Scottish Sanitary Survey Project

Sanitary Survey Report
Forth Estuary: Largo Bay
FF 072
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Cefas

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Report Distribution – Forth Estuary: Largo Bay

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1. General Description

The Forth Estuary: Largo Bay production area lies on the outer part of the Firth of Forth, east of Edinburgh. It extends from the town Buckhaven in the west to Kincraig point in the east. The bay is over 10km wide and is exposed to main estuary to the south. The Fife Coastal Path passes along the shore of Largo Bay.

The shoreline is heavily populated with towns lining western half of the bay. The River Leven flows from Loch Leven into Largo Bay at the town of Leven on the west side of the bay. Methil has two industrial docks in its port, which are used primarily for transport of wood and wood pulp.

Figure 1.1 shows the location of Largo Bay in the Forth Estuary, and the main towns on the shores of the bay.

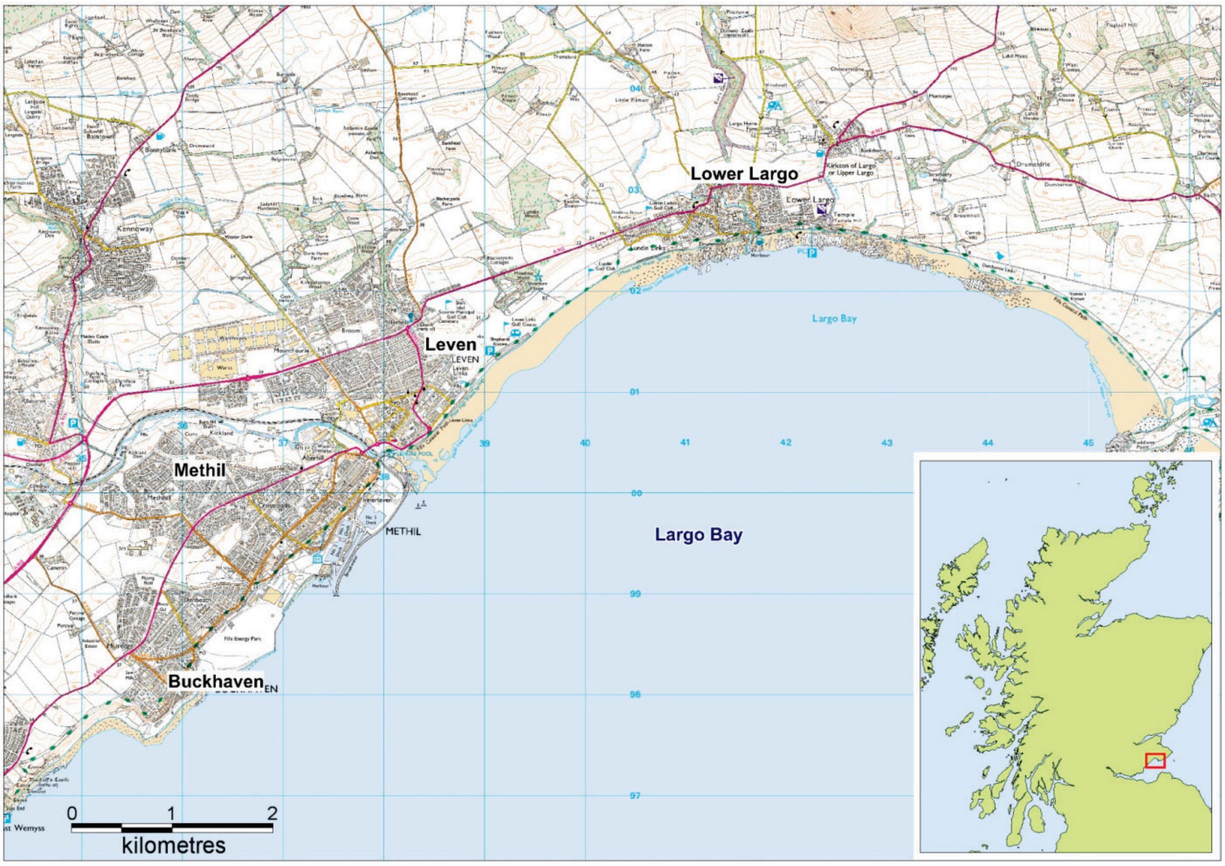


Figure 1.1 Location Forth Estuary: Largo Bay

2. Fishery

The sanitary survey at Largo Bay is being undertaken as a result of the high ranking obtained by area in a risk matrix. The high ranking was driven primarily by recent changes in classification and the large human population in the vicinity.

Table 2.1 Largo Bay production area

Production Area	Site	SIN	Species	RMP
Forth Estuary: Largo Bay	Largo Bay	FF 072 188 16	Razor clams (*Ensis* spp)	NO 445 010

The Forth Estuary: Largo Bay production area is defined as an area bounded by lines drawn between NT 4800 9933 and NT 4800 9600 and NT 3800 9600 and NT 3800 9966 extending to MHWS. The RMP is located at NO 445 010, however samples have been submitted from other locations within the production area. The area is not a designated Shellfish Growing Water (SGW).

The razor clams are gathered by divers and the area is fished by a number of different harvesters all year round, depending on weather conditions. Although razor clams are thought to be found across most of the bay, the harvesters indicated they only dive up to depths of 12 m and do not harvest from the far west side of the bay due to the sewage discharge at Methil.

Figure 2.1 shows the relative positions of the razor clam fishery, RMP and production area at Forth Estuary: Largo Bay.

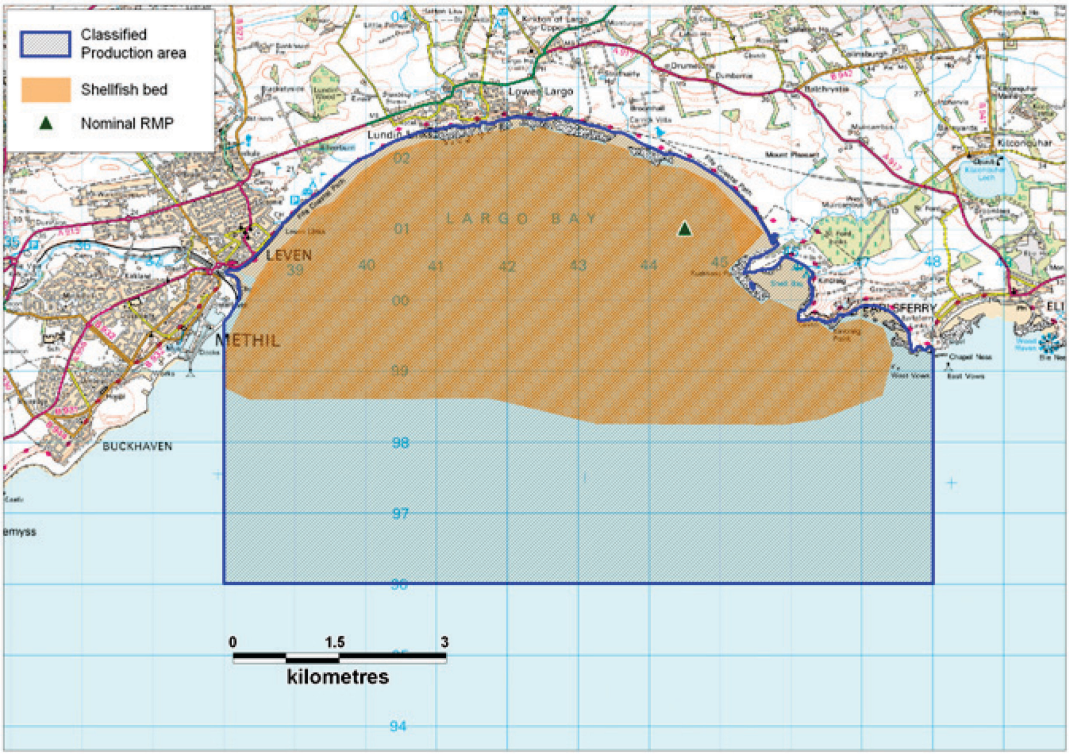
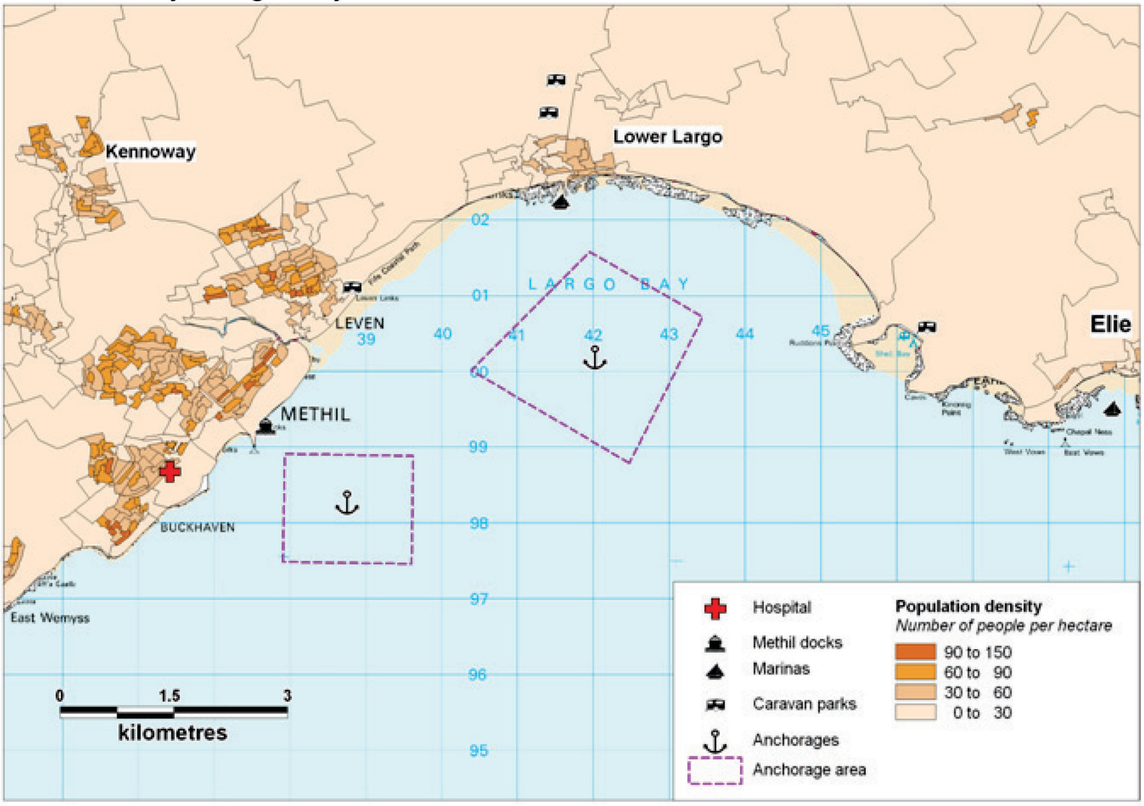


Figure 2.1 Largo Bay Razor Clam fishery

3. Human Population

Figure 3.1 shows information obtained from the General Register Office for Scotland on the population within the census output areas in the vicinity of Forth Estuary: Largo Bay. The last census was undertaken in 2001.



2001 Population Census Data, General Register Office, Scotland.

Figure 3.1 Human population surrounding Forth Estuary: Largo Bay

The towns of Leven (population 8051), Methil (population 11000) and Buckhaven (population 16391) are located along the western shore of the bay. The town of Lower Largo (population 2090) and adjacent area (population 843) are situated on the northern shore of the bay. Further east along the coast is the village of Elie and surrounding area, with a population of 1092.The total estimated resident population of the area adjacent the shores of the bay is approximately 43000.

Population density for the census output areas is represented by area colour with darker areas containing a greater number of people per hectare. The highest concentration of human population is located along the west side of the bay.

Tourism is important to the area, with the Fife Coast Path, golf courses, harbours, an equestrian centre, and other tourist amenities likely to cater to a substantial number of visitors. Three large caravan parks are located within 2 km of the coast along Largo Bay, the largest of which, at Shell Bay, accommodates up to 1600 visitors during the summer months. A number of smaller campsites and caravan parks are also present in the wider area, indicating a large seasonal influx of people.

Further tourist accommodation is available in Lower Largo and Leven. Lower Largo Bay Sailing Club is located close to the harbour and has showers, toilets and changing facilities. There are two large anchorage areas within the bay for small vessels. The largest is located towards the centre of the bay, south of Lower Largo and the second is located to the east of Methil docks.

The Largo Bay coastline is densely populated, especially on the western shore. It is therefore likely that associated faecal pollution from human sources to the shellfish bed will be high. A seasonal increase in pollution from human-related sources is expected during the summer months, as campgrounds and caravan parks reach full capacity and boating activity increases.

4. Sewage Discharges

Scottish Water identified several community septic tanks and sewage discharges for the area surrounding Forth Estuary: Largo Bay. These are detailed in Table 4.1 and mapped in Figure 4.1.

Table 4.1 Discharges identified by Scottish Water

Consent Ref No.	NGR of discharge	Discharge Name	Discharge Type	Level of Treatment	Consented flow m^3/day	Consented Design PE
WPC/E/4372 (CAR/L/1001298)	NO 4119 0217	Lundin Links SEP	Continuous	Septic tank	350	1575
CAR/L/1003099	NT 3890 9910	Levenmouth PFI – Levenmouth WWTW	Continuous	Tertiary	88500	402000
CAR/L/1001255	NO 4232 0241	Lower Largo	Continuous	Secondary	600	3000
WPC/E/4950 (CAR/L/1001145)	NT 4910 9921	Elie STW/CSO	Continuous	Septic tank	260	1200
CAR/L/1001324	NT 4910 9995 NT 4897 9977	Elie South Street WWPS	Intermittent	6mm screen	-	-
CAR/L/1001324	NT 4835 9972	Elie South Street CSO	Intermittent	-	-	-
CAR/L/1001324	NT 4853 9954	Earlsferry Cadgers Wynd SPS CSO	Intermittent	6 mm screen	-	-
-	NT 4850 9948	Earlsferry High Street CSO	Intermittent	-	-	-

- Data not given

The Levenmouth WWTW effluent receives UV tertiary treatment prior to discharge (Entec). The Elie South Street CSO plots 620 m west of the South Street WWPS overflow. As it is not clear whether this is an erroneous reference, both are included here. It is most likely that the CSO spills at the location given for WWPS outfall, which is in line with the grid reference given for the pumping station itself. Earlsferry High Street and Earlsferry Cadgers Wynd CSOs may refer to the same discharge, though the locations given differ slightly.

SEPA provided information regarding a number of discharge consents held for the area of Largo Bay. These are listed in Table 4.2 and mapped in Figure 4.1. At the time of writing this report, full details of the majority of the discharge consents were not available.

Table 4.2 Discharge consents identified by SEPA

No.	Ref No.	NGR of discharge	Discharge Type	Consented flow (DWF) m^3/d	Consented / design PE	Discharges to
1	CAR/L/1003099	NT 3890 9910	Sewage (Private) Primary	88500	402000	Largo Bay
2	CAR/R/1045296	NT 3776 9966	Sewage (Private) CSO	-	-	-
3	CAR/L/1001089	NT 3807 0041	Sewage (Private) CSO	-	-	-
4	CAR/L/1000946	NT 3819 0043	Sewage (Private) Primary	-	-	-
5	CAR/R/1062136	NT 3737 0077	Sewage (Private) Primary	-	-	-
6	CAR/R/1049403	NT 3843 0175	Sewage (Public) Primary	-	-	-
7	CAR/L/1001298	NO 4110 0210	Sewage (Public) CSO	350	1575	Largo Bay
8	CAR/S/1055349	NO 4148 0282	Sewage (Public) Secondary	-	-	-
9	CAR/L/1001255	NO 4232 0241	Sewage (Private) Primary	-	-	Largo Bay
10	CAR/R/1025113	NO 4358 0276	Sewage (Private) Primary	-	-	-
11	CAR/R/1015404	NO 4294 0319	Sewage (Private) Primary	-	-	-
12	CAR/R/1015411	NO 4294 0319	Sewage (Private) Primary	-	-	-
13	CAR/R/1015574	NO 4302 0323	Sewage (Private) Primary	-	-	-

No.	Ref No.	NGR of discharge	Discharge Type	Consented flow (DWF) m^3/d	Consented / design PE	Discharges to
14	CAR/R/1054578	NO 4308 0331	Sewage (Private) Primary	-	-	-
15	CAR/R/1046183	NO 4422 0320	Sewage (Private) Primary	-	-	-
16	CAR/R/1046505	NO 4415 0321	Sewage (Private) Primary	-	-	-
17	CAR/R/1070319	NO 4421 0317	Sewage (Private) Primary	-	-	-
18	CAR/R/1014345	NO 4422 0314	Sewage (Private) Secondary	-	-	-
19	CAR/R/1012565	NO 4418 0306	Sewage (Private) Primary	-	-	-
20	CAR/R/1029042	NO 4419 0308	Sewage (Private) Primary	-	-	-
21	CAR/R/1019473	NO 4419 0250	Sewage (Private) Primary	-	-	-
22	CAR/R/1014109	NO 4637 0360	Septic tank	-	6	Sandyfield Burn
23	CAR/R/1001486	NO 4540 0050	Sewage (Private) Primary	-	-	-
24	CAR/R/1054591	NO 4765 0019	Sewage (Private) Primary	-	-	-
25	CAR/L/1001324	NT 4850 9948	CSO	-	-	Largo Bay
26	CAR/L/1001145	NT 4910 9920	Elie STW	260	-	Largo Bay

- Data not given

Item number one in the list above refers to the Levenmouth WWTW discharge. Item number 7 refers to the Lundin Links septic tank, number 9 refers to the Lower Largo discharge and number 26, the discharge from Elie septic tank. Only discharges near to the shore at Largo Bay are included in the above list. Information regarding further private sewage discharges associated with farms and homes inland from the coastal towns was provided, however as these are mostly likely to discharge to soakaway they are not considered here.

Sewage infrastructure recorded during the shoreline survey is listed in Table 4.3 and mapped in Figure 4.1.

Table 4.3 Discharges and septic tanks observed during shoreline surveys

No.	Date	NGR	Description
1	17/08/2010	NO 4542 0047	Inspection cover for outfall pipe
2	17/08/2010	NO 4535 0050	End of outfall pipe, smells of sewage
3	17/08/2010	NO 4225 0260	Septic tanks/pumping station
4	17/08/2010	NO 4186 0256	Iron pipe from house, green algae, no flow
5	17/08/2010	NO 4156 0249	Septic tank & outfall pipe
6	17/08/2010	NO 4162 0256	6 inspection covers, 2 large green units, possible pumping station.
7	16/08/2010	NT 3888 9911	Approximate end of the Methil outfall pipe (change apparent in water)

During the shoreline survey an inspection cover and outfall pipe were located close to the Shell Bay caravan park at Ruddon's Point. It is likely that these are connected with the septic tank for the caravan park (CAR/R/1001486). A seawater sample collected at the end of the outfall pipe had a very high result of 1600 *E. coli* cfu/100 ml and would have an impact on the water quality on the far eastern side of the bay. The end of the Methil outfall pipe was recorded and a seawater sample taken from the vicinity was found to contain <10 *E. coli* cfu/100 ml.

There are two small vessel anchorage areas within the bay, small harbours at Elie and Lower Largo, and the commercial harbour at Methil docks. There are likely to be discharges from fishing boats and yachts in the area, particularly during during the summer months when there is likely to be more yachting activity in the area.

Figure 4.1 Map of discharges for Forth Estuary: Largo Bay

5. Geology and Soils

Geology and soil types were assessed following the method described in Appendix 3. A map of the resulting soil drainage classes is shown in Figure 5.1. Areas shaded yellow indicate poorly draining soils and areas that are shaded blue indicate freely draining soils. Solid grey areas indicate predominantly impermeable surfaces on built-up areas.

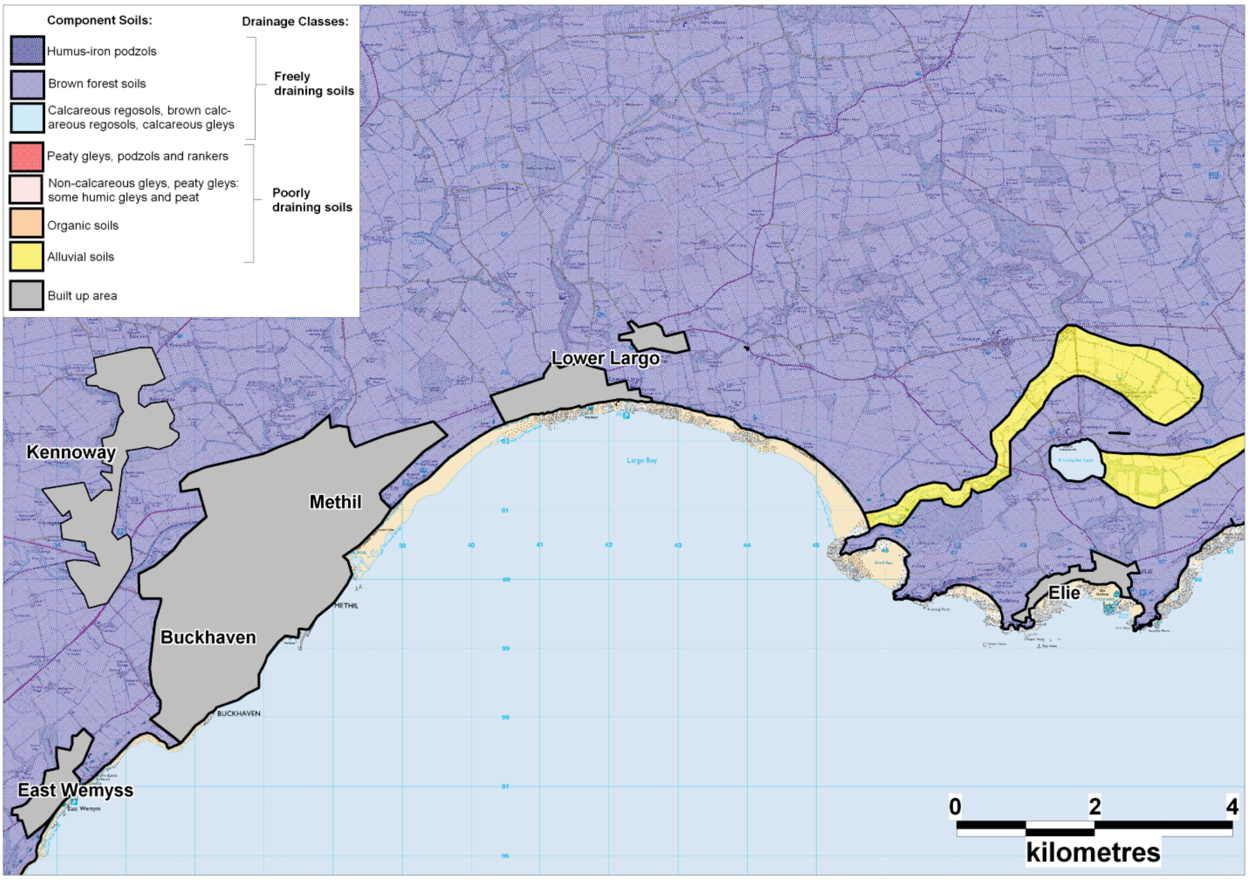


Figure 5.1 Component soils and drainage classes for Forth Estuary: Largo Bay

Two types of component soils are present in the area: brown forest soils and alluvial soils. There is also a large amount of built up area around the towns and villages. Brown forest soils cover the majority of the land area outside the towns. A small area of alluvial soil follows the course of the Cocklemill/Kilconquhar Burn to the sea west of Elie.

The potential for runoff faecally-contaminated runoff attributable to soil permeability will be lower where the brown forest soils are immediately adjacent to the fishery, intermediate where alluvial soils are present along the Cocklemill Burn, and high for built-up areas along the west shore of the bay adjacent to the fishery.

6. Land Cover

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

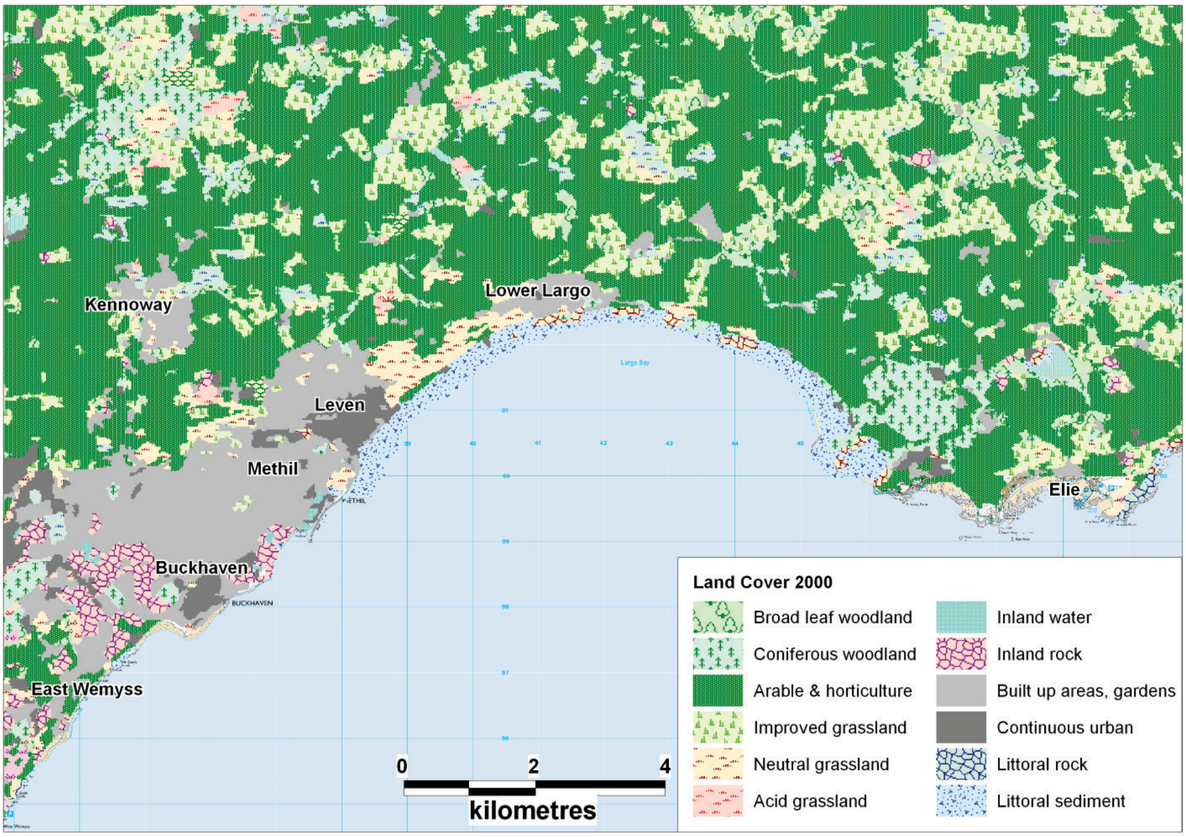


Figure 6.1 LCM2000 class land cover data for Forth Estuary: Largo Bay

The landcover present for the area around Largo Bay is largely arable and horticultural. Small patches of improved grassland, coniferous woodland, acid grassland and calcareous grassland are found interspersed throughout the area. Developed areas correspond with the major settlements in the area. There are also areas of inland rock scattered around the settlements of Methil, Buckhaven and East Wemyss.

Faecal indicator organism export coefficients for faecal coliform bacteria have been found to be highest for urban catchment areas (1.2 – 2.8×10^9 cfu km^{-2} hr^{-1}) and lower for areas of improved grassland (approximately 8.3×10^8 cfu km^{-2} hr^{-1}) and rough grazing (approximately 2.5×10^8 cfu km^{-2} hr^{-1}) (Kay *et al*. 2008). Lowest contributions would be expected from areas of woodland (approximately 2.0×10^7 cfu km^{-2} hr^{-1}). The contributions from all land cover types would be expected to increase significantly after rainfall events, however this effect would be particularly marked from improved grassland areas (roughly 1000-fold) (Kay *et al*. 2008).

Therefore, the expected contribution of faecal indicator bacteria attributable to land cover type would be highest along the west side of the bay where there is a large area of urban catchment.

7. Farm Animals

Agricultural census data to parish level was requested from the Scottish Government Rural Environment, Research and Analysis Directorate (RERAD) for Wemyss, Scoonie, Largo, Newburn and Elie parishes. Reported livestock populations for the parishes in 2009 are listed in Table 7.1. RERAD withheld data for reasons of confidentiality where the small number of holdings reporting would have made it possible to discern individual farm data. Any entries which relate to less than five holdings, or where two or fewer holdings account for 85% or more of the information, are replaced with an asterisk.

With regard to potential sources of pollution of animal origin, agricultural census data to parish level was requested from the Scottish Government. Agricultural census data was provided by the Rural Environment, Research and Analysis Directorate (RERAD) for the parishes of adjacent to Largo Bay (see Figure 7.1). Reported livestock populations for the parishes in 2009 are listed in Table 7.1. RERAD withheld data for reasons of confidentiality where the small number of holdings reporting would have made it possible to discern individual farm data. Any entries which relate to less than five holdings, or where two or fewer holdings account for 85% or more of the information, are replaced with an asterisk.

Table 7.1 Livestock numbers in parishes surrounding Largo Bay, 2009

Census area	Year	Type	Pigs	Poultry	Cattle	Sheep	Horses/ponies
Wemyss ($20.2km^2$)	2009	Holdings	0	0	*	*	*
		Numbers	0	0	*	*	*
Scoonie ($17.7km^2$)	2009	Holdings	*	*	*	*	6
		Numbers	*	*	*	*	23
Largo ($29.8km^2$)	2009	Holdings	0	*	13	6	8
		Numbers	0	*	2,081	1,230	89
Newburn ($12.2km^2$)	2009	Holdings	0	*	*	5	*
		Numbers	0	*	*	1,872	*
Elie ($8.1km^2$)	2009	Holdings	0	*	*	0	0
		Numbers	0	*	*	0	0

* Data withheld for reasons of confidentiality

Very little data on livestock numbers were available, as most of the information was withheld due to the small number of farms reporting data in each parish. From the data provided, cattle and sheep appeared to be the predominant animals in terms of total numbers. In Largo parish, the only one for which data on both cattle and sheep were provided, there were more cattle than sheep present. No data were presented on numbers of poultry, though they were kept in all but Wemyss parish.

Data on the area used for total crops and grass was provided for all parishes but Elie. Total grass and crops for the reported parishes (and percentage of total parish area) were: Wemyss 7.71 km^2 (38%), Scoonie 12.51 km^2 (71%), Largo 22.29 km^2 (75%), and Newburn 6.97 km^2 (57%). The areas given above do not include rough grazing, woodland, set-aside and fallow land, or urban areas. Given the large amount of arable land in the area, there is likely application of slurry or manure to a significant proportion of the land area inland from the urban areas, and this is likely to increase the levels of diffuse faecal pollution found in watercourses draining the area.

The Fife Ness to Elie Shellfish Growing Water report for the coast immediately east of Largo Bay (SEPA 2011), indicated that watercourses discharging to the coast in the area are subject to signficant diffuse agricultural pollution. As the land adjacent Largo Bay is subject to similar agricultural use, it is anticipated that it will be similarly impacted.

At the time of the shoreline survey, (16th – 18th August 2010), no livestock animals were observed along the coastline of Largo Bay, however the agricultural land is located well inland of the shoreline area surveyed.

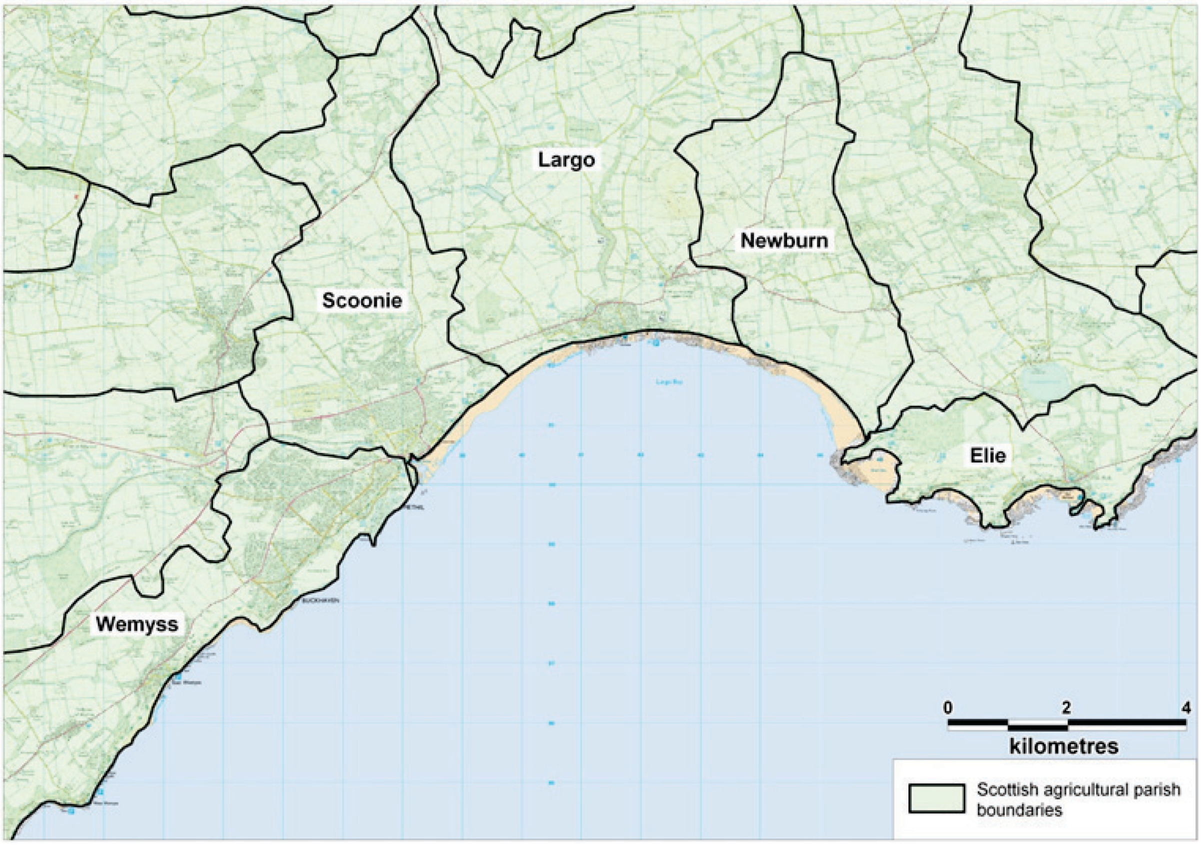


Figure 7.1 Agricultural parishes surrounding Largo Bay

8. Wildlife

A variety of conservation areas and wildlife are present in the vicinity of Largo Bay. There is one Scottish Wildlife Trust (SWT) nature reserve, one Site of Special Scientific Interest (SSSI), and one Special Area of Conservation (SAC) in the surrounding area. The Dumbarnie Links Reserve is a SWT reserve consisting of an area of calcareous dune grassland located approximately 2 km east of Lower Largo (Scottish Wildlife Trust, 2011). Herons and wading birds feed and skylarks and meadow pipits nest at the reserve. Other species common to the area include buzzards, kestrels, terns, gannets and in the winter wildfowl including long-tailed ducks, red-throated divers and scoters are present. Eider ducks are present all year round.

Fife Bird Club (Stuart Rivers, 2011) identified other important areas where wildlife is present. Ruddons Point, located on the east side of the bay is a designated SSSI salt marsh habitat and the most reliable site to observe surf scoters in Britain. Divers, grebes, seaducks, wading birds and gulls are also common in the area. Waders and gulls are commonly seen in Shell Bay,to the east of Ruddons Point. At Lower Largo, divers, grebes, seaducks are common and gulls, waders and sandpipers roost in the area. Large numbers of gulls, waders, divers, grebes and seaducks can be found on the western side of the bay, close to the disused Methil power station.

Seabird 2000 data has been provided for a 5 km radius of Largo Bay. There is one observation within this 5 km radius. Figure 8.1 plots this data and shows that adjacent to Shell Bay, 39 occupied sites of fulmars were recorded.

Marine mammals in the area include seals, common porpoises and bottlenose dolphins. Common seals are widespread along the coast of Fife. The Sea Mammal Research Unit count for common seals observed in the Fife area was 414 in 2004. Grey seals are also found in the area. During the shoreline survey 10 seals were observed close to Shell Bay. The common porpoise is reported to be widespread in the Firth of Forth (Fife Coast and Countryside Trust, 2006). Bottlenose dolphins are also common and seen all year round, especially between June to October. Approximately 40-60 bottlenose dolphins have summered off the coast of Fife every year since 1992. During the shoreline survey 10 bottlenose dolphins were observed less than 1 km offshore from Shell Bay. Other cetaceans may be present in the area however numbers and species were not investigated.

During the shoreline survey various species of wildlife were observed. In addition to the seals and dolphins, sea birds were observed along most of the coastline. At Ruddons Point approximately 35 gulls and 8 grouse were observed. At Lower Largo approximately 200 gulls and 10 ducks were observed. On the shoreline at Leven approximately 80 small sea birds and 30 gulls were observed. On the River Leven next to the disused Methil power station a further 2 ducks, 13 swans and 100 gulls were observed. It is possible that other animals including otters and other species of seabirds may be present in the area. The distribution and numbers of these species was not investigated.

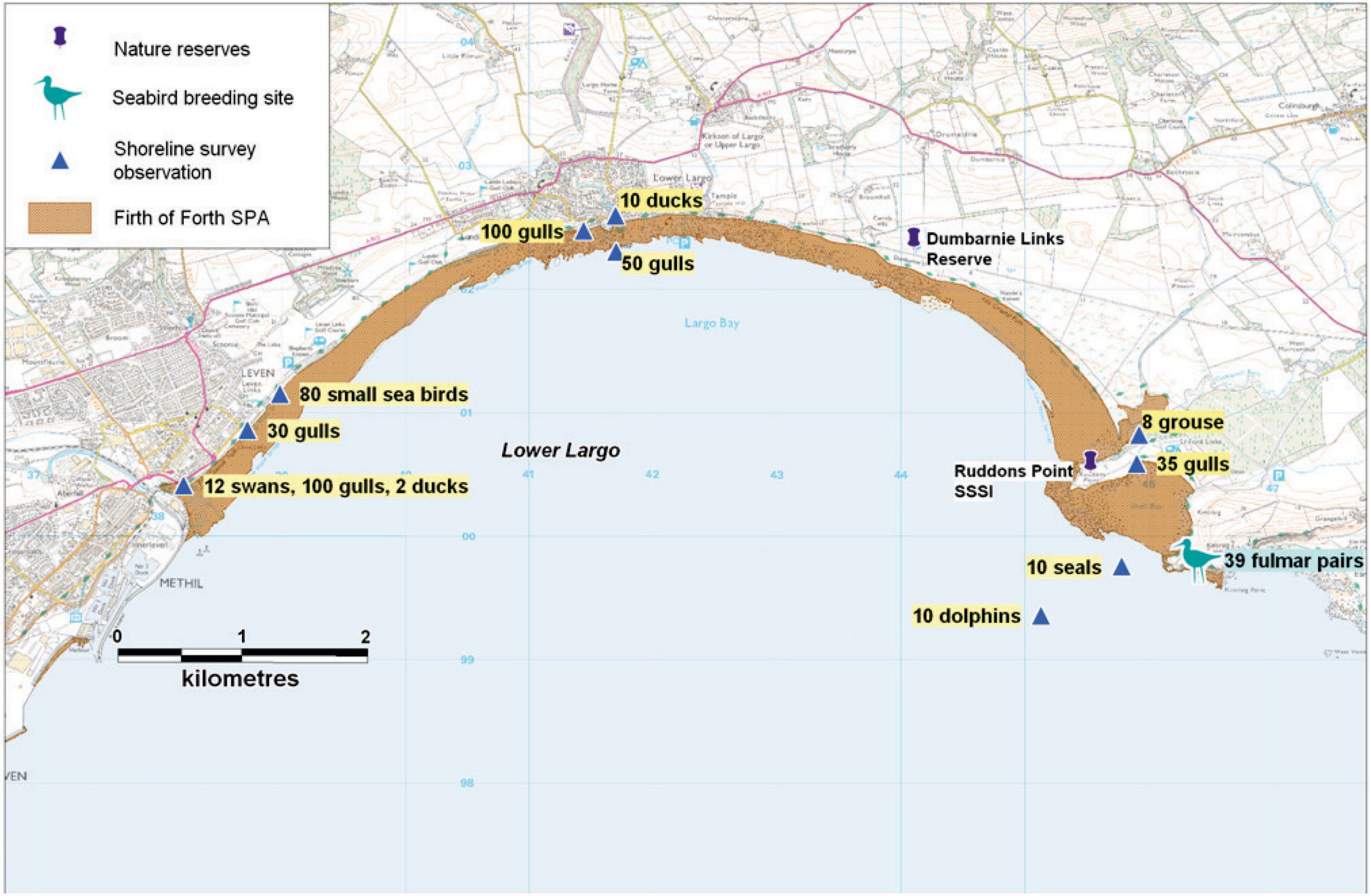


Figure 8.1 Map of wildlife and conservation areas near Largo Bay

9. Meteorological data

The nearest weather station for which the majority of records are available is located at Leven Silverburn, on the shore of the production area. Rainfall data was available for 2004-2009 inclusive apart from the months of December 2005, April 2006 and August 2009. The nearest weather station for which wind data is available is Edinburgh: Gogarbank, 33 km to the south west. Gogarbank lies approximately 6.5 km to the south of the shores of the Firth of Forth, and the Forth Estuary: Largo Bay production area lies on the north shore of the firth.

It is likely that overall wind patterns will be broadly similar at Gogarbank and Largo Bay, though local topography may lead to small, localised variation in wind speed and direction. This section aims to describe the local rain and wind patterns and how they may affect the bacterial quality of shellfish at Forth Estuary: Largo Bay.

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 and 9.2 present box and whisker plots summarising the distribution of individual daily rainfall values by year and by month. The grey box represents the middle 50% of the observations, with the median represented by a line within the box. 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 *.

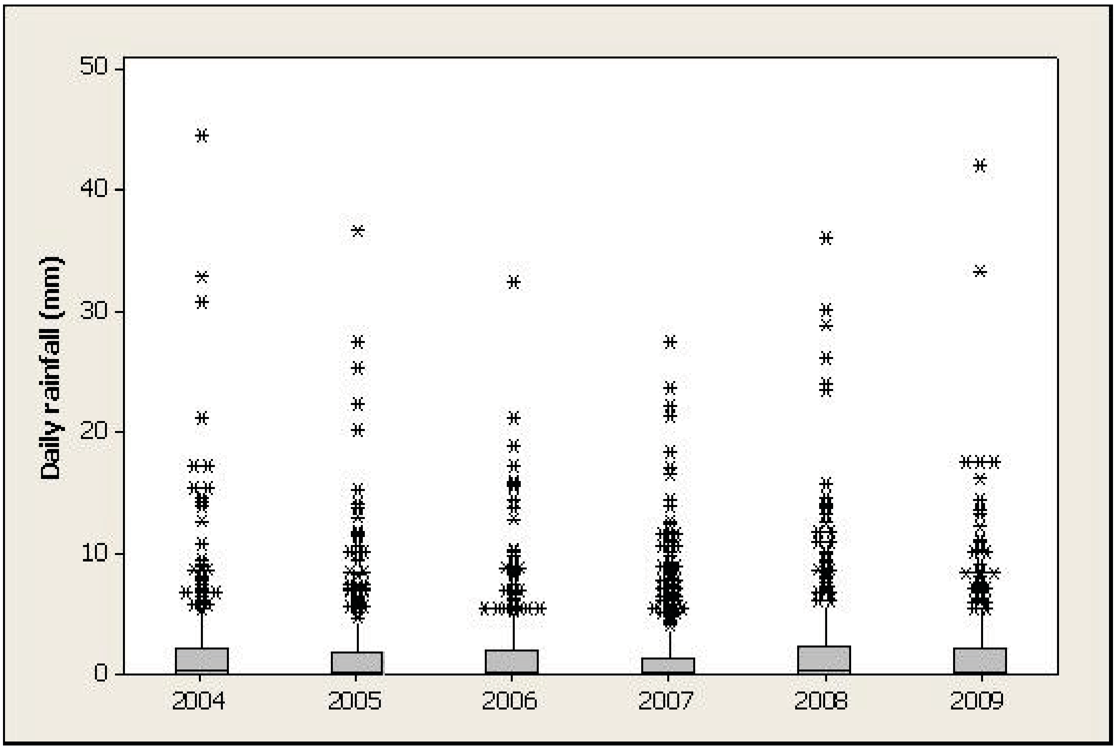


Figure 9.1 Box plot of daily rainfall values by year at Leven Silverburn, 2004-2009

Figure 9.1 shows that rainfall patterns were similar between the years presented here, with 2007 the driest and 2008 the wettest. Daily rainfall was generally very low over the period.

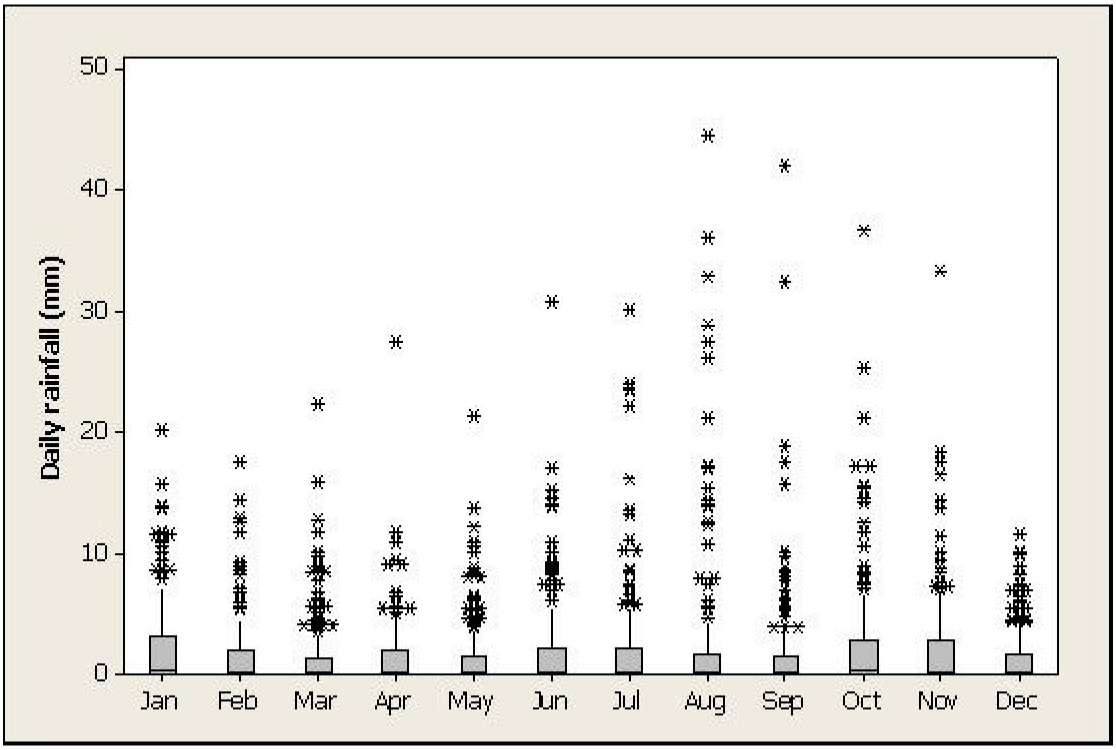


Figure 9.2 Box plot of daily rainfall values by month at Leven Silverburn, 2004-2009

Weather was generally wetter in October, November and January. The more extreme events (>30 mm in a day) occurred from June to November. For the period considered here (2003-2009), 65% of days experienced rainfall less than 1 mm, and 5% of days experienced rainfall of 10 mm or more.

In general, it is expected that levels of runoff associated with rainfall will be higher during the late autumn. However, increases in contamination carried into the bay via rainfall runoff may be higher after extreme rainfall events during the summer months when there is likely to be a greater 'first-flush' effect after periods of dry weather.

9.2 Wind

Wind data collected at the Edinburgh Gogarbank weather station is summarised by season and presented in Figures 9.3 to 9.7.

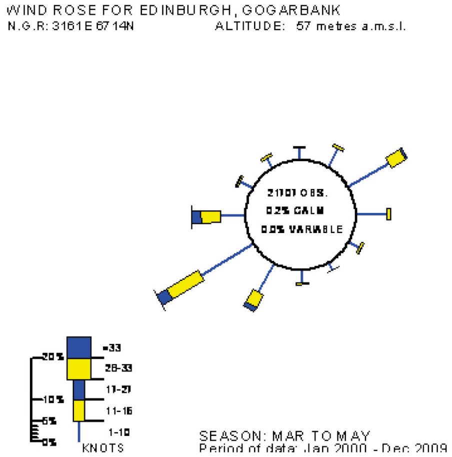


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Figure 9.3 Wind rose for Edinburgh Gogarbank (March to May)

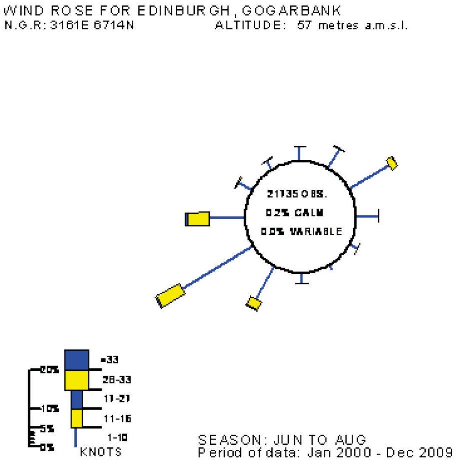

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Figure 9.4 Wind rose for Edinburgh Gogarbank (June to August)

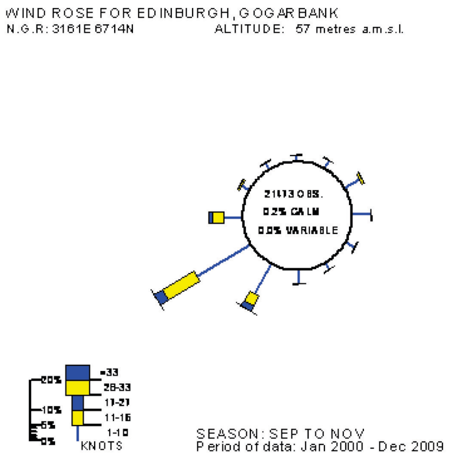

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Figure 9.5 Wind rose for Edinburgh Gogarbank (September to November)

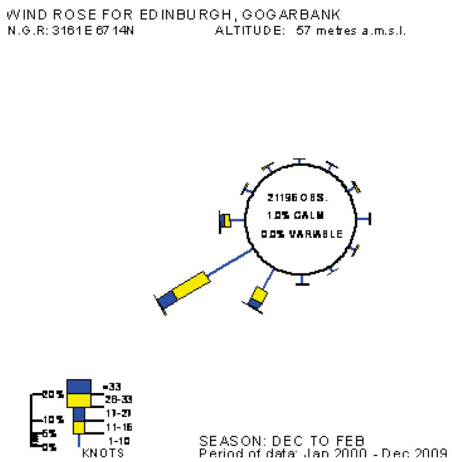

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Figure 9.6 Wind rose for Edinburgh Gogarbank (December to February)

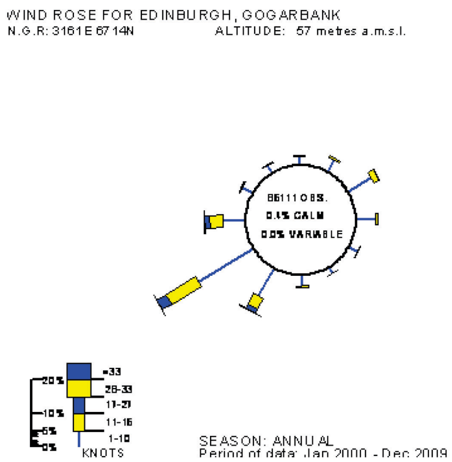

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Figure 9.7 Wind rose for Edinburgh Gogarbank (All year)

The prevailing wind direction at Edinburgh: Gogarbank is from the south west. Overall patterns appear to be heavily skewed along the south west-north east axis. Presumably this is due at least in part to local topography. There is a higher occurrence of north easterly winds during the spring and summer. Winds are generally lightest in the summer and strongest in the winter, but seasonal differences in wind strength are not particularly marked.

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. Therefore strong winds may significantly alter the pattern of surface currents at Largo Bay. Strong winds may affect tide height depending on wind direction and local hydrodynamics. A strong wind combined with a spring tide may result in higher than usual tides, which will carry accumulated faecal matter from livestock, in and above the normal high water mark, into the production area. Largo Bay is exposed to the south and southwest, therefore winds from this direction would tend to drive surface currents toward the northeastern side of the bay. A strong southwesterly wind will also result in increased wave action in the eastern side of Largo Bay, which may resuspend any organic matter settled in the substrate.

10. Current and historical classification status

Forth Estuary: Largo Bay was first given a provisional classification for razor clams (*Ensis* spp) in 2001-2002 under SIN FF0301. No classification records were available for this area for 2003. It was next given a full classification in 2004 for surf clams (*Spisula solida*).

Table 10.1 Forth Estuary: Largo Bay, razor clams

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	b	b	b	b	b	b	b	b	b	b	b	b
2002	b	b	b	b	b	b	b	b	b	b	b	b
2003	Not Classified											
2004	Not Classified											
2005	B	B	B	B	B	B	B	B	B	B	B	B
2006	B	B	A	A	B	B	B	B	B	B	B	B
2007	B	B	A	A	A	A	A	A	A	B	B	B
2008	B	B	A	B	A	A	B	B	B	B	B	B
2009	B	B	B	A	A	A	A	A	A	B	B	B
2010	B	B	B	A	A	A	A	A	A	A	A	A
2011	B	B	B									

Lower case denotes provisional classification

Table 10.2 Forth Estuary: Largo Bay, surf clams

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	B	B	B	B	B	B	B	B	B	A	B	B
2005	Not Classified											
2006	B	A	A	B	B	B	B	B	B	B	B	B
2007	B	A	A									

Lower case denotes provisional classification

Months with A classification have tended to be from March onward for razor clams and February and March for surf clams. However, there has been much more limited history on surf clams.

11. Historical *E. coli* data

11.1 Validation of historical data

All shellfish samples taken Largo Bay from the beginning of 2002 up to the 11th May 2010 were extracted from the database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data.

Three surf clam samples had no sampling location recorded, and so were removed from the analysis. Three razor clam samples had reported sampling locations that fell about 47 km outside the production area so were removed from the analysis. Thirteen reported sampling locations had the wrong two letter prefix to their grid references, and these were corrected.

All samples were received by the testing laboratory within two days of collection. One mussel sample had an invalid test result and so could not be used. Three razor clam samples had the result reported as <20, and were assigned a nominal value of 10 for statistical assessment and graphical presentation, and one razor clam sample had a result of >18000, and this was adjusted to 36000.

All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intravalvular fluid.

11.2 Summary of microbiological results

A summary of all sampling and results is presented in Table 11.1 by species. A small number of common mussel, venus clam and common cockle samples were reported for Largo Bay in 2004-2007. However, due to the very small numbers of samples involved, these are not considered further in this report.

Table 11.1 Summary of historical sampling and results

Sampling Summary		
Production area	**Forth Estuary: Largo Bay**	**Forth Estuary: Largo Bay**
Site	Largo Bay	Largo Bay
Species	Razor clams	Surf clams
SIN	FF-072-188-16	FF-072-188-19
Location	25 locations	13 locations
Total no of samples	55	16
No. 2002	3	1
No. 2003	0	5
No. 2004	0	2
No. 2005	12	6
No. 2006	7	2
No. 2007	13	0
No. 2008	8	0
No. 2009	10	0
No. 2010	2	0
Results Summary		
Minimum	<20	40
Maximum	>18000	2400
Median	160	220
Geometric mean	148	252
90 percentile	500	1200
95 percentile	715	1580
No. exceeding 230/100g	18 (33%)	7 (44%)
No. exceeding 1000/100g	1 (2%)	3 (19%)
No. exceeding 4600/100g	1 (2%)	0 (0%)
No. exceeding 18000/100g	1 (2%)	0 (0%)

Due to the limited numbers of surf clam samples, more detailed analyses of temporal, seasonal and environmental effects were only carried out for razor clams. The range of results indicates that this area is occasionally subject to high levels of faecal contamination.

11.3 Overall geographical pattern of results

As there is little evidence that razor clams and surf clams accumulate faecal indicator bacteria at different rates, for the purposes of assessing any geographic variation in results, the two species are considered together. Figure 11.1 presents a thematic map of log *E. coli* result by sampling location for razor clams and surf clams combined.

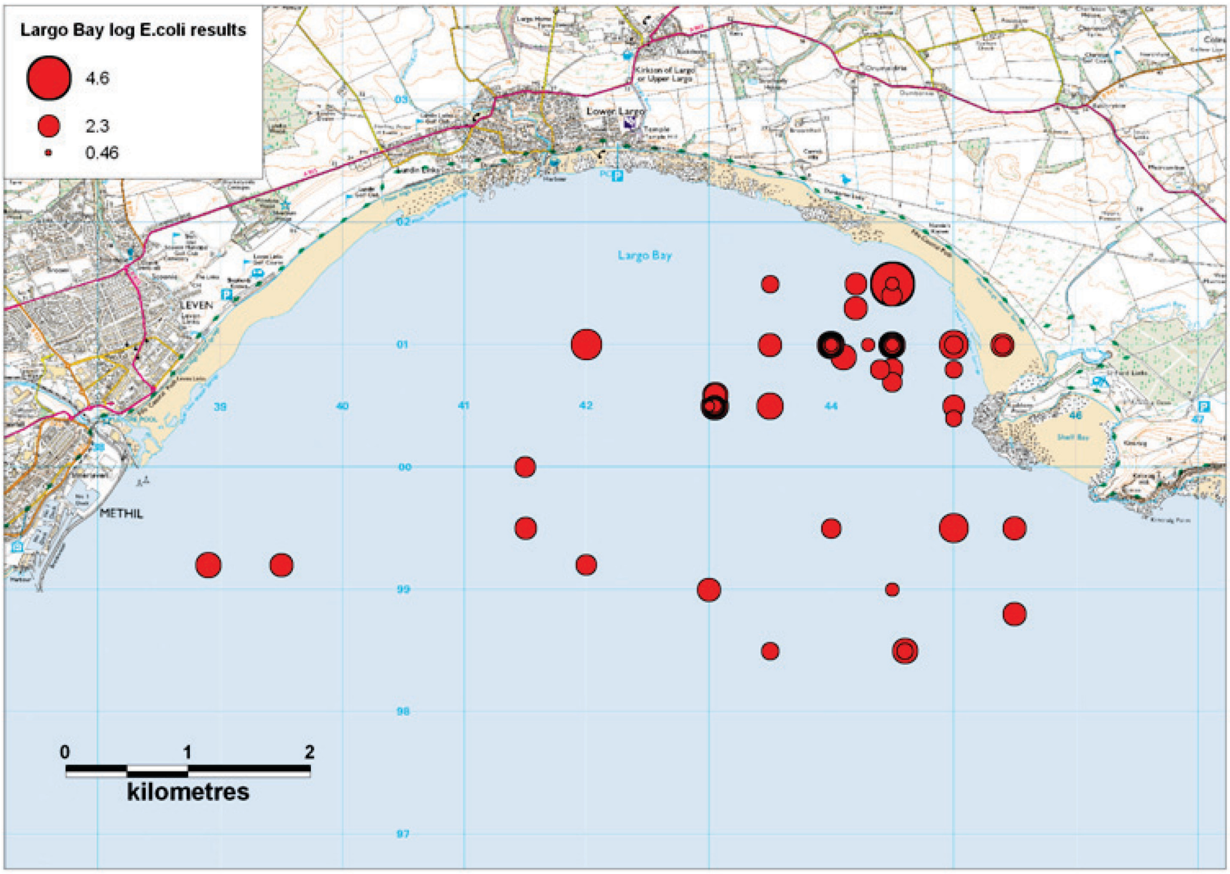

Figure 11.1 Map of geometric mean *E. coli* result by sampling location

No obvious geographical patterns are apparent in Figure 11.1. Most samples were taken near the eastern shore of the bay.

11.4 Overall temporal pattern of results

Figure 11.3 presents a scatter plot of individual razor clam results against date, fitted with a loess line, which stands for 'locally weighted regression scatter plot smoothing'. At each point in the data set an estimated value is fit to a subset of the data, using weighted least squares. The approach gives more weight to points near to the x-value where the estimate is being made and less weight to points further away. In terms of the monitoring data, this means that any point on the loess line is influenced more by the data close to it (in time) and less by the data further away. The trend line helps to highlight any apparent underlying trends or cycles.

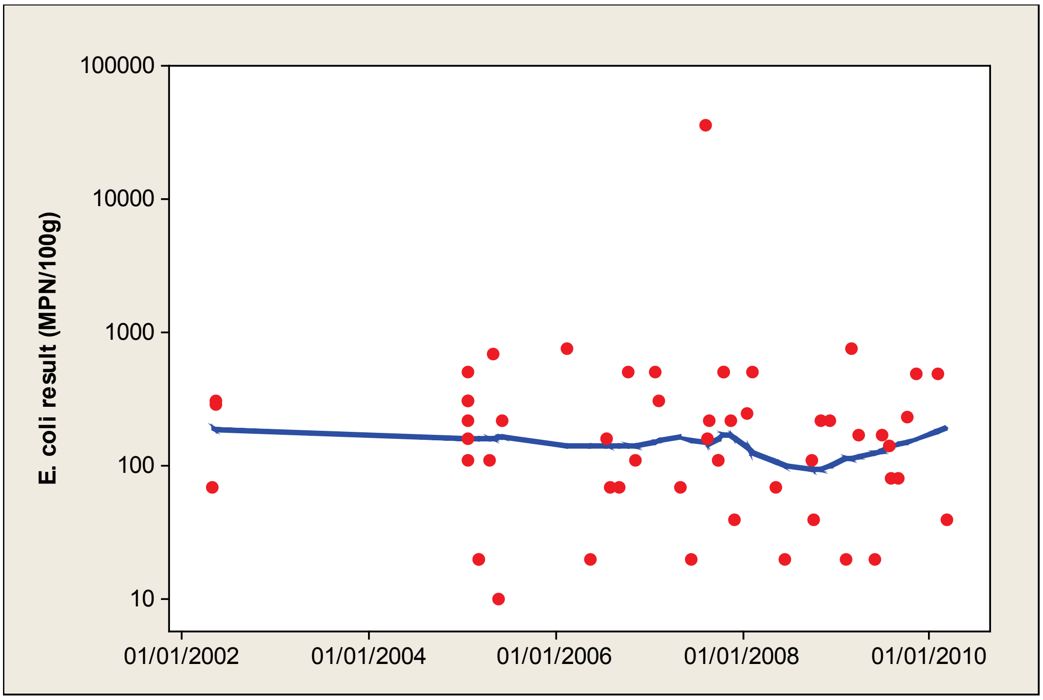

Figure 11.2 Scatterplot of *E. coli* results by date with loess line (Razor clam)

No overall trends or cycles are apparent in Figure 11.3.

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 a scatterplot of *E. coli* result by month, overlaid with a loess line to highlight any trends.

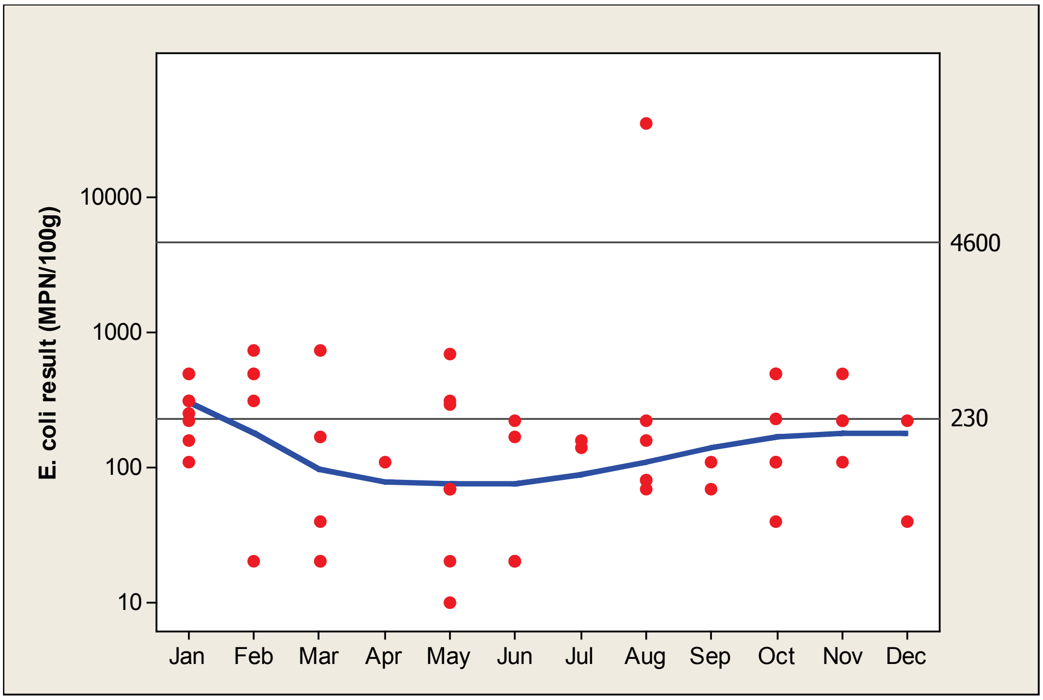

Figure 11.3 Scatterplot of results by month (Razor clam)

No strong seasonal pattern is apparent in Figure 11.4, although results do appear to be slightly higher on average during the winter, with results of over 230 mainly occurring from October to May. Months in which no results above 230 MPN/100 g tended to be months with fewer than four samples.

For statistical evaluation, seasons were split into spring (March - May), summer (June - August), autumn (September - November) and winter (December - February).

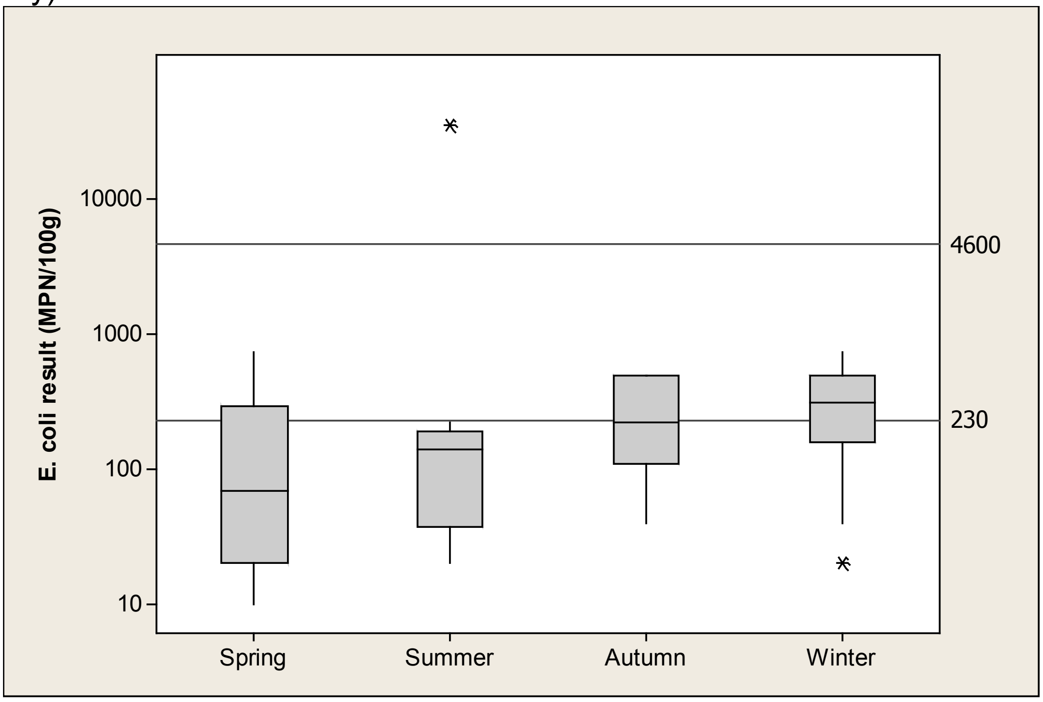

Figure 11.4 Boxplot of result by season

No significant difference was found between results by season (One-way ANOVA, p=0.226, Appendix 6).

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 at Leven Silverburn, on the shore of the production area. Rainfall data was purchased from the Meteorological Office for the period 1/1/2003 to 31/12/2009 (total daily rainfall in mm). Figure 11.6 presents a scatterplot of *E. coli* results against rainfall in the previous two days. A Spearman's Rank correlation was carried out between results and rainfall.

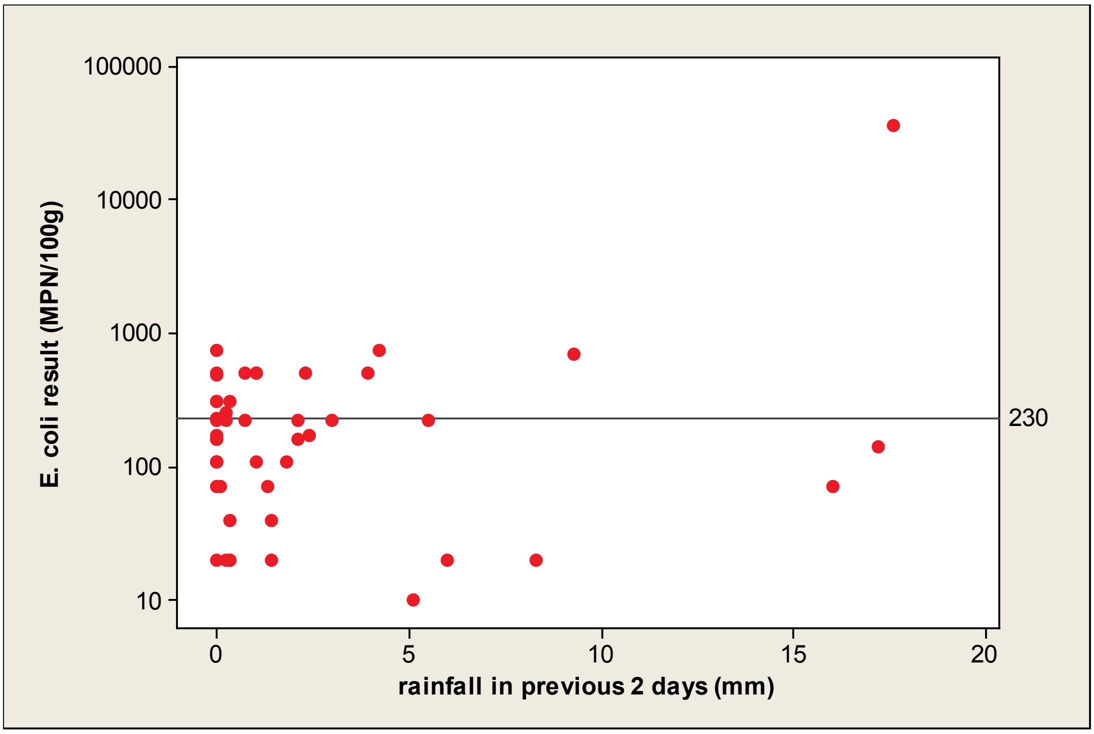

Figure 11.5 Scatterplot of result against rainfall in previous 2 days

No significant correlation was found between *E. coli* result and rainfall in the previous 2 days (Spearman's rank correlation=0.003, p>0.25, Appendix 6).

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.

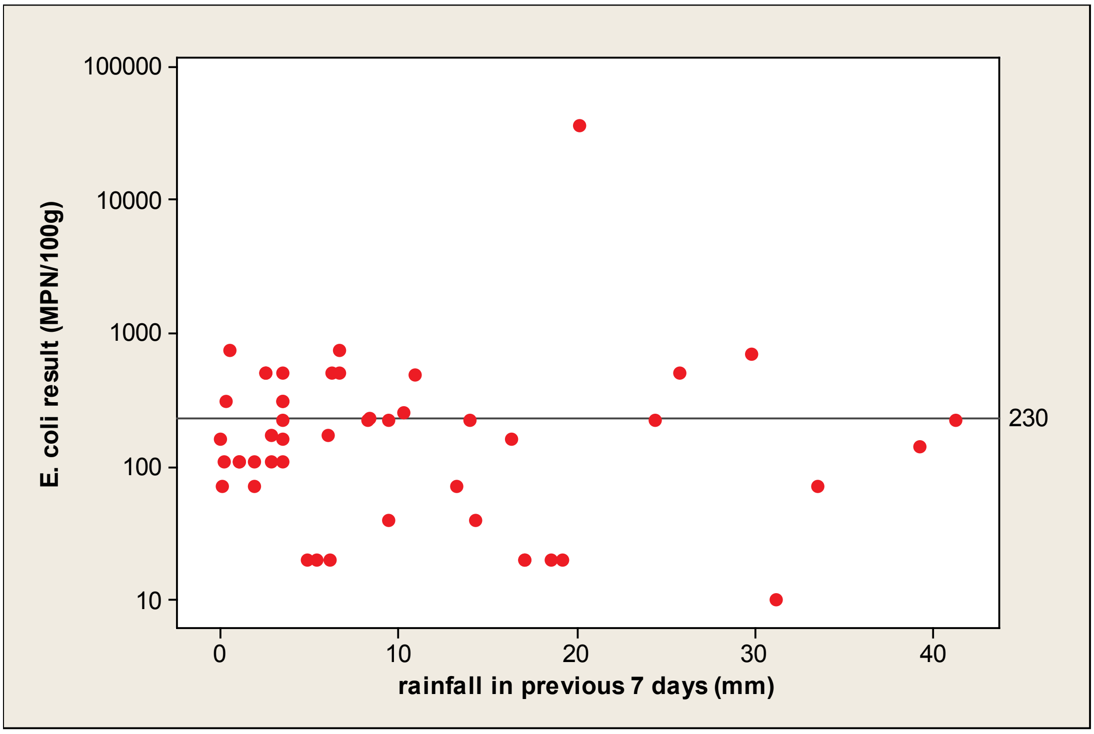

Figure 11.6 Scatterplot of result against rainfall in previous 7 days

No significant correlation was found between *E. coli* result and rainfall in the previous 7 days (Spearman's rank correlation= -0.088, p>0.25, Appendix 6).

11.6.2 Analysis of results by tidal height and state

Spring/Neap tidal cycle

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 area. Figure 11.8 presents a polar plot of $\log_{10}$ *E. coli* results on the lunar spring/neap tidal cycle. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of under 230 *E. coli* MPN/100g are plotted in green, those between 230 and 1000 *E. coli* MPN/100g are plotted in yellow, and those over 1000 *E. coli* MPN/100g are plotted in red. 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.

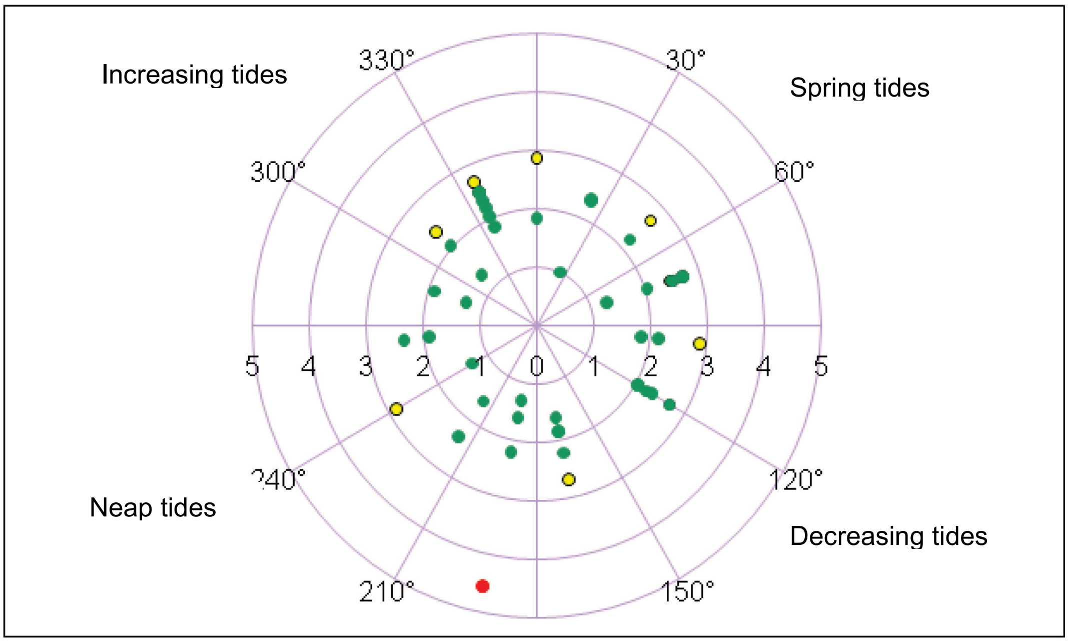

Figure 11.7 Polar plot of $\log_{10}$ *E. coli* results on the spring/neap tidal cycle

A weak correlation was found between *E. coli* results and the spring/neap cycle (circular-linear correlation, r=0.258, p=0.031, Appendix 6) suggesting that the results were not entirely random with respect to this tidal cycle, but the correlation was weak and no obvious patterns are apparent in Figure 11.8.

High/Low tidal cycle

Direction and strength of flow around the production areas 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 some shellfish species 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. Figure 11.8 presents a polar plot of log_{10} *E. coli* results on the lunar high/low tidal cycle. High water is at located 0º and low water at 180º. Again, results of under 230 *E. coli* MPN/100g are plotted in green, those between 230 and 1000 *E. coli* MPN/100g are plotted in yellow, and those over 1000 *E. coli* MPN/100g are plotted in red.

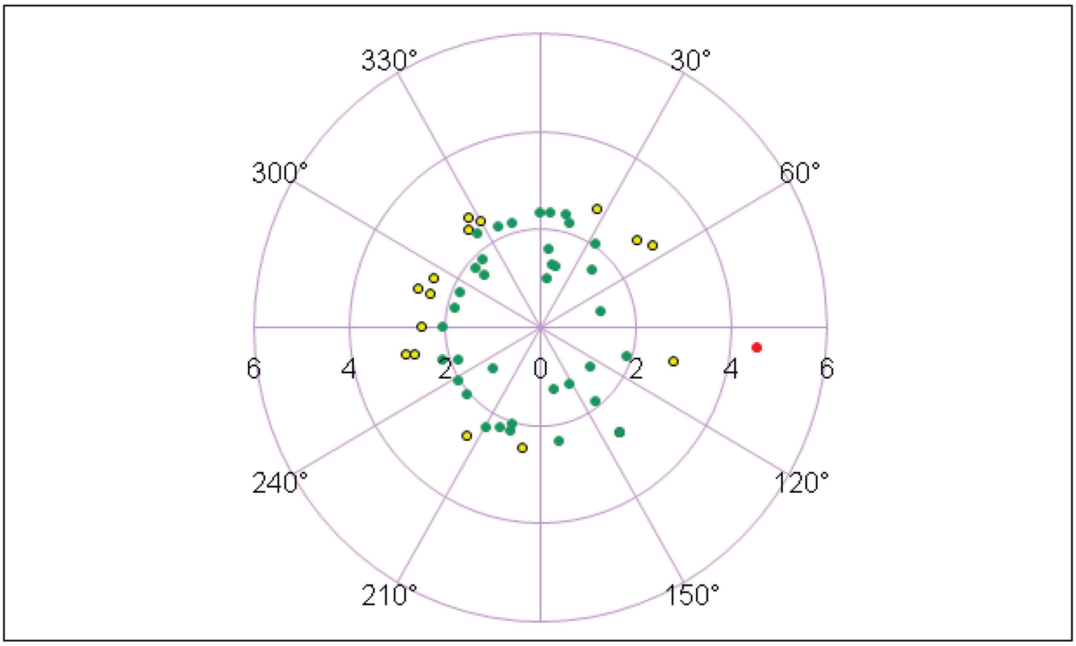

Figure 11.8 Polar plot of log_{10} *E. coli* results on the high/low tidal cycle

No significant correlation was found between *E. coli* results and the high/low tidal cycle (circular-linear correlation, r=0.047, p=0.891, Appendix 6).

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. Water temperature was not recorded on any razor sampling occasions however, so a comparison with *E. coli* results was not possible for this area.

11.6.4 Analysis of results by salinity

Salinity will give a direct measure of freshwater influence, and hence freshwater borne contamination at the site. Salinity was only recorded on one razor sampling occasion however, so a comparison with *E. coli* results was not possible for this area.

11.6.5 Evaluation of results over 1000 *E. coli* MPN/100g (razor clam)

Of the razor clam samples, only one gave a result of over 1000 *E. coli* MPN/100g. Details of this sample are presented in Table 11.2.

Table 11.2 Historic *E. coli* sampling results over 500 *E. coli* MPN/100g

Collection date	*E. coli* (MPN/100g)	Location	2 day rainfall (mm)	7 day rainfall (mm)	Water Temp (ºC)	Salinity (ppt)	Tidal state (high/low)	Tidal state (spring/neap)
07/08/2007	>18000	NO 445 015	17.6	20.1	*	*	Neap	Ebb

The sample was taken towards the eastern end of the bay, although it must be noted that sampling effort was most concentrated there. It was taken in August following a heavy, 2-day rainfall event on an ebbing neap tide

11.7 Summary and conclusions

Samples of razors (55), surf clams (16), mussels (6), venus clams (5), and cockles (1) have been submitted from this production area since 2002. Due to the low sample numbers for some of these species, geographical analyses were only carried out for razors and surf clams, and more detailed analyses of temporal patterns and relationships with environmental variables were only carried our for razors.

No geographic patterns were obvious for either razors or surf clams when sample results were thematically mapped. No overall temporal trends were apparent over the years for razors. No significant seasonal pattern was found for razors, although a slight tendency for higher results during the colder months was noted.

No correlation between razor results and either 2 day or 7 day preceding rainfall, although it was noted that the highest overall razor result by far was taken following a high 2 day rainfall event. A weak correlation was found between razor results and the spring neap tidal cycle, but no strong pattern was seen when this data was plotted. No correlation was found between *E. coli* results and the high/low tidal cycle.

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.

11.8 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 within the last three years for razors, the only species for which it is currently classified.

12. Designated Shellfish Growing Waters Data

Largo Bay is not a designated shellfish growing water, though the near-shore waters immediately to the east, from Elie to Fife Ness, are designated. The monitoring point identified on the map in the Shellfish Growing Water report lies 3.7 km east of the eastern boundary of the Largo Bay production area, on the other side of the point at Elie. Monitoring data was only available for this location through 2005. Therefore, due to the distance to the monitoring point and the relatively old data available the SGW monitoring results are not considered further here. Other aspects of the SGW report have been considered in other sections of this report.

13. River Flow

There are no gauging stations on watercourses entering Largo Bay itself. There are a number of gauging stations on the River Forth or its tributaries above the tidal limit of the Forth estuary, and three gauging stations on watercourses discharging to the southern side of the Firth of Forth. However, while these watercourses may contribute to background *E. coli* levels within the wider Firth, including Largo Bay, they are very unlikely to result in differences in *E. coli* levels across the shellfish bed within the bay.

The watercourses listed in Table 13.1 were measured and sampled during the shoreline survey. The weather was dry at the time of the survey but there had been heavy rain during the preceding week. The locations are shown on the map presented in Figure 13.1. Where the bacterial loading is labelled on the map, the scientific notation is written in digital format, as this is the only format recognised by the mapping software. So, where normal scientific notation for 1000 is 1 x 10^3, in digital format it is written as 1E+3.

Table 13.1 Watercourse loadings for Largo Bay

No	Grid Reference	Description	Width (m)	Depth (m)	Flow (m/s)	Flow in m^3/day	*E. coli* (cfu/ 100ml)	Loading (*E. coli* per day)
1	NO 46368 00366	Burn	1.9	0.15	0.048[1]	1180	1900	2.3×10^{10}
2	NO 45793 00731	Cocklemill Burn	4.1	0.15	0.233[1]	12400	2000	2.5×10^{11}
3	NO 42797 02542	Burn	0.6	0.03	0.592[1]	921	11000	1.0×10^{11}
4	NO 42266 02596	Largo Burn	0.5	0.04	0.301[1]	520	>10000	$>5.2 \times 10^{10}$
5	NO 41668 02563	River	6.2	0.15	0.113[1]	9080	30000	2.7×10^{12}
6	NO 39811 01854	Stream	1.1	0.04	0.239[1]	909	300	2.7×10^{9}
7	NO 38866 01058	Scoonie Burn	2.8	0.18	0.009[2]	392	3400	1.3×10^{10}
8	NO 38122 00430	River Leven	Unable to measure due to size			N/A	1400	N/A

Notes: [1]Mean of 2 separate measurements; [2]Mean of 6 separate measurements

The combined calculated loadings for the three watercourses in the Lower Largo area (Nos. 3, 4 and 5 in Table 13.1) streams (Nos. 1and 3) were high and would be expected to significantly impact on the water quality over the shellfishery in the area off Lower Largo. The combined calculated loadings for the two watercourses on the eastern side of the bay (Nos. 1 and 2) were moderately high and would be expected to have an impact on the water quality on that side of the bay. The dimensions and flow of the River Leven (No. 8) could not be safely measured during the shoreline survey due to the size of the watercourse. The river is one of the two main rivers of Fife and despite the moderate *E. coli* concentration on the day of the survey, would have a large *E. coli* loading due to the large volume of water discharged into the bay. The loading from Scoonie Burn (No. 7) would add to this to impact on the water quality on the western side of the bay. Using an average value of 6.45 m^3/s for the flow for the River Leven (see Section 14) would give an estimated loading of 7.8×10^{12}.

The survey took place after a period of heavy rain and the loadings of the watercourses would be expected to be significantly lower following a dry period.

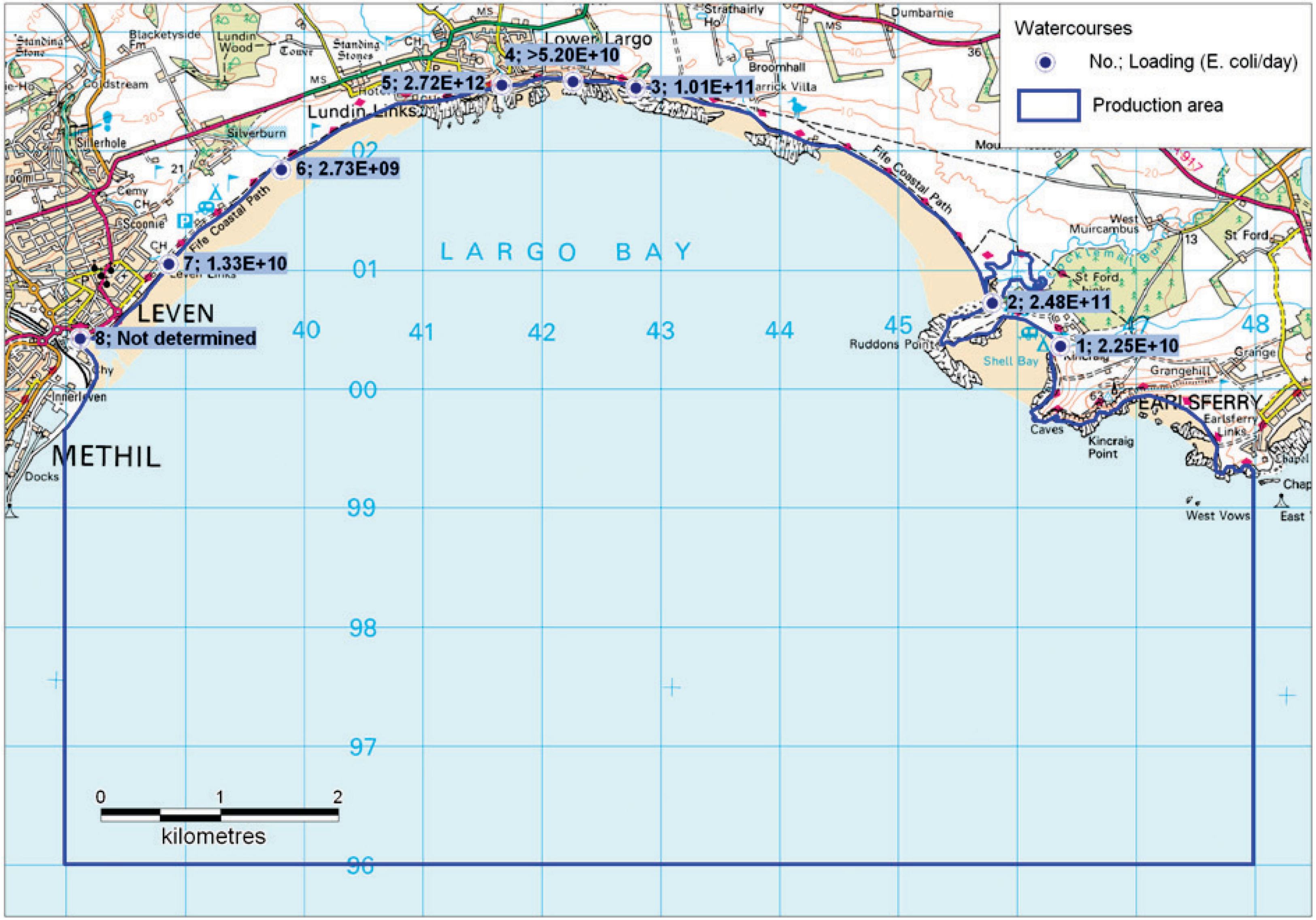

Figure 13.1 Map of watercourse loadings at Largo Bay

14. Bathymetry and Hydrodynamics

The OS map and Hydrographic Chart for the area are shown in Figures 14.1 and 14.2 respectively.

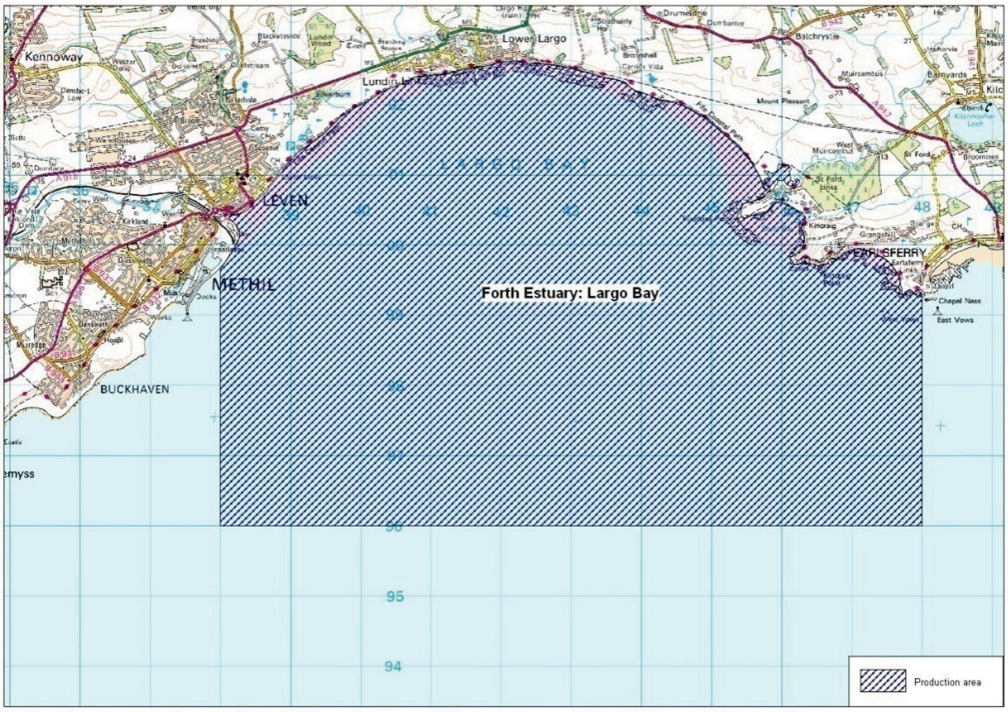

Figure 14.1 OS map of Largo Bay

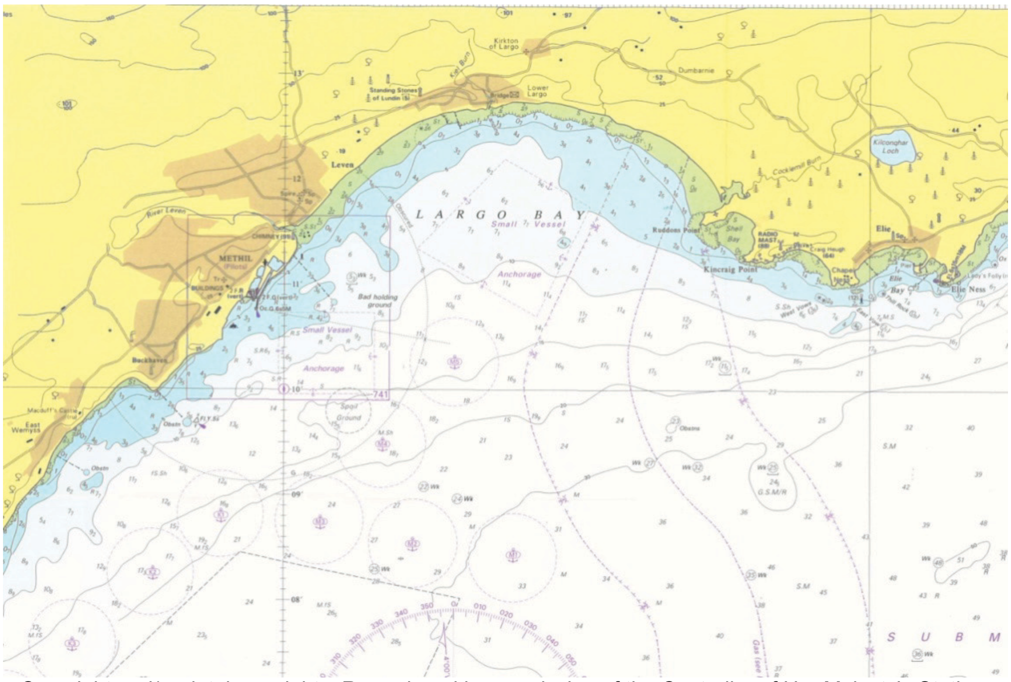

Figure 14.2 Bathymetry at Largo Bay

Largo Bay is located on the north side of the Firth of Forth. From Methil to Kincraig Point, it is approximately 8 km wide. However, the current production area extends south of that line. There is a significant extent of drying area around the shore of the bay. From there, the seabed slopes fairly gradually: at the southerly limit of the production area the depth is approximately 30 m. The chart identifies a small vessel anchorage that occupies a large section of the deeper parts of the bay.

14.1 Tidal Curve and Description

The two tidal curves below are for Methil, located on the western side of Largo Bay. The tidal curves have been output from UKHO TotalTide. The first is for seven days beginning 00.00 BST on 16/08/10 and the second is for seven days beginning 00.00 BST on 23/08/10. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle, including the dates of the shoreline survey.

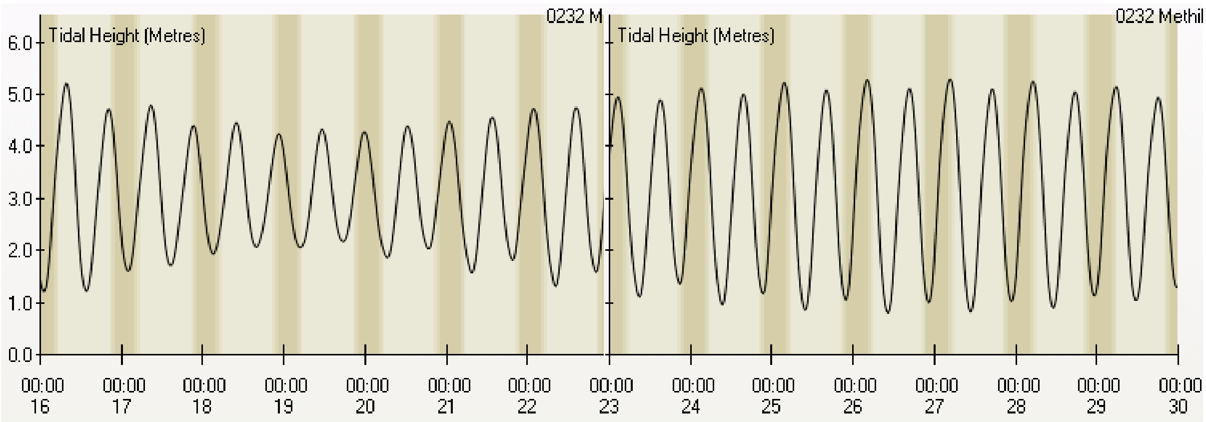

Figure 14.3 Tidal curves for Methil

The following is the summary description for Methil from TotalTide:

0232 Methil is a Secondary Harmonic port. The tide type is Semi-Diurnal.

HAT	6.2 m
MHWS	5.5 m
MHWN	4.3 m
MSL	3.10 m
MLWN	1.9 m
MLWS	0.7 m
LAT	-0.2 m

Predicted heights are in metres above Chart Datum. The tidal range at spring tide is 4.8 m, and at neap tide 2.4 m, and so tidal ranges in the area are moderate.

14.2 Currents

Tidal stream information was available for several stations in the Firth of Forth. The location of the stations in the part containing Largo Bay, together with the tidal streams for peak flood and ebb tide, are presented in Figures 14.4 and 14.5. Unfortunately, none of the stations are located within, or in the near vicinity of the bay. For this reason, only one tidal diamond is presented as an example (see Table 14.1): this is for the station located south of the bay.

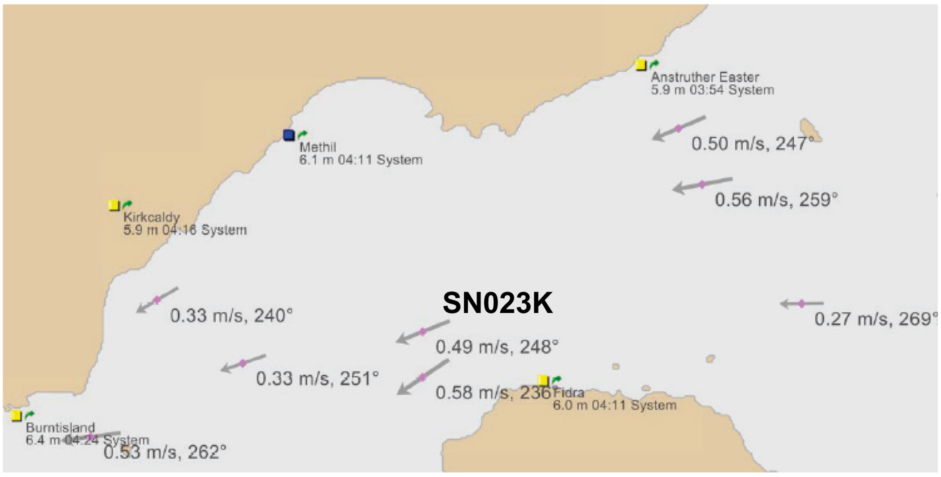

Figure 14.4 Spring flood tide in the Firth of Forth

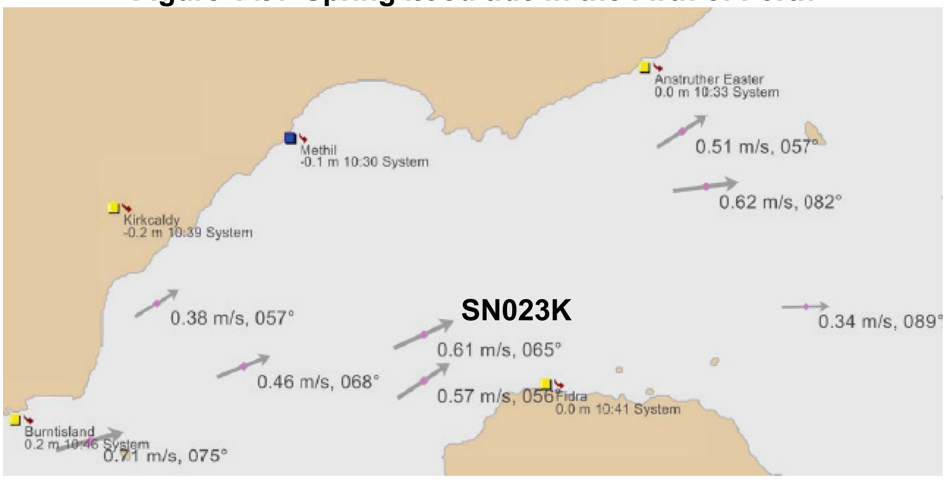

Figure 14.5 Spring ebb tide in the Firth of Forth

Table 14.1 Tidal streams for station SN023K (56°05.40'N 2°53.19'W) (taken from Totaltide)

Time	Direction	Spring rate (m/s)	Neap rate (m/s)
-06h	061°	0.15	0.10
-05h	252°	0.10	0.05
-04h	249°	0.31	0.15
-03h	249°	0.36	0.21
-02h	248°	0.41	0.21
-01h	244°	0.36	0.21
HW	238°	0.21	0.10
+01h	188°	0.05	0.05
+02h	073°	0.21	0.10
+03h	067°	0.41	0.21
+04h	065°	0.51	0.26
+05h	064°	0.46	0.21
+06h	063°	0.26	0.15

The general tendency is therefore for the currents to travel directly up the firth during flood tide and directly down the firth during ebb tide. It is likely that this tendency will be modified within Largo Bay itself due to the shape of the bay.

Dyke (1988) reviewed available information on currents in the Firth of Forth. He identified a number of key points:

- The lack of freshwater input means that the firth acts more like an inlet or embayment than an estuary
- Currents are small and difficult to measure; measured tidal velocities are in the order of 0.5 m/s
- The prevailing wind direction is along the axis of the firth and, due to the weak currents, wind-driven flows may be significant
- The occurrence of a halocline, and thus potentially density driven flows, occurs intermittently, usually in February or March, and the location varies.
- Residual current speeds range from 0.016 to 0.089 m/s, due largely to wind effects, but also influenced by density effects.
- There may be a residual flow along the northern coast near Pittenweem that is of the order of 0.02 m/s to seaward and may operate when the water is stratified.
- In general, the circulation in the firth is for the flooding tide to travel mainly up the northern side of the main channel and for the ebbing tide to travel along the southern coast of the firth.
- Further extensive surveys were needed to confirm the available data.

SEPA and Scottish Water were approached for information on any modelling that might have been undertaken in support of sewage improvement schemes but none was available. Hydrodynamic modelling had been undertaken to support the Environmental Statement for the Forth Replacement Crossing (Jacobs ARUP, 2009). Much of the data used in the model came from UKHO TotalTide. The eastern boundary of the modelled area lay immediately to the east of Largo Bay (running south from Elie) while the western boundary lay near the Kincardine Bridge. However, the main outputs naturally concentrated on the proposed area of the crossing in the vicinity of Queensferry and no detailed information was provided in the Environmental Statement regarding predicted current speeds in the vicinity of Largo Bay. Predicted current speeds at several tidal diamond locations were similar to the TotalTide predictions. Modelled spring tide flows to the east of the crossing ranged from less than 0.25 m/s near the shores to 1 m/s at the centre of the channel with the peak neap speeds being significantly less than these. The current direction was essentially bidirectional, with the flows following the shoreline within bays. The report noted that an average salinity value had been provided by SEPA for a point at Methil (on the western end of Largo Bay) and this was 34 ppt. No indication was given of variability. Salinities of samples taken in support of the study at the River Leven were reported as ranging from 34.4 to 34.8 psu. Values at Elie Ness were 34.9 psu. The modelling report also noted that a mean flow value of 6.45 m^3/s had been used for the River Leven (obtained from the SEPA website).

14.3 Conclusions

Depths within Largo Bay are restricted (<10 m) compared to the adjacent firth and thus dilution of contaminants arising within the bay or from the adjacent coastline will be limited. Current speeds are relatively low with a maximum in the order of 0.5 m/s (1 knot) at springs. However, at this speed, contaminants could be taken a distance of approximately 7 km over the course of a flood or ebb tide, ignoring any dilution or dispersion. Current direction will tend to follow the shoreline, including around the bay. There may be eddies on the flood tide in the vicinity of Elie Ness that will complicate the general current flow but, in general, it is expected that contamination will be taken parallel to the shore. Strong winds along the axis of the firth may increase the ebb currents and the resulting residual current will tend to carry contaminants seawards over the course of consecutive tides. The effect of south-westerly winds will be to drive contaminants towards the eastern shore of Largo Bay. Salinity in the area will be largely that of full-strength seawater and density driven flows will not be expected as far down the firth as Largo Bay.

15. Shoreline Survey Overview

The shoreline survey was conducted on the 16th, 17th and 18th August 2010 under mostly calm and dry weather conditions.

The harvester indicated that razor clams are believed to occur across much of the bay. However, they are only dived to depths of 12 m and are not harvested from the west side of the bay due to the Methil discharge. A number of harvesters dive the bay for razor clams, which are fished year-round depending on weather conditions. Although reportedly hand-dived, there is anectodal evidence to suggest that they are more commonly electro-fished.

A number of sewage related assets were observed in Lower Largo. A fresh water sample taken at one of the outfall pipes in Lower Largo returned a low result of <10 *E. coli* cfu/100 ml, suggesting that it was not carrying sewage or contaminated runoff at the time. Another pumping station was observed in Leven. A sea water sample taken at the end of the outfall pipe at Ruddon Point indicated relatively high levels of contamination with a result of 1600 *E. coli* cfu/100 ml. No sanitary debris was observed during the shoreline survey.

No livestock animals were observed at the time of the shoreline survey.

Approximately 35 sea gulls and 8 grouse were observed at the SSSI at Ruddons Point on the east side of Largo Bay. Offshore from Ruddons Point, approximately 10 seals and a pod of 10 dolphins were observed. At Lower Largo, there were approximately 200 sea gulls and 10 ducks. At Leven there were approximately 130 sea gulls, 12 swans, 2 ducks and 80 other unknown seabirds.

A total of five sea water samples were taken from various points around Largo Bay. All but one contained relatively low concentrations of E. coli (<10 to 20 cfu/100 ml). One of these (< 10 cfu/100 ml) was taken from adjacent the Levenmouth WWTW discharge off Methil. At Ruddons Point, a sea water sample taken at the end of an outfall result had a high result of 1600 *E. coli* cfu/100 ml. Salinity profiles taken at the razor clam sample sites indicated little freshwater influence at the time, though a sea water sample collected from the west side of Largo Bay had an observed salinity of 32.0 g/L, indicating some fresh water influence.

Freshwater samples and discharge measurements were taken at all of the streams draining into the survey area. The streams were of varying size and drained areas of arable land with some areas of improved grassland. Fresh water samples collected from the streams contained varying levels of contamination (300 to 30000 *E. coli* cfu/100 ml). The three streams with the highest *E. coli* results of >10000, 11000 and 30000 (*E. coli* cfu/100 ml) were all located in Lower Largo and discharged into the centre of the bay. Razor clam samples were collected from three sites within the bay and all returned low results of <20 *E. coli* MPN/100 g.

Figure 15.1 shows a summary map of the most significant findings from the shoreline survey.

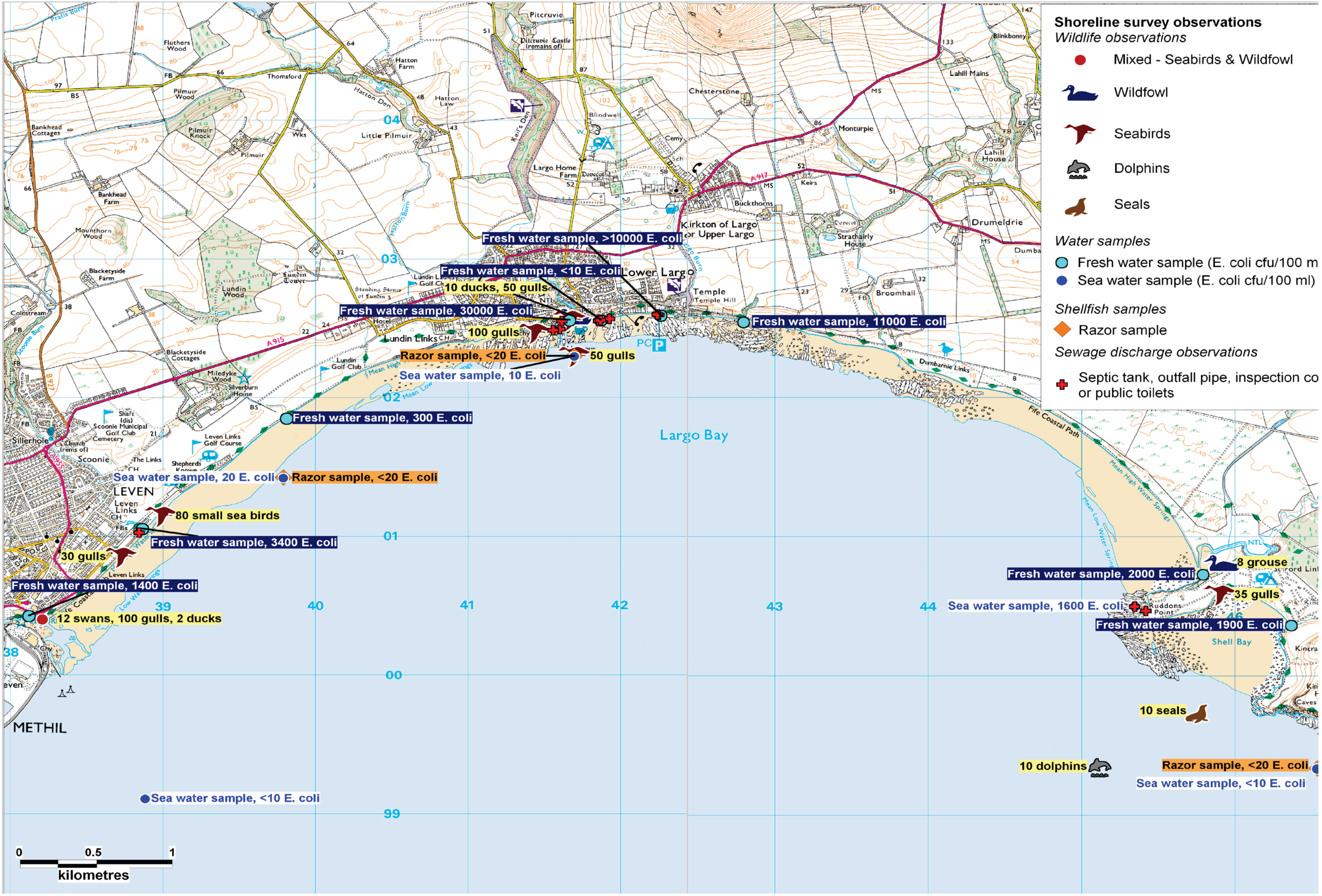

Figure 15.1 Summary of shoreline survey findings for Largo Bay

16. Overall Assessment

The fishery at Forth Estuary: Largo Bay consists of a wild razor clam bed, the boundaries of which have been estimated but are not conclusively known.

Human sewage impacts

The western side of Largo Bay is heavily populated. The majority of the population are connected to mains sewerage. The largest sewage discharge to the bay is from the Levenmouth WWTW (PE 402000) and discharges 1km offshore from the Methil Docks. This discharge receives UV treatment and a water sample taken from the vicinity of the discharge on the day of shoreline survey contained <10 *E. coli* cfu/100 ml. Although the Levenmouth discharge is by far the largest in the area, it also has the highest treatment level. When operating optimally, this discharge is unlikely to contribute high levels of faecal bacteria to the waters of the bay. In the event of a spill from the associated CSO, however, water quality is likely to be severely compromised across the fishery. Information on spill frequency was sought from Scottish Water, however this information was not known.

Two further community septic discharges, (combined PE 4575) are located at east and west of Lower Largo. The larger of the two (Lower Largo WWTW) receives secondary treatment and the smaller (Lundin Links) discharges septic tank effluent. These are likely to affect the parts of the bay near to the north shore where they discharge and for a distance along the shore in either direction, depending on tidal flow and wind conditions. It is not known whether these have asso

Outside the eastern boundary of the production area, discharges and CSOs to Elie would be expected to impact the eastern side of the fishery, particularly on the flood tide.

Consents for other discharges to the area were provided by SEPA. As few details were available, it was not possible to assess the overall impact of most of these to the fishery. However, most are likely to have a low impact relative to the community discharges. A septic tank associated with the large caravan park at Shell Bay was identified at Ruddons Point. The park accommodates up to 1600 visitors during the peak summer months and a seawater sample collected at the end of the outfall pipe had a very high result of 1600 *E. coli* cfu/100 ml. Discharges from this site would have an impact on the water quality on the far eastern side of the bay, particularly during the summer.

Although boat traffic in Largo Bay is fairly light, further sewage input is possible from fishing boats and yachts that visit the bay and anchor in the designated anchorage zones. In addition to the anchorage available in the bay there is a small harbour and pier at Lower Largo. In Methil, there are three large industrial docks, which are mainly used by commercial and fishing vessels.

Agricultural impacts

Much of the land outside the towns is used for arable agriculture, and streams discharging the adjacent Shellfish Growing Water were identified by SEPA as being impacted by diffuse agricultural pollution. Therefore, it is expected that the eastern side of Largo Bay, in particular, would be similarly impacted. The two agricultural parishes for which livestock numbers were reported, Largo and Newburn, both border the eastern side of the bay. However, RERAD could provide very little of the information requested on these parishes due to the limited number of farms reporting data in each parish.

Wildlife impacts

Largo Bay lies within the Firth of Forth SPA, which is noted for its populations of wading and sea birds. Significant numbers of birds were observed during the shoreline survey and the largest assemblages were seen near Leven and Lower Largo. At the east end of the bay, south of Ruddons Point is a seabird nesting area. Seals and dolphins were observed in the same area during the shoreline survey. Although wildlife are likely to contribute to background levels of *E. coli* found in the bay, their impact is likely to be insignificant when compared to human sewage discharges in the area.

Seasonal variation

The population in the area is likely to be highest during the summer months, when local accommodation, caravan parks and campsites are likely to be most fully occupied. Some seasonal variation is expected in agricultural inputs, though there was insufficient information available to accurately characterise these in relation to the fishery. Seasonal variation is likely to occur in the wildlife populations present in the bay. Seabirds nesting at the southeast end of the bay are most likely to be present at that location during the summer months only.

Daily rainfall has tended to be higher in October, November and January and similar for the rest of the year. However, extreme rainfall events of greater than 20 mm per day mainly occurred in the second half of the year.

No seasonal pattern was apparent in historical *E. coli* sampling results.

Rivers and streams

Significant streams and rivers were identified along the western and northern shores of the bay. Two further streams discharge to Shell Bay on the eastern side of Largo Bay. The combined calculated loadings to the north shore were high and would be expected to significantly impact on the water quality over the shellfishery in the area off Lower Largo.

Along the western side of the bay, the combined estimated loading for the River Leven and Scoonie Burn was 7.8 $x10^{12}$ *E. coli*/day. The two watercourses discharging to Shell Bay had moderately high loadings and therefore would be expected to impact water quality on that side of the bay.

Streams discharging to the west and north of the bay pass through urban catchment areas and are expected to carry higher loadings of faecal contamination, especially after rainfall, that the streams discharging to the east side of the bay.

Overall, the impact from contaminants carried via rivers and streams is expected to be highest along the west and north sides of the bay.

Hydrography and movement of contaminants

Due to restricted depths within the bay, contamination reaching the shores either from point source discharges or via rivers and streams will be subject to only limited dilution. Currents are relatively slow, however even at the low predicted current speeds particle transport distances could reach approximately 7km on a spring ebb or flood tide. Currents are expected to carry contaminants predominantly along the shoreline of the bay, though there may be some eddy effect around Elie Ness. Strong southwesterly winds would tend to drive contaminants into the northeastern section of Largo Bay, whilst strong northwest winds may tend to carry contaminants seawards over successive tides.

Contaminants from sewage overflows at any of the identified community discharges would be expected to severely impact water quality in their immediate vicinity, but may have a wider effect with the area affected dependent on currents.

Temporal and geographical patterns of sampling results

No obvious geographical trends in sampling results for razor clams and surf clams were observed. Most of the samples have come from near the northeastern shore of the bay. No significant seasonal trends were identified in the sampling results for razor clams.

Conclusions

The main sources of faecal indicator bacteria, and consequently potential pathogens, to the fishery are from sewage discharges to the west, north and east sides of the bay. The discharges to the north and east sides of the bay receive a lower level of treatment and therefore pose a greater risk of continuous impact to bacteriological water quality than the Levenmouth discharge to the west. However, sewage spills from any of these would significantly affect water quality over much of the fishery. Impacts from spill events would be unlikely to be reflected in monthly, or less frequent, monitoring of shellfish.

Area streams and rivers carry significant diffuse pollution loadings and the largest of these are to the west and north of the fishery near the towns of Leven and Lower Largo.

No clear seasonality in results was observed, though there is anticipated to be significant seasonal variation in some of the sources of contamination. The fishery has historically received seasonal classifications, therefore is ineligible for reduced sampling frequency based on a stability assessment.

17. Recommendations

Production area

The recommended production area boundaries are described by the area bounded by lines drawn between NO 4492 0180 and NO 4100 0180 and NT 4100 9800 and NT 4600 9800 and NO 4600 0000 and NO 4500 0000 and NO 4500 0078 and NO 4577 0078 and extending to MHWS. This curtails the boundaries to exclude areas around sewage discharges and encompasses the area of the fishery based on the bathymetry and historical sampling locations. If this area does not cover the entire area of commercial interest, it should be identified during the consultation on the draft report. The recommendations can then be revised before the report is finalised..

RMP

Given the large area and species involved, a representative monitoring zone (RMZ) has been identified to ensure that sufficient stock is likely to be available for monitoring purposes. The RMZ is the area described by lines drawn between NO 4100 0180 and NO 4200 0180 and NO 4200 0150 and NO 4100 0150. This gives an area of 1 km by 300 metres from which to obtain samples. The RMZ lies in the northwest corner of the production area, nearer to sources along the north shore near Lower Largo.

Frequency

As this area has held a seasonal classification over the past three years, it is recommended that monthly monitoring be continued. If a defined, consistent harvesting season is subsequently identified, monitoring could be targeted immediately prior to, and during, this period.

Depth of sampling

Not applicable

Tolerance

No tolerance is applied as an RMZ has been recommended.

Figure 17.1 Map of recommendations at Forth Estuary: Largo Bay

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Sampling Plan for Forth Estuary: Largo Bay

PRODUCTION AREA	Forth Estuary: Largo Bay
SITE NAME	Largo Bay
SIN	FF 072 188 16
SPECIES	Razor clam (*Ensis* spp)
TYPE OF FISHERY	Wild harvest
AREA OF RMZ	Area described by lines drawn between NO 4100 0180 and NO 4200 0180 and NO 4200 0150 and NO 4100 0150
EAST	NA
NORTH	NA
TOLERANCE (M)	None
DEPTH (M)	NA
METHOD OF SAMPLING	Dived
FREQUENCY OF SAMPLING	Monthly
LOCAL AUTHORITY	Fife Council
AUTHORISED SAMPLER(S)	John Lecyn
LOCAL AUTHORITY LIAISON OFFICER	John Lecyn

Table of Proposed Boundaries and RMPs

PRODUCTION AREA	**Forth Estuary: Largo Bay**
SPECIES	**Razor clam (*Ensis* spp)**
SIN	**FF 072 188 16**
EXISTING BOUNDARY	Defined as the area bounded by lines drawn between NT 4800 9933 and NT 4800 9600 and NT 3800 9600 and NT 3800 9966 extending to MHWS
EXISTING RMP	NO 445 010
RECOMMENDED BOUNDARY	Area bounded by lines drawn between NO 4492 0180 and NO 4100 0180 and NT 4100 9800 and NT 4600 9800 and NO 4600 0000 and NO 4500 0000 and NO 4500 0078 and NO 4577 0078 and extending to MHWS
RECOMMENDED RMZ	Area described by lines drawn between NO 4100 0180 and NO 4200 0180 and NO 4200 0150 and NO 4100 0150
COMMENTS	Production area boundaries curtailed to exclude sewage discharges, Monitoring zone recommended in northwest corner.

Geology and Soils Assessment

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

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%.

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. They have a very high surface % runoff of between 48.4 – 60%.

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 this region have an average surface % runoff of 44.3%, so it is likely that in this case they would be poorly draining.

These component soils were classed broadly into two groups based on whether they are freely or poorly draining. Drainage classes were created based on information obtained from the both the Macaulay Institute website and personal communication with Dr. Alan Lilly. GIS map layers were created for each class with poorly draining classes shaded red, pink or orange and freely draining classes coloured blue or grey. These maps were then used to assess the spatial variation in soil permeability across a survey area and it's potential impact on runoff.

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.

General Information on Wildlife Impacts

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 seal surveys are conducted every 5 years and an estimate of minimum numbers is available through Scottish Natural Heritage.

According to the Scottish Executive, in 2001 there were approximately 119,000 grey seals in Scottish waters, the majority of which were found in breeding colonies in Orkney and the Outer Hebrides.

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 concentration 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).

Cetaceans

As mammals, whales and dolphins would be expected to have resident populations of *E. coli* and other faecal indicator bacteria in the gut. Little is known about the concentration of indicator bacteria in whale or dolphin faeces, in large part because the animals are widely dispersed and sample collection difficult.

A variety of cetacean species are routinely observed around the west coast of Scotland. Where possible, information regarding recent sightings or surveys is gathered for the production area. As whales and dolphins are broadly free ranging, this is not usually possible to such fine detail. Most survey data is supplied by the Hebridean Whale and Dolphin Trust or the Shetland Sea Mammal Group and applies to very broad areas of the coastal seas.

It is reasonable to expect that whales would not routinely affect shellfisheries located in shallow coastal areas. It is more likely that dolphins and harbour porpoises would be found in or near fisheries due to their smaller physical size and the larger numbers of sightings near the coast.

Birds

Seabird populations were surveyed all over Britain as part of the SeaBird 2000 census. These counts are investigated using GIS to give the numbers observed within a 5 km radius of the production area. This gives a rough idea of how many birds may be present either on nests or feeding near the shellfish farm or bed.

Further information is gathered where available related to shorebird surveys at local bird reserves when present. Surveys of overwintering geese are queried to see whether significant populations may be resident in the area for part of the year. In many areas, at least some geese may be present year round. The most common species of goose observed during shoreline surveys has been the Greylag goose. Geese can be found grazing on grassy areas adjacent to the shoreline during the day and leave substantial faecal deposits. Geese and ducks can deposit large amounts of faeces in the water, on docks and on the shoreline.

A study conducted on both gulls and geese in the northeast United States found that Canada geese (*Branta canadiensis*) contributed approximately 1.28×10^5 faecal coliforms (FC) per faecal deposit and ring-billed gulls (*Larus delawarensis*) approximately 1.77×10^8 FC per faecal deposit to a local reservoir (Alderisio and DeLuca, 1999). An earlier study found that geese averaged from 5.23 to 18.79 defecations per hour while feeding, though it did not specify how many hours per day they typically feed (Bedard and Gauthier, 1986).

Waterfowl can be a significant source of pathogens as well as indicator organisms. Gulls frequently feed in human waste bins and it is likely that they carry some human pathogens.

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 will be present particularly in wooded areas where the habitat is best suited for them. Deer, like cattle and other ruminants, shed *E. coli*, *Salmonella* and other potentially pathogenic bacteria via their faeces.

Other

The European Otter (*Lutra lutra*) is present around Scotland with some areas hosting populations of international significance. Coastal otters 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 10 m depth contour and feed on a variety of fish, crustaceans and shellfish (Paul Harvey, Shetland Sea Mammal Group, personal communication).

Otters leave faeces (also known as spraint) along the shoreline or along streams, which may be washed into the water during periods of rain.

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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 *E. coli* data was log transformed prior to statistical tests.

Section 11.5 One way ANOVA comparison of *E. coli* results by season (razors)

```
Source  DF      SS     MS     F      P
Season   3   1.500  0.500  1.50  0.226
Error   51  17.033  0.334
Total   54  18.533

S = 0.5779   R-Sq = 8.09%   R-Sq(adj) = 2.69%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
1      14  1.9276  0.5957  (---------*----------)
2      13  2.1216  0.8288        (----------*---------)
3      13  2.2651  0.3632             (----------*---------)
4      15  2.3578  0.4305                 (---------*---------)
                           ------+---------+---------+---------+---
                               1.80      2.10      2.40      2.70

Pooled StDev = 0.5779
```

Section 11.6.1 Spearman's rank correlation for *E. coli* result and 2 day rainfall (razors)

```
Pearson correlation of ranked 2 day rain and ranked ecoli for 2 day rain =
     0.003
```

n=50, p>0.25

Section 11.6.1 Spearman's rank correlation for *E. coli* result and 7 day rainfall (razors)

```
Pearson correlation of ranked 7 day rain and ranked e coli for 7 day rain =
     -0.088
n=50, p>0.25
```

Section 11.6.2 Circular linear correlation for *E. coli* result and tidal state on the spring/neap cycle (razors)

CIRCULAR-LINEAR CORRELATION
Analysis begun: 21 May 2010 11:09:42

Variables (& observations)	r	p
Angles & Linear (55)	0.258	0.031

Section 11.6.2 Circular linear correlation for *E. coli* result and tidal state on the high/low cycle (razors)

CIRCULAR-LINEAR CORRELATION
Analysis begun: 11 June 2010 10:07:21

Variables (& observations)	r	p
Angles & Linear (55)	0.047	0.891

Hydrographic Methods

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

The hydrography at most sites will be assessed on the basis of bathymetry and tidal flow software only. 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 consider the more basic hydrographic processes and describes the common methodology applied to all sites.

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

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

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

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.

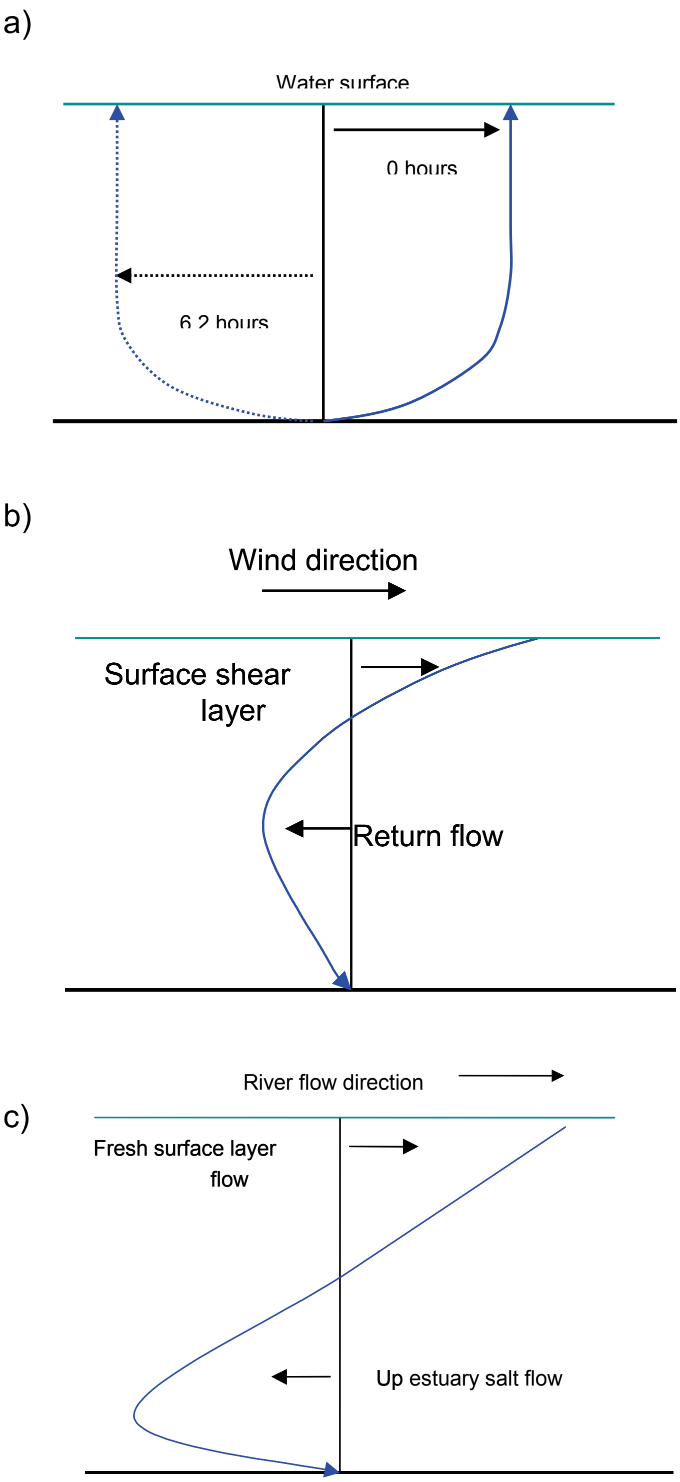

Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction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

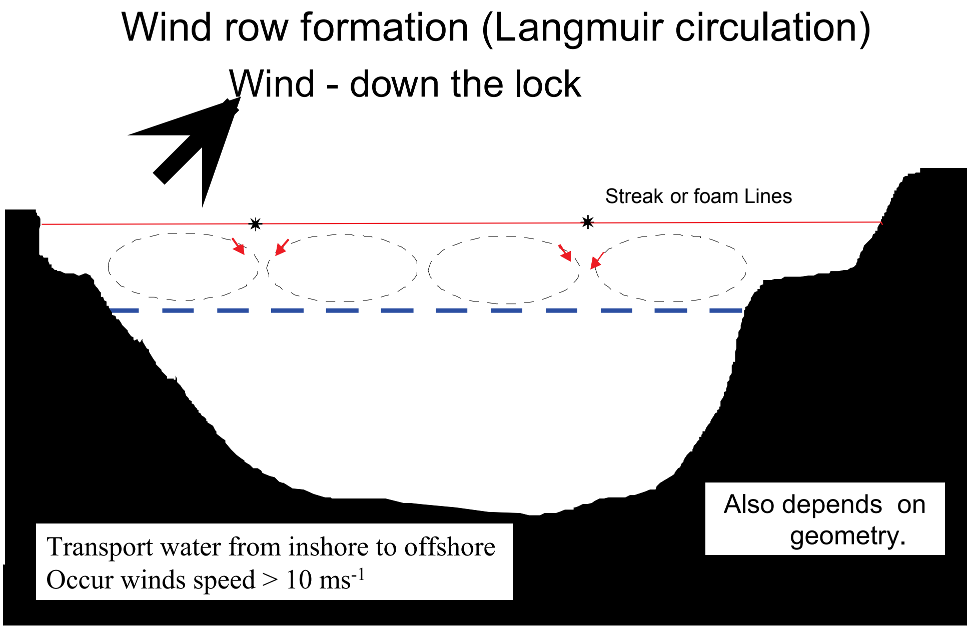

Figure 2. Schematic of wind driven 'wind row' currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

Non-modelling Assessment

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'.

Many Scottish shellfish 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.

The catalogue of Scottish Sea Loch 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 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.

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

The following technical terms may 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 near shore 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.

Shoreline Survey Report

Production Area:

Production Area	Site	SIN	Species
Forth Estuary: Largo Bay	Largo Bay	FF 072 188 16	Razor fish

Harvester:	Various (including Rab Maxwell & Ross Coventry – Buckhaven Shellfish)	
Status:	Classified	
Date Surveyed:	16/08/2010 - 18/08/2010	
Surveyed by:	Jessica Larkham	Cefas
	John Lecyn	Fife Council
	Ronnie Vaughan	Fife Council
Area Surveyed:	See Figure 1.	

Routine Monitoring Point:

Site	Nominal RMP
Largo Bay	NO 445 010

Weather Observations

16/08/10 Warm, some clouds, otherwise sunny, slight breeze F3
17/08/10 Warm, slight breeze F3, overcast
18/08/10 Warm, slight breeze F3, overcast
The weather had been windy with heavy rain in the week preceding the survey.

Site Observations

Specific observations made on site are mapped in Figure 1 and listed in Table 1. Water and shellfish samples were collected at sites marked on Figures 2 and 3. Bacteriology results are given in Tables 2 and 3. Salinity profiles are presented in Table 4. Photographs are presented in Figures 4-32.

Fishery

The area is currently fished for razor clams (*Ensis spp*). A natural razor clam bed is found within the bay. Communication with the harvester indicates that razors are found across most of the bay, however this is only speculative as they will only dive up to depths 12 m and do not harvest from the far west hand side of the bay due to the Methil discharge. The razor clams bed is hand dived and fished all year round depending on weather conditions by various harvesters.

Sewage/Faecal Sources

Human – There are five centres of population adjacent to Largo Bay; Lower Largo to the north and Leven, Methil, Buckhaven and East Wemyss to the west. The towns of Methil, Leven and Buckhaven are joined together. Septic tanks, outfall pipes and a pumping station were observed in Lower Largo and another pumping station was observed in Leven. No sanitary debris was observed during the shoreline survey. There are three golf courses between Lower Largo and Leven and a large number of hotels and B&B's to support a year round influx of tourists to the area. There is a caravan park at Shell Bay, with 287 caravan pitches and additional tent pitches. During the summer months the number of residents at the Shell Bay Caravan Park can vary from 1100 to 1600 at full capacity. There is a septic tank at the caravan park. There is also another caravan park near Leven, adjacent to the golf course, which also has caravan and tent pitches.

Livestock – No livestock was observed during the shoreline survey.

Several burns and rivers, which drain the urban areas, arable land, wood land and golf courses, were recorded discharging into Largo Bay. The largest fresh water input to the bay is the River Leven, located on the western shoreline of the bay. A fresh water sample (1400 *E. coli* cfu/100 ml) was taken from the River Leven but it was too large to measure the size and flow safely. The highest *E. coli* result of 30000 *E. coli* cfu/100 ml was taken from a river running under a railway bridge in Lower Largo. A further six burns were observed discharging into the bay, these were all sampled and measured.

E. coli levels in sea water samples taken offshore in the vicinity of the razor fish bed were low (<10 - 20 *E. coli* cfu/100 ml in all four cases). A fifth sea water sample taken towards the end of the outfall pipe at Ruddons Point had a very high result of 1600 *E. coli* cfu/100 ml. No additional sea water samples were taken from the shore.

The three razor clam samples collected from the northern, south eastern and western end of the production area, all gave *E. coli* results of <20 MPN/100 g. Salinity profiles taken during the survey indicated that there was little freshwater influence on the water body at the time, with salinities all around that of full strength seawater with little stratification.

Seasonal Population

There are numerous hotels or B&B's in the area. The main attractions are camping, caravanning and sports and leisure, including golf. Tourists are attracted to the area all year round, but it is the summer months when the caravan parks, hotels and B&B's are likely to reach full capacity.

Boats/Shipping

Boat traffic in Largo Bay is fairly light and limited to small fishing boats and some pleasure boats and yachts. During the shoreline survey fishing boats were seen anchored out in the bay harvesting razor clams. A single yacht was observed anchored near Lower Largo. There is a small harbour and pier at Lower Largo. In Methil, there are three large industrial docks, which are now mainly used by fishing vessels.

Land Use

The land surrounding Largo Bay was mainly arable land, with areas of woodland, grassland and built up urban areas.

Wildlife/Birds

Ruddons Point to the east of Largo Bay is a designated SSSI salt marsh habitat and is a renowned viewing point for surf scoters and other sea birds. During the shoreline survey, approximately 35 sea gulls and 8 grouse were observed at Ruddons Point.

Individual gulls, ducks, swans and other unknown seabirds were also observed during the shoreline survey. Approximately ten seals were observed on the shore of Shell Bay. A pod of ten dolphins were also observed offshore of Shell Bay.

General observations

Recorded observations apply to the date of survey only. 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 sound.

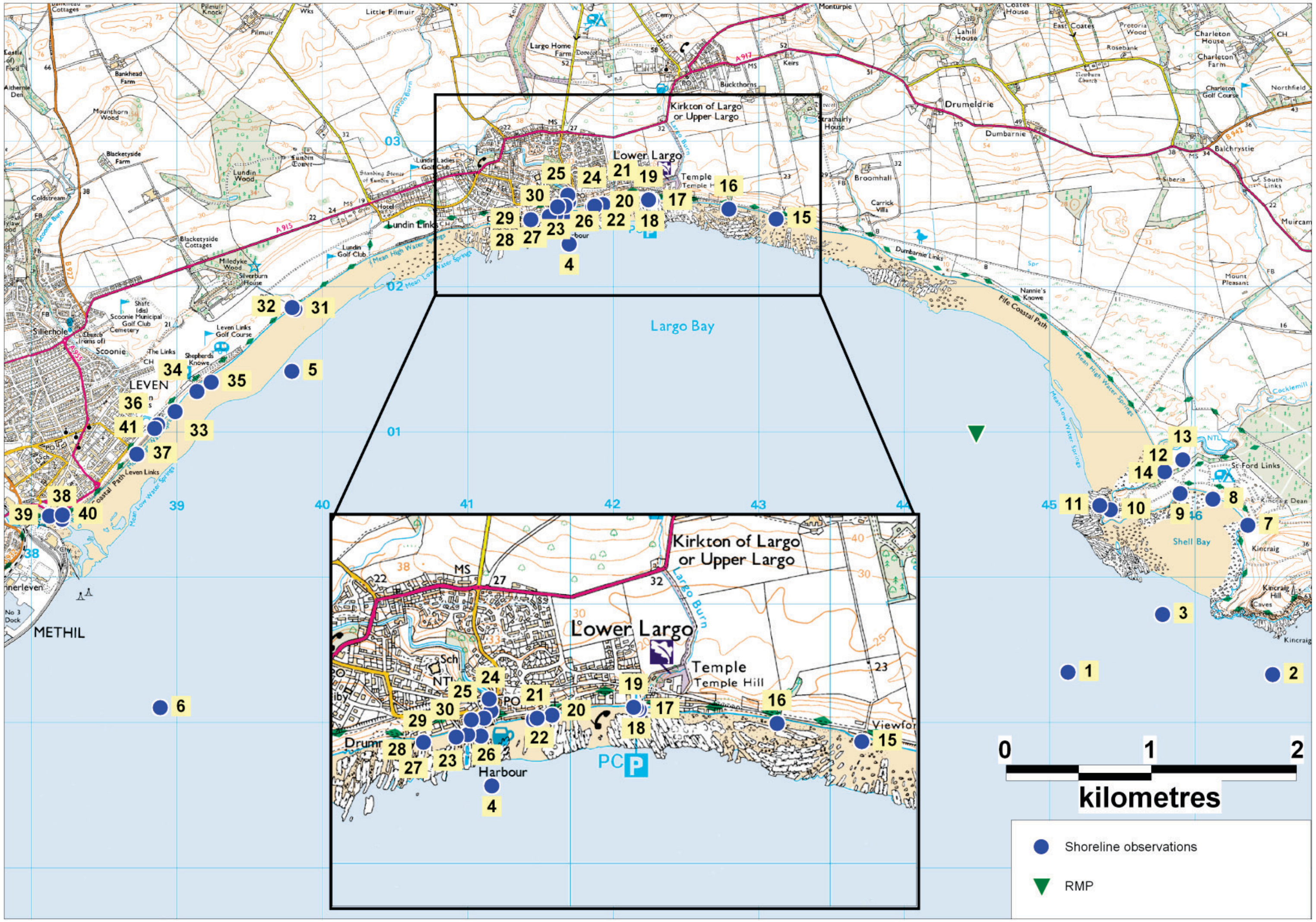

Figure 1. Shoreline Observations

Table 1. Shoreline observations

No.	Date	Time	Position	Photograph	Associated sample	Observation
1	16/08/2010	14:00	NT 45131 99353	Figure 4		Pod of 10 dolphins swimming offshore of Shell Bay
2	16/08/2010	14:13	NT 46538 99337	Figure 5	LB Razor 1, LBSW1	Location of razor sample (LB Razor 1), collected at depth of 5.6 m (during low tide - low water at 13:30) and sea water sample (LBSW1). Salinity profile 1 m: 13.9 ˚C- 33.65ppt, 2 m: 13.8˚C - 35.93ppt, 3 m: 13.7˚C - 36.09ppt, 4 m: 13.7˚C - 36.10ppt, 5 m: 13.7 ˚C - 36.10ppt, 6 m: 13.7˚C - 36.10. Co-ordinates taken from fishing boat: N 56˚11'543 W 002˚52'052. Photograph of Shell Bay and the arable and woodland land cover on the shoreline.
3	16/08/2010	14:44	NT 45780 99751			10 seals on adjacent shoreline
4	16/08/2010	15:10	NO 41699 02302	Figure 6	LB Razor 2, LBSW2	Location of razor sample (LB Razor 2), collected at depth of 3.1 m (during low tide - low water at 13:30) and sea water sample (LBSW2). Salinity profile 1 m: 14.4 ˚C- 36.20ppt, 2 m: 14.2˚C - 36.15ppt, 3 m: 14.0˚C - 36.21ppt. Co -ordinates taken from fishing boat: N 56˚12'566 W 002˚56'482. 50 seagulls on the shoreline.
5	16/08/2010	15:49	NO 39790 01425	Figure 7	LB Razor 3, LBSW3	Location of razor sample (LB Razor 1), collected at depth of 2.7 m (during low tide - low water at 13:30) and sea water sample (LBSW3). Salinity profile 1 m: 14.1 ˚C- 36.09ppt, 2 m: 13.8˚C - 36.16ppt, 3 m: 13.8˚C - 36.17ppt, 4 m: 13.8˚C - 36.18ppt. Co-ordinates taken from fishing boat: N 56˚12'088 W 002˚58'232. Photograph of Lower Largo.
6	16/08/2010	16:07	NT 38884 99111		LBSW4	Location of LBSW4 (taken from the end of the Methil outfall pipe - could see a change in the water). Co-ordinates taken from fishing boat: N 56˚10'835 W 002˚59'163
7	17/08/2010	09:42	NO 46368 00366	Figures 8 & 9	LBFW1	Location of fresh water sample (LBFW1). Burn W 190 cm, D 15 cm, Flow 0.041/0.055. Next to caravan park - population of 11,000 - 16,000 (at full capacity) with 287 pitches.
8	17/08/2010	09:54	NO 46126 00546			Dog faeces on the beach
9	17/08/2010	09:57	NO 45901 00585			35 seagulls. Mussel, clam & razor shells along the strand line of the beach
10	17/08/2010	10:09	NO 45421 00472			Inspection cover for outfall pipe
11	17/08/2010	10:12	NO 45349 00502	Figure 10	LBSW5	Location of sea water sample (LBSW5) taken from the end of an outfall pipe, smells of sewage.
12	17/08/2010	10:31	NO 45793 00731	Figure 11	LBFW2	Location of fresh water sample (LBFW2). Burn W 410 cm, D 15 cm, Flow 0.225/0.241. Sewage fungus in water.
13	17/08/2010	10:43	NO 45919 00815			8 Grouse
14	17/08/2010	10:49	NO 45793 00734	Figure 12		No outfall pipe was observed, however bubbles were coming up from the bed of the burn, in an area that smelled of sewage and a sewage fungus in the water. Water slightly cloudy and discoloured.
15	17/08/2010	12:33	NO 43122 02473	Figure 13		Fishing boat out to sea - harvesting razor clams
16	17/08/2010	12:38	NO 42797 02542	Figure 14	LBFW3	Location of fresh water sample (LBFW3). Burn W 60 cm, D 3 cm, Flow 0.589/0.595. Flows through culvert that goes under railway line.
17	17/08/2010	12:56	NO 42266 02596	Figure 15	LBFW4	Location of fresh water sample (LBFW4). Burn W 50 cm, D 4 cm, Flow 0.298/0.303. Flows through a culvert under road.

No.	Date	Time	Position	Photograph	Associated sample	Observation
18	17/08/2010	13:04	NO 42254 02602	Figure 16		Septic tanks/pumping station
19	17/08/2010	13:05	NO 42244 02605	Figure 17		Public toilets
20	17/08/2010	13:13	NO 41930 02574	Figure 18		Inspection cover, no sign of an outfall pipe
21	17/08/2010	13:17	NO 41859 02558			Iron pipe from house, green algae, no flow
22	17/08/2010	13:21	NO 41873 02563	Figure 19	LBFW5	Three white pipes coming from a house on the beach, lots of green algae, one pipe flowing - location of fresh water sample (LBFW5)
23	17/08/2010	13:27	NO 41656 02494	Figure 20		Lots of sewage fungus in the river, very strong smell of sewage.
24	17/08/2010	13:33	NO 41694 02591			10 ducks further up river
25	17/08/2010	13:38	NO 41688 02637	Figure 21		River running under railway bridge, W 620 cm, D 15 cm, Flow 0.111/0.114
26	17/08/2010	13:45	NO 41668 02563	Figure 22	LBFW6	Location of fresh water sample (LBFW6) from the river with the sewage fungus, noted above. 50 sea gulls.
27	17/08/2010	13:50	NO 41606 02499	Figure 23		Inspection cover
28	17/08/2010	13:52	NO 41561 02491	Figure 24		Septic tank & outfall pipe covered in green algae. Could not locate the end of the pipe. Took sea water & razor sample off shore of this location yesterday.
29	17/08/2010	13:59	NO 41435 02470			100 gulls on the shoreline
30	17/08/2010	14:23	NO 41619 02557	Figure 25		5 inspection covers, 2 large green units, possible pumping station, no signage
31	18/08/2010	09:35	NO 39811 01854	Figure 26	LBFW7	Location of fresh water sample (LBFW7) from a stream running down the side of the golf course, W 110 cm, D 4 cm, Flow 0.246/0.231
32	18/08/2010	09:56	NO 39792 01864			Golf course
33	18/08/2010	10:30	NO 38987 01148			80 small sea birds. Horse mussel, native oyster, cockle, mussel & razor clam shells on shore of Leven beach (Blue Flag beach)
34	18/08/2010	10:34	NO 39137 01287	Figure 27		Holiday caravan park, directly adjacent to the beach.
35	18/08/2010	10:36	NO 39235 01350			Dog faeces on the beach
36	18/08/2010	10:51	NO 38866 01058	Figure 28	LBFW8	Location of fresh water sample (LBFW8), W 280 cm, D 18 cm, Flow (middle) 0.002/0.001 (left side) 0.004/0.011 (right side) 0.012/0.021
37	18/08/2010	11:03	NO 38723 00855	Figure 29		30 sea gulls. Lots of dogs being walked along the beach. Photograph of abandoned power station.
38	18/08/2010	11:26	NO 38209 00406	Figure 30		River Leven. 12 swans, 100 sea gulls, 2 ducks.
39	18/08/2010	11:28	NO 38122 00430	Figure 30	LBFW9	Location of fresh water sample (LBFW9), unable to measure due to large size
40	18/08/2010	11:34	NO 38212 00435	Figure 30		Pumping station (no longer in use?) for power station
41	18/08/2010	11:58	NO 38846 01032	Figure 31		Public toilets

Sampling

Water and shellfish samples were collected at sites marked on the maps in Figures 2 and 3 respectively. Bacteriology results follow in Tables 2 and 3.

Samples of seawater were tested for salinity by the laboratory using a salinity meter under controlled conditions. These results are shown in Table 2, given in units of grams salt per litre of water. Note that this is equivalent to ppt.

Table 2. Water sample *E. coli* results

No.	Sample Ref.	Date	Position	Type	*E. coli* (cfu/100 ml)	Salinity (g/L)
1	LBSW1	16/08/2010	NT 46538 99337	Sea water	<10	36.7
2	LBSW2	16/08/2010	NO 41699 02302	Sea water	10	35.6
3	LBSW3	16/08/2010	NO 39790 01425	Sea water	20	32.0
4	LBSW4	16/08/2010	NT 38884 99111	Sea water	<10	35.4
5	LBSW5	17/08/2010	NO 45349 00502	Sea water	1600	34.2
6	LBFW1	17/08/2010	NO 46368 00366	Fresh water	1900	NA
7	LBFW2	17/08/2010	NO 45793 00731	Fresh water	2000	NA
8	LBFW3	17/08/2010	NO 42797 02542	Fresh water	11000	NA
9	LBFW4	17/08/2010	NO 42266 02596	Fresh water	>10000	NA
10	LBFW5	17/08/2010	NO 41873 02563	Fresh water	<10	NA
11	LBFW6	17/08/2010	NO 41668 02563	Fresh water	30000	NA
12	LBFW7	18/08/2010	NO 39811 01854	Fresh water	300	NA
13	LBFW8	18/08/2010	NO 38866 01058	Fresh water	3400	NA
14	LBFW9	18/08/2010	NO 38122 00430	Fresh water	1400	NA

Table 3. Shellfish sample *E. coli* results

No.	Sample Ref.	Date	Position	Species	Depth	Result (*E. coli* MPN/100 g)
1	LB Razor 1	16/08/2010	NT 46538 99337	Razor fish	5.6	<20
2	LB Razor 2	16/08/2010	NO 41699 02302	Razor fish	3.1	<20
3	LB Razor 3	16/08/2010	NO 39790 01425	Razor fish	2.7	<20

Table 4. Salinity profiles

Profile	Date	Time	Position	Depth (m)	Temp (˚C)	Salinity (ppt)
1	17/08/2010	14:13	NT 46538 99337	<1	13.9	33.65
				2	13.8	35.93
				3	13.7	36.09
				4	13.7	36.10
				5	13.7	36.10
				6	13.7	36.10
				7	13.7	36.10
				8	13.7	36.09
				9	13.8	36.08
				10	13.8	36.05
2	17/08/2010	15:10	NO 41699 02302	<1	14.4	36.20
				2	14.2	36.15
				3	14.0	36.21
3	17/08/2010	15:49	NO 39790 01425	<1	14.1	36.09
				2	13.8	36.16
				3	13.8	36.17
				4	13.8	36.18

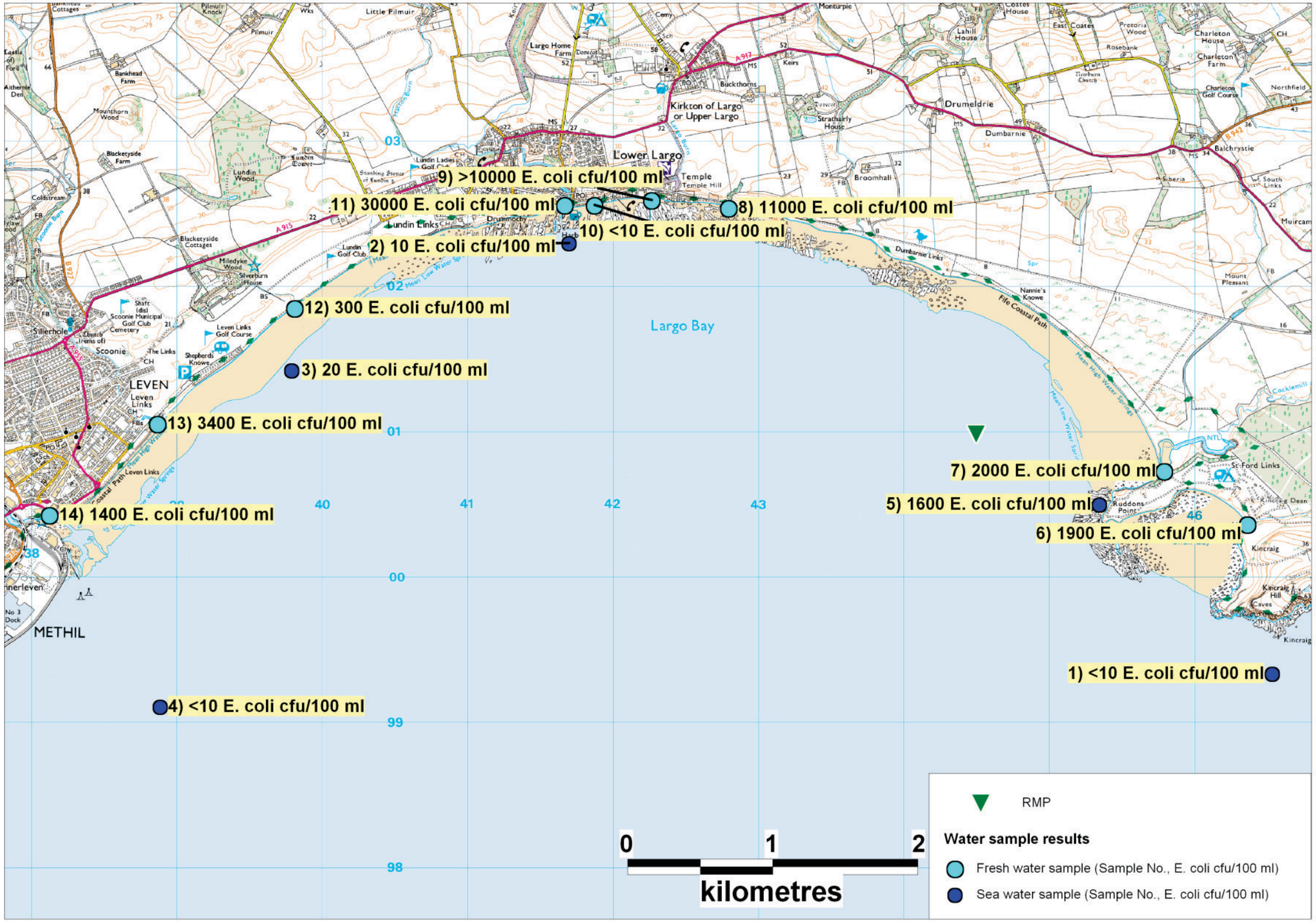

Figure 2. Water sample results

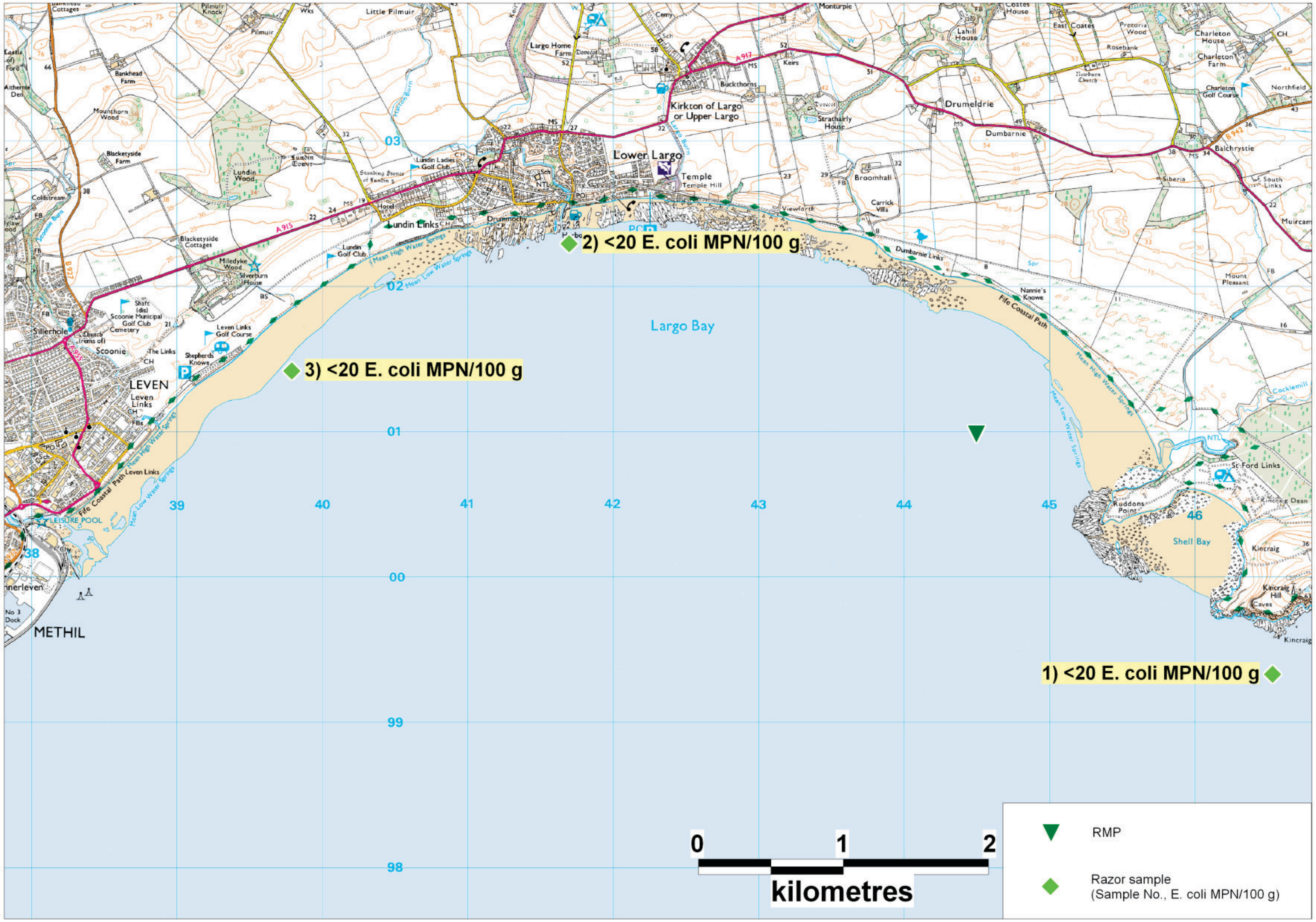

Figure 3. Shellfish sample results

Photographs

Figure 4. Pod of ten dolphins swimming offshore from Shell Bay

Figure 5. Shell Bay and arable and wooded land cover on shoreline

Figure 6. 50 sea gulls on shoreline

Figure 7. Lower Largo

Figure 8. Caravan Park

Figure 9. Location of fresh water sample (LBFW1)

Figure 10. Inspection cover & outfall pipe. Also location of sea water sample (LBSW5)

Figure 11. Location of fresh water sample (LBFW2)

Figure 12. Sewage fungus in the stream at the location of fresh water sample (LBFW2)

Figure 13. Fishing boat off shore

Figure 14. Location of fresh water sample (LBFW3)

Figure 15. Location of fresh water sample (LBFW4)

Figure 16. Septic tanks/pumping station

Figure 17. Public toilets

Figure 18. Inspection cover, no sign of outfall pipe

Figure 19. Three white pipes coming from a house on the beach, location of fresh water sample (LBFW5)

Figure 20. Looking north towards Lower Largo

Figure 21. River running under railway bridge

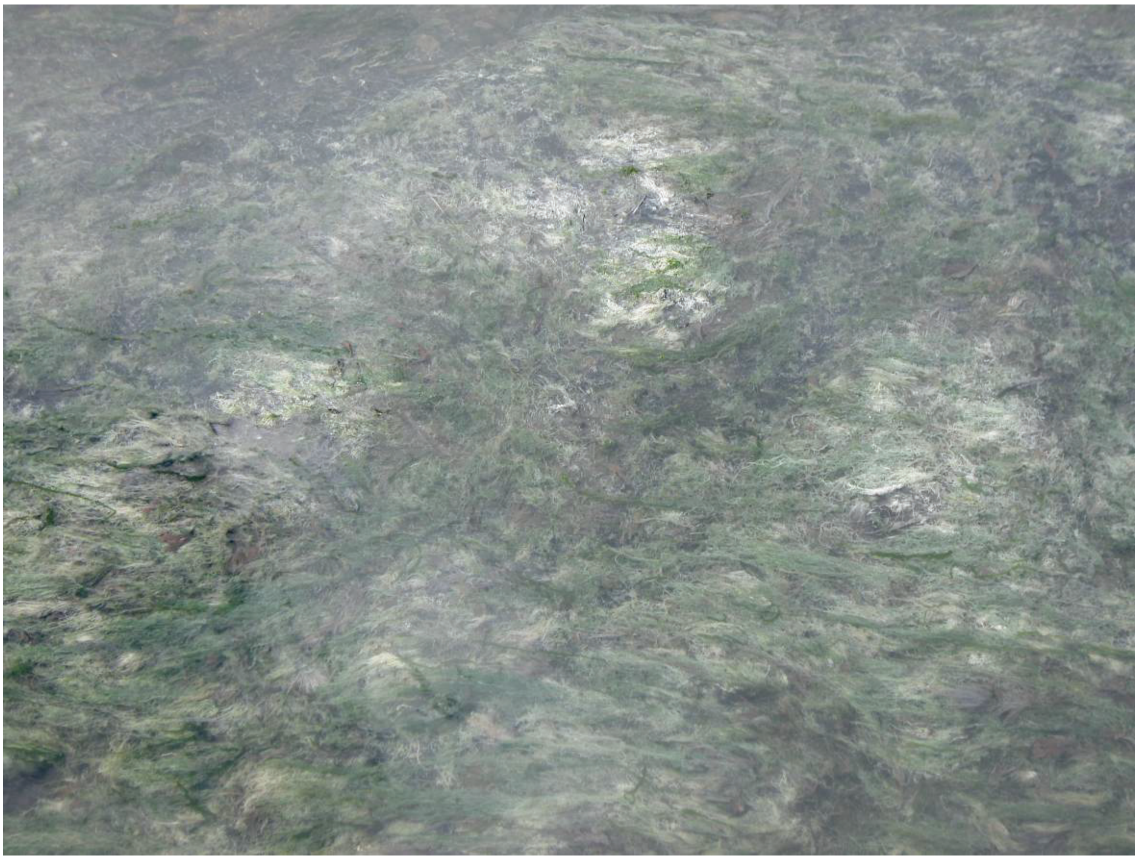

Figure 22. River with a large amount of sewage fungus & a strong smell of sewage. Location of fresh water sample (LBFW6)

Figure 23. Inspection cover

Figure 24. Septic tank and outfall pipe covered in green algae, could not locate end of pipe

Figure 25. 5 inspection covers and 2 large green units, possible pumping station, no signage

Figure 26. Location of fresh water sample (LBFW7)

Figure 27. Holiday caravan park on beach

Figure 28. Location of fresh water sample (LBFW8)

Figure 29. Abandoned power station

Figure 30. River Leven, 12 swans, 100 seagulls, 2 ducks. Also location of fresh water sample (LBFW9)

Figure 31. Pumping station for power station

Figure 32. Public toilets