8	11/9/07	Inchard 8	Mussel	NC24853 53531	500	5
9	11/9/07	Inchard 9	Mussel	NC24882 53261	500	<1
10	11/9/07	Inchard 10	Mussel	NC24882 53261	310	5
11	11/9/07	Inchard 11	Mussel	NC23909 54435	310	<1
12	11/9/07	Inchard 12	Mussel	NC23909 54435	2400	5

Table 4. *E. coli* Results for Measured Watercourses and Discharges.

Sample	**NGR**	**Width (m)**	**Depth (m)**	**Flow (m/s)**	**Discharge (l/s)**	***E. coli* (cfu/100ml)**
Inchard15	NC 22167 55924				0.3	<100
Inchard17	NC 22334 56073	0.3	0.027	0.02		<100
Inchard18	NC 22926 55837	9.1	0.26	0.7		500
Inchard19	NC 25616 54057	39	0.2	0.9		<100
Inchard20	NC 25386 52221	17	1	0.8		<100
Inchard21	NC 25522 54514	2	.8	0.4		<100
Inchard22	NC 24933 55010	1.2	.3	0.1		400
Inchard23	NC 24854 55221	1	0.05	0.4		800
Inchard24	NC 23915 54161	0.93	0.19	0.2		<100
Inchard25	NC 24338 53562	0.66	0.17	0.02		<100
Inchard26	NC 24703 53058	0.74	0.18	0.2		<100

Figure 3.

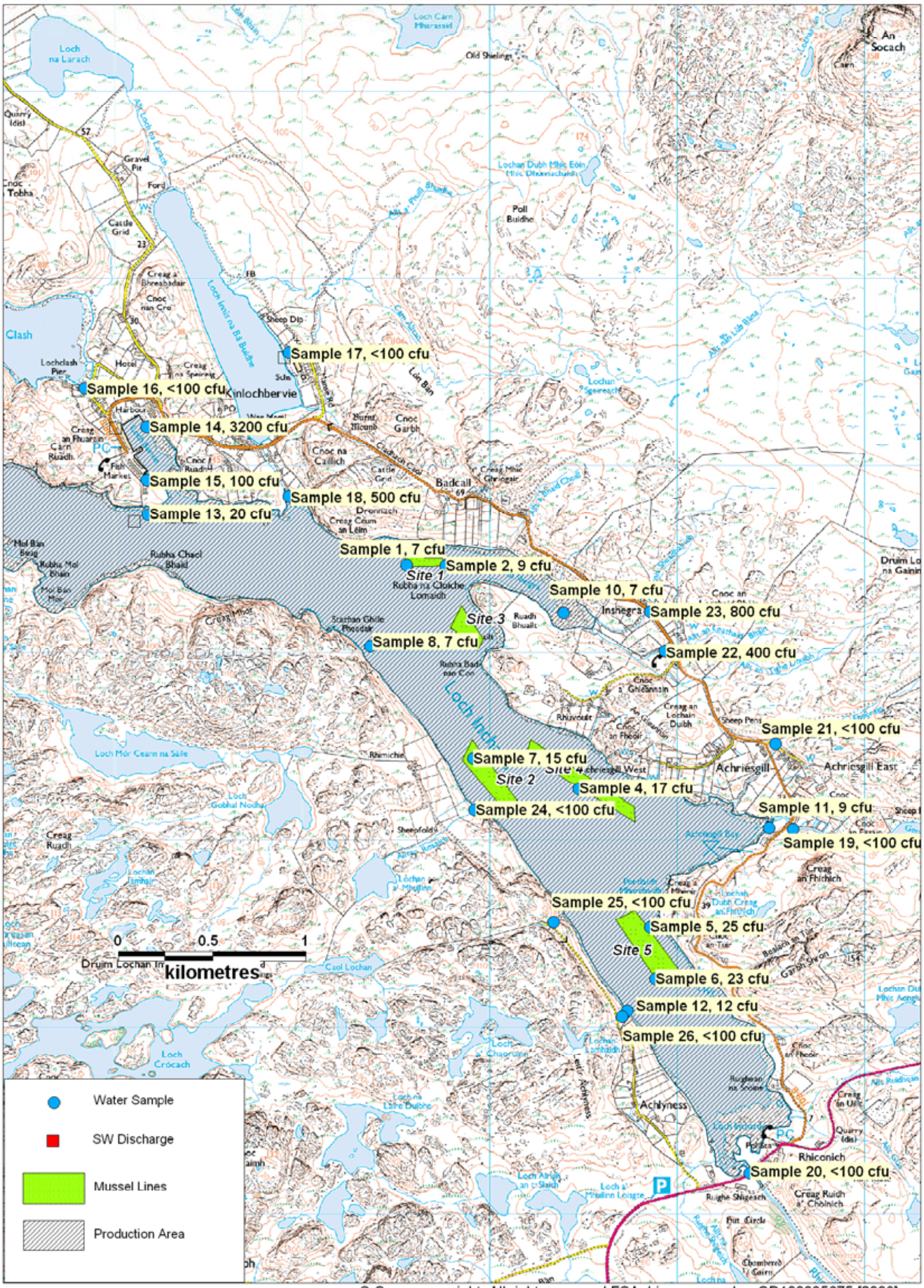
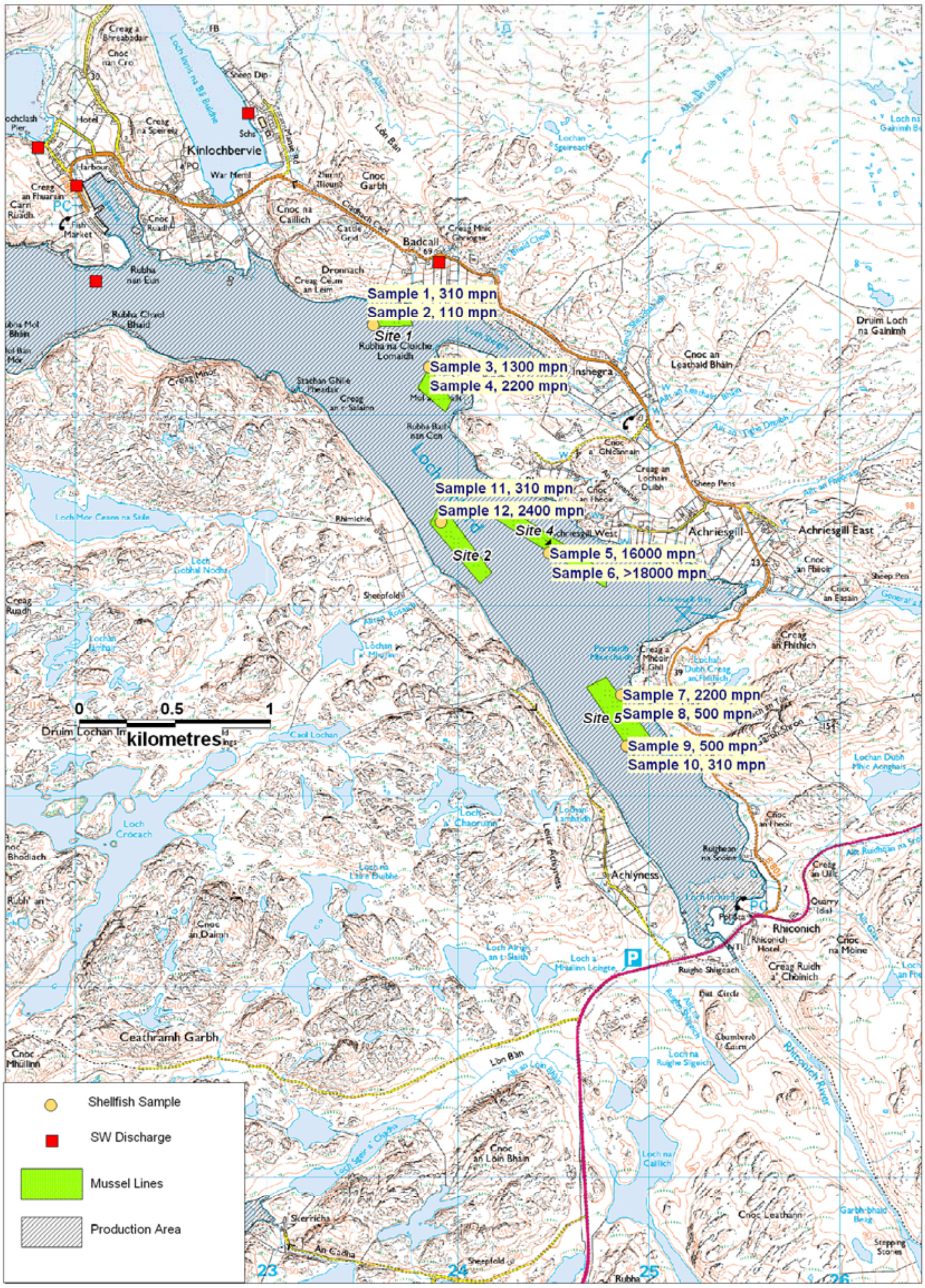

Sample 17, <100 cfu
Sample 16, <100 cfu
Kinlochbervie
Sample 14, 3200 cfu
Sample 15, 100 cfu
Sample 18, 500 cfu
Sample 13, 20 cfu
Sample 1, 7 cfu
Sample 2, 9 cfu
Site 1
Sample 10, 7 cfu
Sample 23, 800 cfu
Site 3
Sample 8, 7 cfu
Sample 22, 400 cfu
Loch Inchard
Sample 21, <100 cfu
Sample 7, 15 cfu
Site 2
Sample 4, 17 cfu
Sample 24, <100 cfu
Sample 11, 9 cfu
Sample 19, <100 cfu
Sample 25, <100 cfu
Sample 5, 25 cfu
Site 5
Sample 6, 23 cfu
Sample 12, 12 cfu
Sample 26, <100 cfu
Sample 20, <100 cfu
0 0.5 1
kilometres
Water Sample
SW Discharge
Mussel Lines
Production Area

Figure 4.


Sample 1, 310 mpn
Sample 2, 110 mpn
Site 1
Sample 3, 1300 mpn
Sample 4, 2200 mpn
Sample 11, 310 mpn
Sample 12, 2400 mpn
Site 4
Site 2
Sample 5, 16000 mpn
Sample 6, >18000 mpn
Sample 7, 2200 mpn
Sample 8, 500 mpn
Site 5
Sample 9, 500 mpn
Sample 10, 310 mpn
Kinlochbervie
Badcall
Achriesgill
Achriesgill East
Achlyness
Rhiconich
Ceathramh Garbh
0
0.5
1
kilometres
Shellfish Sample
SW Discharge
Mussel Lines
Production Area

Photographs

Figure 5. South shore of loch West of RMP.

Figure 6. View toward Badcall from just outside Loch Shiegra.

Figure 7. Habitation and livestock on North shore.

Figure 8. Looking toward shore from D. Forbes mussel lines.

Figure 9. D. Forbes mussel lines looking away from shore.

Figure 10. Croft on North shore

Figure 11. C. Morrison lines.

Figure 12. Shoreline looking across N. Ross toward Achriesgill.

Figure 13. Feed store shed on shore, looking across D. Forbes mussel lines.

Figure 14. Cliffs

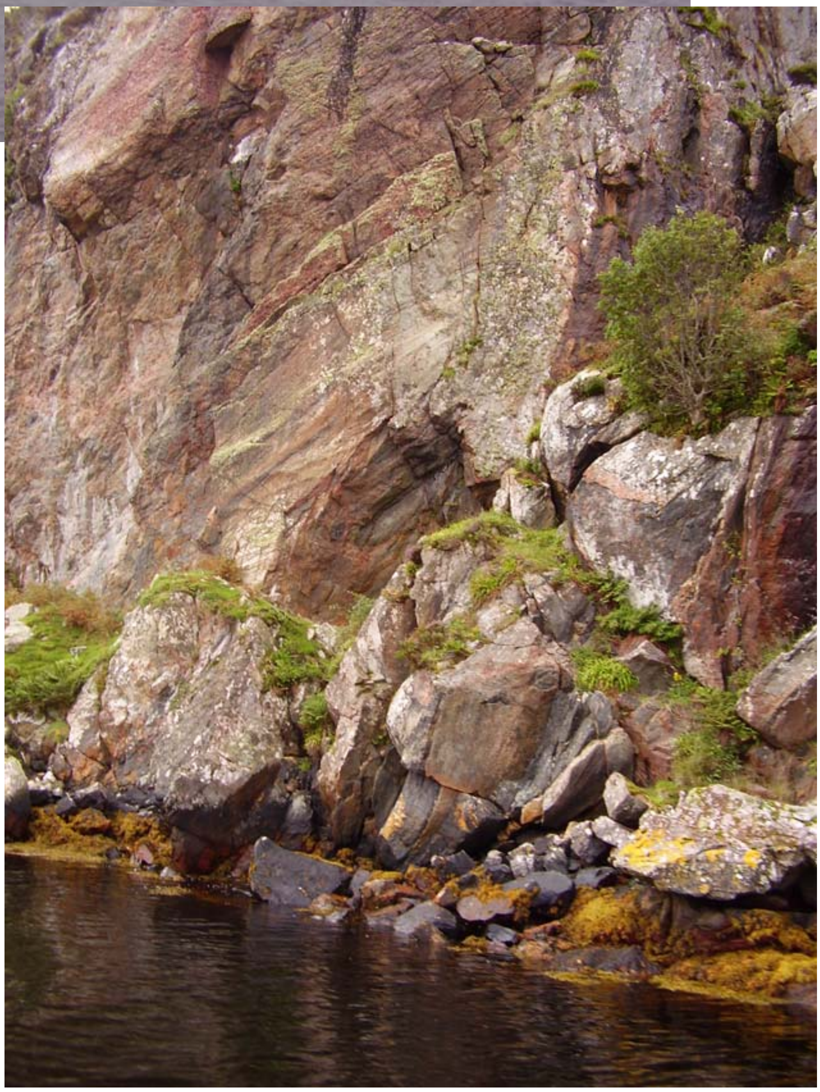


Figure 15. Service pontoons.

Figure 16. Kinlochbervie ST outfall near here.

Figure 16. Stream with litter, sample 17

Figure 17. Work boats in Kinlochbervie harbour.

Figure 18. Kinlochbervie marina.

Figure 19. Discharge pipe.

Figure 20. Discharge at base of pier, Kinlochbervie.

Figure 21.
Discharge from pier in line with Fisherman's Mission.

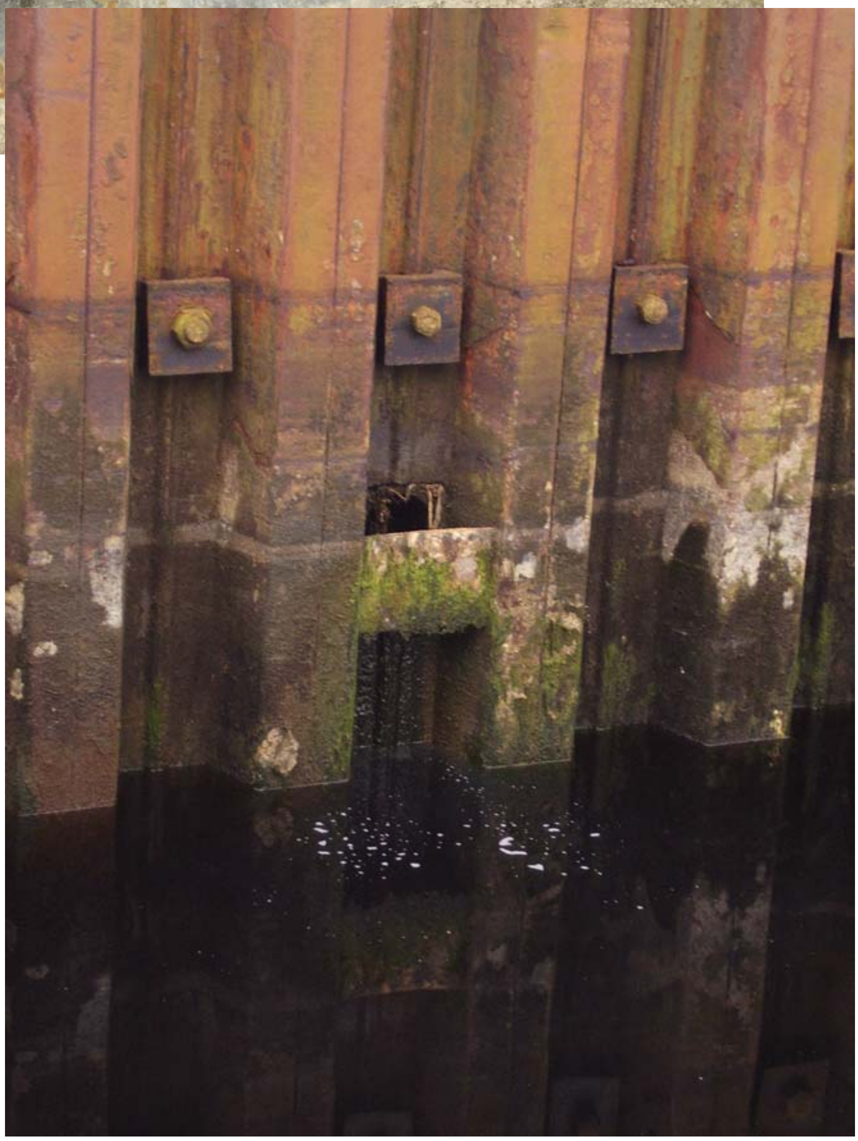


Figure 22. Discharge from near corner of pier.

Figure 23. Kinlochbervie Harbour Septic Tank.

Figure 24. Seawall where water sample 16 was taken.

Figure 25. Old pipe.

Figure 26. Kinlochbervie Manse septic tank.

Figure 27. Kinlochbervie Manse septic tank.

Figure 28. Burn adjacent septic tank.

Figure 29. Manse Road PS

Figure 30. Innis Place septic tank

Figure 31. Achriesgill river noting colour of water.

Figure 32. Rhiconich River

Figure 33. Drain at shore

Figure 34. Burn at Achriesgill East

Figure 35.
Septic pipe discharge

Sampling Plan for Loch Inchard

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
Loch Inchard	Site 4	HS 162 614	Common mussels	Long line	NC 2482 5298	22482	95298	20	5	Hand	Monthly	CNES	Anne Grant	Alan Yates

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

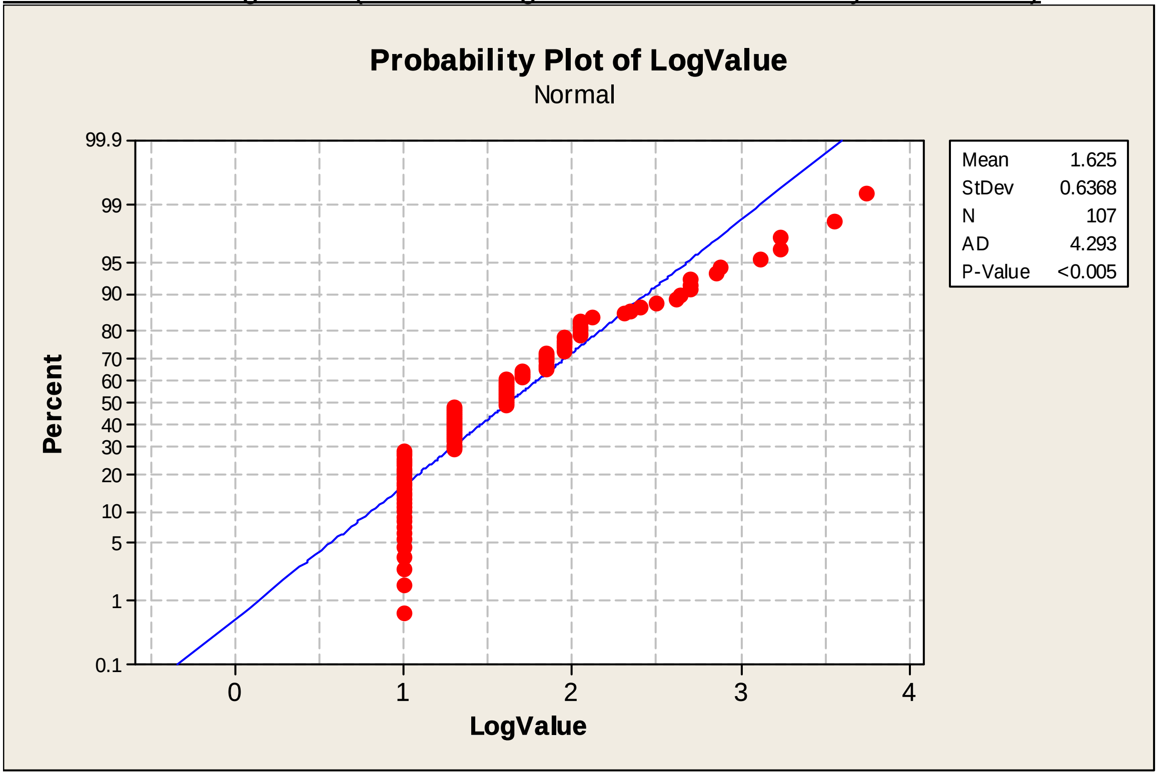
Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^8
Cow	230,000	23,600	5.4×10^9
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^8
Pig	3,300,000	2,700	8.9×10^8
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^8
Human	13,000,000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



Section 11.2 ANOVA comparison of all results by site

```
Source   DF      SS     MS     F      P
Site      4   1.649  0.412  1.02  0.402
Error   102  41.331  0.405
Total   106  42.980

S = 0.6366   R-Sq = 3.84%   R-Sq(adj) = 0.06%


Level                N    Mean   StDev
Site 1 - D. Ross    16  1.6671  0.8043
Site 2 - D. Forbes  26  1.6614  0.6528
Site 3 - Morrison   15  1.8172  0.8741
Site 4 - J. Ross    22  1.6600  0.5094
Site 5 - N. Ross    28  1.4355  0.4229

                    Individual 95% CIs For Mean Based on
                    Pooled StDev
Level               --+---------+---------+---------+-------
Site 1 - D. Ross          (------------*-----------)
Site 2 - D. Forbes           (--------*---------)
Site 3 - Morrison               (------------*------------)
Site 4 - J. Ross            (---------*----------)
Site 5 - N. Ross    (--------*---------)
                    --+---------+---------+---------+-------
                    1.25      1.50      1.75      2.00

Pooled StDev = 0.6366
```

Section 11.4.1 ANOVA comparison of results by season

```
Source   DF       SS     MS     F      P
Season    3    8.552  2.851  8.53  0.000
Error   103   34.427  0.334
Total   106   42.980

S = 0.5781   R-Sq = 19.90%   R-Sq(adj) = 17.57%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
1      23  1.3193  0.3696  (-------*-------)
2      28  2.0604  0.8012                          (-------*------)
3      32  1.6229  0.5942             (------*------)
4      24  1.4114  0.3699     (-------*-------)
                           ----+---------+---------+---------+-----
                             1.20      1.50      1.80      2.10

Pooled StDev = 0.5781


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

Individual confidence level = 98.96%


Season = 1 subtracted from:

Season    Lower  Center   Upper  --------+---------+---------+---------+-
2        0.3166  0.7411  1.1656                       (------*------)
3       -0.1088  0.3036  0.7160                (------*------)
4       -0.3481  0.0921  0.5323            (-------*------)
                                 --------+---------+---------+---------+-
                                      -0.60      0.00      0.60      1.20


Season = 2 subtracted from:

Season    Lower   Center    Upper  --------+---------+---------+---------+-
3       -0.8278  -0.4375  -0.0471      (------*-----)
4       -1.0686  -0.6490  -0.2294  (------*------)
                                   --------+---------+---------+---------+-
                                        -0.60      0.00      0.60      1.20


Season = 3 subtracted from:

Season    Lower   Center   Upper  --------+---------+---------+---------+-
4       -0.6188  -0.2115  0.1958          (-----*------)
                                  --------+---------+---------+---------+-
                                       -0.60      0.00      0.60      1.20
```

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

```
The regression equation is
log result for rain = 1.73 - 0.00019 rain prev 2 days

Predictor              Coef   SE Coef      T      P
Constant             1.7348    0.1097  15.81  0.000
rain prev 2 days  -0.000193  0.005383  -0.04  0.971


S = 0.731985   R-Sq = 0.0%   R-Sq(adj) = 0.0%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.0007	0.0007	0.00	0.971
Residual Error	61	32.6839	0.5358		
Total	62	32.6846			

Unusual Observations

Obs	rain prev 2 days	log result for rain	Fit	SE Fit	Residual	St Resid
21	86.8	1.0000	1.7180	0.4180	-0.7180	-1.19 X
29	2.2	3.7324	1.7344	0.1038	1.9980	2.76R
32	10.7	3.5441	1.7327	0.0922	1.8113	2.49R
33	10.7	3.2304	1.7327	0.0922	1.4977	2.06R
40	76.4	1.9542	1.7201	0.3636	0.2342	0.37 X
41	76.4	1.9542	1.7201	0.3636	0.2342	0.37 X
50	0.3	3.2304	1.7348	0.1089	1.4957	2.07R

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

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

Source	DF	SS	MS	F	P
rq2d	3	1.817	0.606	1.16	0.334
Error	59	30.867	0.523		
Total	62	32.685			

S = 0.7233   R-Sq = 5.56%   R-Sq(adj) = 0.76%

```
                           Individual 95% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev   -+---------+---------+---------+--------
Q1     21  1.6426  0.6264        (----------*---------)
Q2     14  1.6190  0.8225     (------------*------------)
Q3     17  2.0116  0.8537                  (-----------*-----------)
Q4     11  1.6184  0.5063   (--------------*-------------)
                            -+---------+---------+---------+--------
                           1.20      1.50      1.80      2.10
```

Pooled StDev = 0.7233

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

The regression equation is
log result for rain = 1.50 + 0.00582 rain prev 7 days

Predictor	Coef	SE Coef	T	P
Constant	1.5038	0.1631	9.22	0.000
rain prev 7 days	0.005818	0.003454	1.68	0.097

S = 0.715545   R-Sq = 4.4%   R-Sq(adj) = 2.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.4523	1.4523	2.84	0.097
Residual Error	61	31.2323	0.5120		
Total	62	32.6846			

Unusual Observations

Obs	rain prev 7 days	log result for rain	Fit	SE Fit	Residual	St Resid
1	99	1.3010	2.0786	0.2243	-0.7775	-1.14 X
2	99	1.3010	2.0786	0.2243	-0.7775	-1.14 X
21	112	1.0000	2.1548	0.2664	-1.1548	-1.74 X
29	52	3.7324	1.8051	0.0999	1.9273	2.72R
32	60	3.5441	1.8517	0.1145	1.6924	2.40R
40	100	1.9542	2.0844	0.2275	-0.1302	-0.19 X
41	100	1.9542	2.0844	0.2275	-0.1302	-0.19 X
50	30	3.2304	1.6806	0.0953	1.5498	2.19R

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

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

Source	DF	SS	MS	F	P
rq7d	3	3.569	1.190	2.41	0.076
Error	59	29.115	0.493		
Total	62	32.685			

S = 0.7025   R-Sq = 10.92%   R-Sq(adj) = 6.39%

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
Q1     11  1.4498  0.3848  (---------*----------)
Q2     20  1.6001  0.7051        (-------*-------)
Q3     18  1.7350  0.7765           (-------*--------)
Q4     14  2.1413  0.7815                    (---------*--------)
                           ----+---------+---------+---------+-----
                             1.20      1.60      2.00      2.40
```

Pooled StDev = 0.7025

Section 11.4.3 ANOVA comparison of log Result by tide size.

Source	DF	SS	MS	F	P
tide size	2	1.949	0.975	2.47	0.089
Error	104	41.031	0.395		
Total	106	42.980			

S = 0.6281   R-Sq = 4.54%   R-Sq(adj) = 2.70%

```
                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  ------+---------+---------+---------+---
Large   45  1.7831  0.6796                  (--------*--------)
Medium  33  1.5137  0.6398   (----------*----------)
Small   29  1.5053  0.5215  (----------*-----------)
                            ------+---------+---------+---------+---
                                1.40      1.60      1.80      2.00
```

Pooled StDev = 0.6281

Section 11.4.4 Regression analysis (log Result versus water temperature)

```
The regression equation is
logresult for temp = - 0.421 + 0.180 Temp


Predictor      Coef  SE Coef      T      P
Constant   -0.4209   0.4141  -1.02  0.322
Temp       0.18040  0.03772   4.78  0.000


S = 0.450493   R-Sq = 54.6%   R-Sq(adj) = 52.2%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  4.6427  4.6427  22.88  0.000
Residual Error  19  3.8559  0.2029
Total           20  8.4987


Unusual Observations

           logresult
Obs  Temp   for temp     Fit  SE Fit  Residual  St Resid
  5  14.0     3.2304  2.1047  0.1596    1.1258      2.67R

R denotes an observation with a large standardized residual.
```

Section 11.4.5 Circular-linear correlation of wind direction and log result

CIRCULAR-LINEAR CORRELATION
Analysis begun: 12 February 2008 12:17:38
Loch Inchard

Variables (& observations)	r	p
Angles & Linear (58)	0.299	0.007

Hydrographic Methods

1.0 Introduction

This document outlines the methodology used by Cefas to fulfill 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. This document collects together information common to all hydrographic assessments avoiding the repetition of information in each individual report.

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.

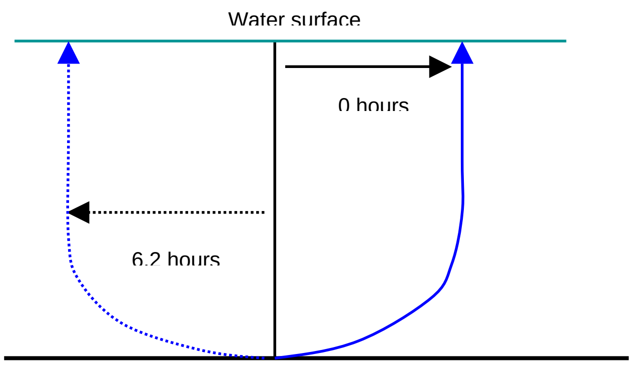
The regulations require an appreciation of the hydrography and currents within a region classified for shellfish production.

2.0 Background processes

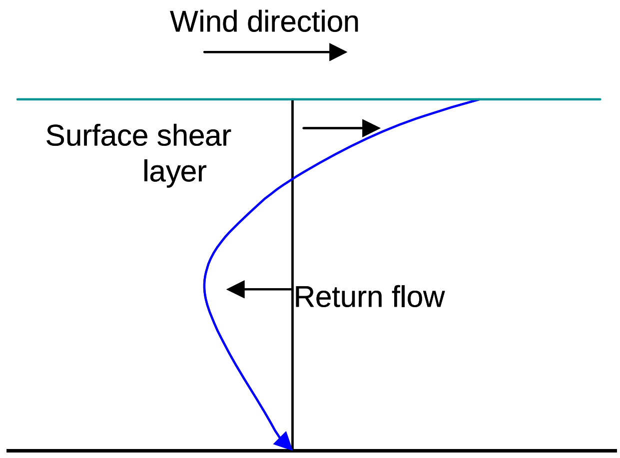
This section gives an overview of the hydrographic processes relevant to sanitary surveys.

Movement in the estuarine and coastal waters is generally driven by one of three mechanisms: 1) Tides, 2) Winds, 3) Density differences. Unless tidal flows are weak they usually dominate over the short term (~12 hours) and move material over the length of the tidal excursion. The tidal residual flow acts over longer time scales to give a net direction of transport. Whilst tidal flows generally move material in more or less the same direction at all depths, wind and density driven flows often move material in different directions at the surface and at the bed. Typical vertical profiles are depicted in figure 1. However, it should be understood that in a given water body, movement will often be the sum of all three processes.

a)



b)



c)

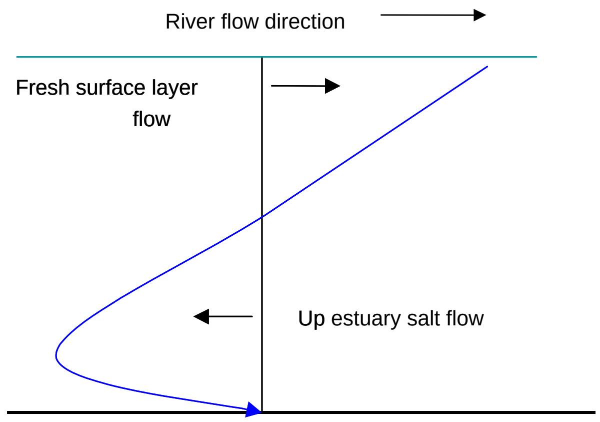


Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction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

In sea lochs, mechanisms such as “wind rows” can transport sources of contamination at the edge of the loch to production areas further offshore. Wind rows are generated by winds directed along the main length of the loch. An illustration of the waters movements generated in this way is given in Figure 2. As can be seen the water circulates in a series of cell 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.

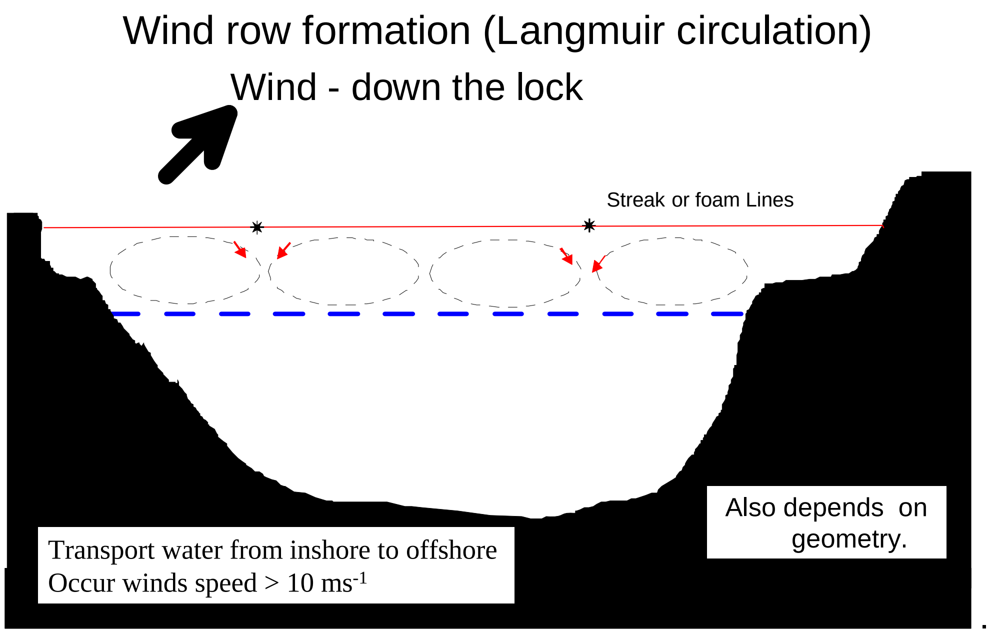


Figure 2: Schematic of wind driven 'wind row' currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

2.0 Basic Assessment

This will be applied to most sites and consists of a description of bathymetry and the tidal regime obtained from admiralty charts and tidal diamonds and is not described in detail here.

3.0 More Detailed Assessment

This is applied at the request of the regulator (FSAS) when particular circumstances apply. Typically this will be at sites where production areas regular fail or where unusual results have been reported.

3.1 Modelling approach

The Hydrotrack computer model is used. This is able to simulate depth averaged tidal currents and give some indication of wind driven currents. Model output from the model is analysed to provide information on:

- Particle paths due to tides and winds.
- Residual current patterns due to tide and winds.

Tidal forcing is a simple sinusoidal current applied at the model boundary. Where possible the assumption is made that the change in tidal phase across the boundary is negligible. Basic checking of the model is limited to the available data. In most cases this is limited to reproducing the observed tidal range. If tidal diamond or current meter observations are available, model results are checked against these.

Model calculations are carried out for five cases: tides only and tides plus winds from north, south east and west directions. The resulting winds patterns are for winds blowing constantly for 48 hours so that a steady current pattern is produced. In reality of course winds are highly variable. For each of these cases the results over the last two tidal periods are analysed to provide tidal phase and amplitude and the residual current. The paths of particles moving with the water and starting from known sources of contamination are calculated using the analysed currents. For point sources very near the shore, model release points may be moved slightly offshore out to ensure particles are caught by the prevailing current and not trapped at the release point.

For a given water body, the strength of the applied wind is chosen to ensure wind driven currents are large relative to the tidal currents so that particle paths clearly show the wind driven movement.

Although Hydrotrack calculates currents over the spatial area of a water body, it cannot calculate the vertical profile of currents. Although adequate for tidal flows this has limitations for wind and density driven systems characteristic of many sea lochs. Therefore the modelling approach is more usefully applied to tidally dominated systems or shallow regions where vertical structure may be less significant.

3.2 Non-modelling approach

In this approach the assessment requires a certain amount of expert judgment and subjectivity enters in. For all production areas, the following general guidelines are used:

1. Near-shore flows will generally align parallel to the shore.
2. Tidal flows are bi-directional, thus sources on either side of a production area are potentially polluting.
3. For tidal flows, the tidal excursion gives an idea of the likely main ‘region of influence’ around an identified pollutant source.
4. Wind driven flows can drive material from any direction depending on the wind direction. Wind driven current speeds are usually at a maximum when the wind direction is aligned with the principle axis of the loch.
5. Density driven flows generally have a preferred direction.
6. Material will be drawn out in the direction of current, often forming long thin ‘plumes’.
7. Estimates of flow speed combined with T_{90} will give a ‘region of influence’.
8. The ratio of river run-off to tidal prism gives an indication of the importance of density effects.

Many Scottish shell fish production areas occur within sea lochs. These are fjord like water bodies consisting of one or more basins, deepened by glacial activity and having relatively shallow sills that control the mixing and flushing processes. The sills are often regions of relatively high currents, while the basins are much more tranquil often containing higher density water trapped below a fresh lower density surface layer. Tidal mixing primarily occurs at the sills.

For the more detailed assessment of sea loch regions, the “Sea Loch catalogue” produced by the SMBA is used to quantify sills, volume fluxes and likely flow velocities. Because the flow is so constrained by the rapidly varying bathymetry, care has to be used in the extrapolation of direct measurements of current flow. Mean flow velocities can be estimated at the sills by using estimates of the sill area and the volume change through a tidal cycle. This in turn can be used to estimate the maximum distance travelled in a tidal cycle in the sill area. Away from the sill area, tidal velocities are general low and transport events are dominated by wind or density effects. Sea Lochs generally have a surface layer of fresher water, the extent of this depends, on freshwater input, sill depth and quantity of mixing.

In addition to movement of particles by currents, dilution is also an important consideration. Dilution reduces the effect of an individual point source although at the expense of potentially contaminating a larger area. Thus class A production areas can be achieved in water bodies area with significant faecal coliform inputs if no transport pathway exists and little mixing can occur. Conversely a poor classification might occur where high mixing causes high and permanent background concentrations arising from many weak diffuse sources.

Dilution calculations in regions with steep and variable bathymetry typical of sea lochs are extremely difficult. The following methods are applied.

For class A and B classifications, correlation with data (European Commission 1996) suggest the following water concentration need to be achieved:

Class A: 1 bacterium per 100 ml = 10^4 m^{-3}
Class B: 100 bacterium per 100 ml = 10^6 m^{-3}

3.2.1 Integrated inputs

Given *E. coli* loadings and estimates of water body volume and flushing time, the E. coli concentration averaged over the entire water body can be estimated from

$$C = S T_f / V$$

C = number *e-coli* m^{-3}
S = Sum of all loadings (number of *e-coli* per day)
T_f = Flushing time (days)
V = Water body volume (m^3)

This can then be compared with the Class A and B requirements.

3.2.2 Individual inputs

For a source with a loading M *E. coli* per second, discharging into water flowing at speed u (ms^{-1}), the number of *E. coli* per meter in the flow direction is given by M/u (*E. coli* m^{-1}). To achieve a target concentration of T, the cross sectional area that the material needs to be mixed over is given by

$$A = M/(u T)$$

Assuming an average depth for the water body this can be converted to a distance offshore. A subjective judgement can then made as to whether this is likely to occur over the relevant time scales (< 3 days). That is, will the required dilution occur quickly enough that only localised impacts would be expected? For sea lochs the assumption is made that away from the sills, mixing is likely to be quite weak.

References

European Commission 1996. Report on the equivalence of EU and US legislation for the Sanitary Production of Live Bivalve Molluscs for Human Consumption. EU Scientific Veterinary Committee Working Group on Faecal Coliforms in Shellfish, August 1996.

Glossary of terms

The following technical terms appear in the hydrographic assessment.

Bathymetry. The underwater topography given as depths relative to some fixed reference level e.g. mean sea level.
Hydrography. Study of the movement of water in navigable waters e.g. along coasts, rivers, lochs, estuaries.
Tidal period. The dominant tide around the UK is the twice daily one generated by the moon. It has a period of 12.42 hours. For nearshore so-called rectilinear tidal currents then roughly speaking water will flow one way for 6.2 hours then back the other way for 6.2 hours.
Tidal range. The difference in height between low and high water. Will change over a month.
Tidal excursion. The distance travelled by a particle over one half of a tidal cycle (roughly~6.2 hours). Over the other half of the tidal cycle the particle will move in the opposite direction leading to a small net movement related to the tidal residual. The excursion will be largest at Spring tides.
Tidal residual. For the purposes of these documents it is taken to be the tidal current averaged over a complete tidal cycle. Very roughly it gives an idea of the general speed and direction of travel due to tides for a particle over a period of several days.
Tidal prism. The volume of water brought into an estuary or sea loch during half a tidal cycle. Equal to the difference in estuary/sea loch volume at high and low water.
Spring/Neap Tides. The strongest tides in a month are called spring tides and the weakest are called neap tides. Spring tides occur every 14 days with neaps tides occurring 7 days after springs. Both tidal range and tidal currents are strongest at Spring tides.
Tidal diamonds. The tidal velocities measured and printed on admiralty charts at specific locations are called tidal diamonds.
Wind driven shear/surface layer. The top metre or so of the surface that generally moves in the rough direction of the wind typically at a speed that is a few percent (~3%)of the wind speed.
Return flow. Often a surface flow at the surface is accompanied by a compensating flow in the opposite direction at the bed (see figure 1).
Stratification. The splitting of the water into two layers of different density with the less dense layer on top of the denser one. Due to either temperature or salinity differences or a combination of both.