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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Three Rivers Estuary

January 2014

Food Standards Agency

Cover photo: St Ishmaels Point

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Statement of use

This report provides a sanitary survey relevant to bivalve mollusc beds within the Three Rivers estuary, as required under EC Regulation 854/2004 which lays down specific rules for official controls on products of animal origin intended for human consumption. It provides an appropriate hygiene classification zoning and monitoring plan based on the best available information with detailed supporting evidence. The Centre for Environment, Fisheries & Aquaculture Science (Cefas) undertook this work on behalf of the Food Standards Agency (FSA).

Report prepared by

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Revision history

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Consultation

Consultee	Date of consultation	Date of response
Carmarthenshire CC	29/01/2014	10/07/2014
Natural Resources Wales/Cyfoeth Naturiol Cymru	06/02/2014	07/03/2014
Welsh Government Fisheries	06/02/2014	06/03/2014
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Dissemination

Food Standards Agency, Carmarthenshire CC. The report is available publicly via the Cefas website.

Recommended Bibliographic Reference

Cefas, 2014. Sanitary survey of the Three Rivers Estuary. Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under EC regulation No. 854/2004.

Contents

1. Introduction

1.1. Legislative Requirement

Filter feeding, bivalve molluscan shellfish (e.g. mussels, clams, oysters) retain and accumulate a variety of microorganisms from their natural environments. Since filter feeding promotes retention and accumulation of these microorganisms, the microbiological safety of bivalves for human consumption depends heavily on the quality of the waters from which they are taken.

When consumed raw or lightly cooked, bivalves contaminated with pathogenic microorganisms may cause infectious diseases (e.g. Norovirus-associated gastroenteritis, Hepatitis A and Salmonellosis) in humans. In England and Wales, fish and shellfish constitute the fourth most reported food item causing infectious disease outbreaks in humans after poultry, red meat and desserts (Hughes *et al.*, 2007).

The risk of contamination of bivalve molluscs with pathogens is assessed through the microbiological monitoring of bivalves. This assessment results in the classification of BMPAs, which determines the level of treatment (e.g. purification, relaying, cooking) required before human consumption of bivalves (Lee and Younger, 2002).

Under EC Regulation 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption, sanitary surveys of BMPAs and their associated hydrological catchments and coastal waters are required in order to establish the appropriate representative monitoring points (RMPs) for the monitoring programme.

The Centre for Environment, Fisheries & Aquaculture Science (Cefas) is performing sanitary surveys for new BMPAs in England and Wales, on behalf of the Food Standards Agency (FSA). The purposes of the sanitary surveys are to demonstrate compliance with the requirements stated in Annex II (Chapter II paragraph 6) of EC Regulation 854/2004, whereby 'if the competent authority decides in principle to classify a production or relay area it must:

a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;

b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human and animal populations in the catchment area, rainfall readings, waste-water treatment, etc.;

c) determine the characteristics of the circulation of pollutants by virtue of current patterns, bathymetry and the tidal cycle in the production area; and

d) establish a sampling programme of bivalve molluscs in the production area which is based on the examination of established data, and with a number of samples, a geographical distribution of the sampling points and a sampling frequency which must ensure that the results of the analysis are as representative as possible for the area considered.'

EC Regulation 854/2004 also specifies the use of *Escherichia coli* as an indicator of microbiological contamination in bivalves. This bacterium is present in animal and human faeces in large numbers and is therefore indicative of contamination of faecal origin.

In addition to better targeting the location of RMPs and frequency of sampling for microbiological monitoring, it is believed that the sanitary survey may serve to help to target future water quality improvements and improve analysis of their effects on shellfish hygiene. Improved monitoring should lead to improved detection of pollution events and identification of the likely sources of pollution. Remedial action may then be possible either through funding of improvements in point sources of contamination or as a result of changes in land management practices.

This report documents the information relevant to undertake a sanitary survey for mussels (*Mytilus* spp.) and cockles (*Cerastoderma edule*) in the Three Rivers estuary. The area was prioritised for survey in 2013-14 by a shellfish hygiene risk ranking exercise of existing classified areas.

1.2. Area description

The Three Rivers estuary survey area is situated on the south west coast of Wales and opens out into Carmarthen Bay. It is a double spit enclosed estuary with three converging river channels. It covers an area of around 37 km², of which 91% is intertidal (Futurecoast, 2002).

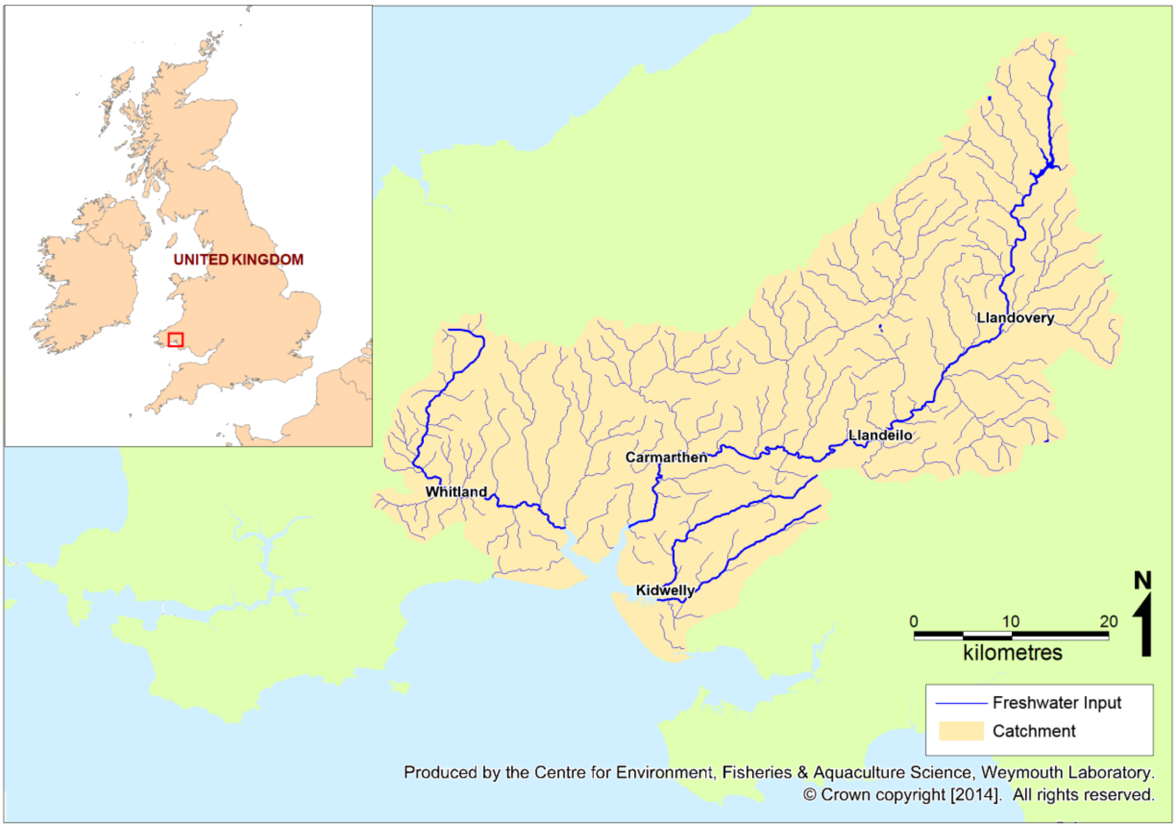


Figure I.1 Location of the Three Rivers estuary

Carmarthen Bay and its estuaries, including the Three Rivers estuary have been recognised for their variety of habitats; intertidal mudflats and sandflats, sand dunes, shallow bays and extensive saltmarsh system and the wildlife communities that they support. Consequently, the area has been classified as a Special Area of Conservation (SAC) and the survey area is protected by five Sites of Special Scientific Interest (SSSI) and a Local Nature Reserve (LNR). There are four main watercourses which drain the catchment; the largest is the Afon Tywi which drains around 50% of the entire catchment followed by the Afon Taf, Gwendraeth Fach and Gwendraeth Fawr. The latter two drain to the same arm of the estuary. The Three Rivers supports a small mussel fishery, and has sporadically supported a large cockle fishery. The cockle fishery has been closed due to low stock levels since 2011 apart from two brief openings in 2012.

1.3. Catchment

The hydrological catchment of the Three Rivers estuary is large (2,052 km^2), extending into the Cambrian Mountains in its upper reaches where elevations exceed 800 m. It is predominantly covered by rural land, principally pastures, with areas of forestry and natural areas in the upper catchment (Figure I.1). There are also some urban areas which generally lie on the banks of the main rivers, but these cover less than 4 % of the area. The total resident population within the catchment is about 153,000, of which about 10 % reside in the main town of Carmarthen on the upper reaches of the tidal Tywi.

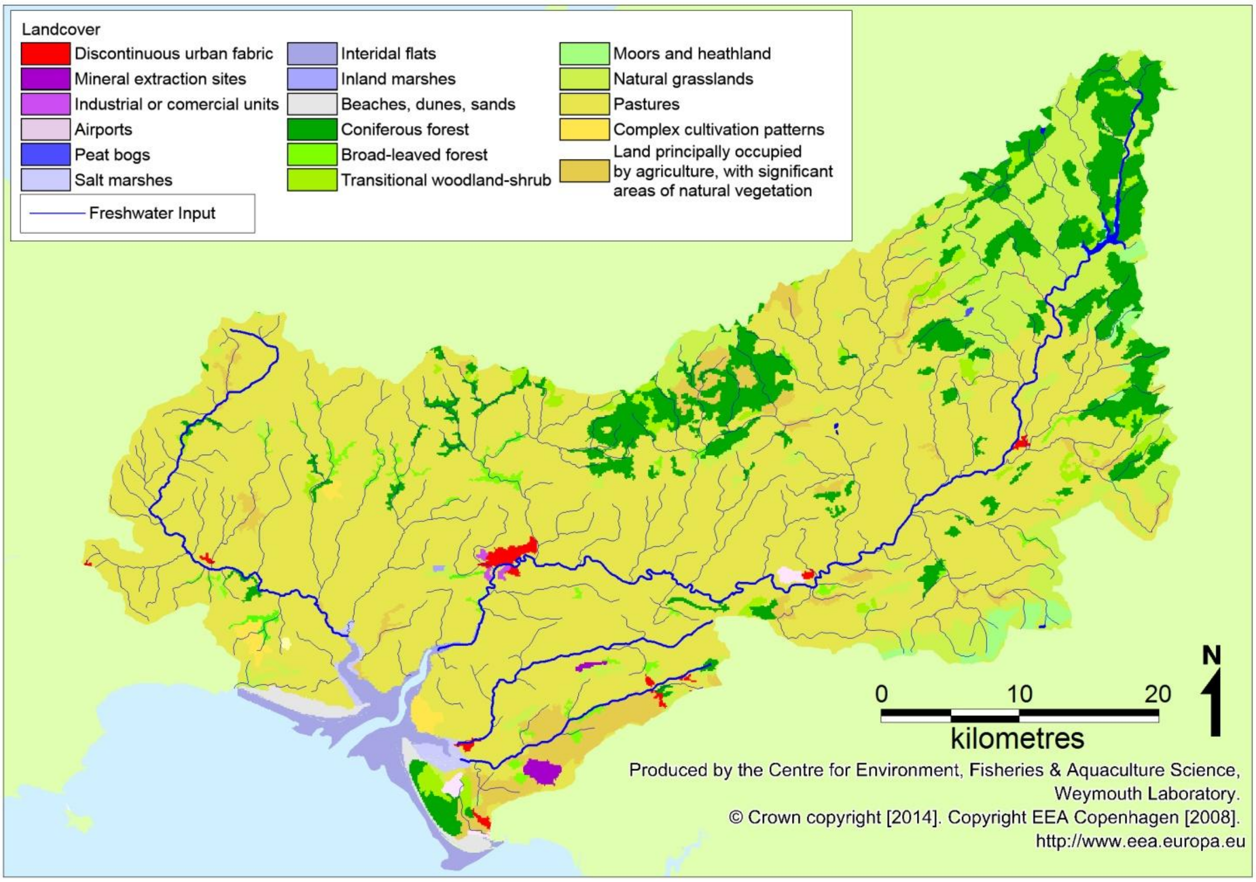


Figure I.1 Landcover in the Three Rivers catchment area

Different land cover types will generate differing levels of contamination in surface runoff. Highest faecal coliform contribution arises from developed areas, with intermediate contributions from the improved pastures and lower contributions from the other land types (Kay *et al*. 2008a). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, particularly for improved grassland which increase up to 100 fold. The hydrogeology of the catchment primarily comprises of low permeability sandstone and mudstone with high permeability limestone in the south of the catchment towards the Gower Peninsular (May, 2003). The topography and geology of the catchment is such that there will generally be relatively high rates of runoff and the rivers will respond rapidly to rainfall.

2. Recommendations

It is recognised that the there are slight uncertainties about the exact distribution of some stocks, and that the recommended RMPs may require some adjustments to their locations following the first sampling run. Any adjustments should follow the principles identified in the recommendations (e.g. samples should be taken as far up-estuary as stocks extend). Carmarthenshire Council should communicate any adjustments to the classification team at Cefas.

2.1. Cockles

Cockle stocks in the Three Rivers estuary are all temporarily declassified at present. The fishery is closed, but may be reopened at any time from April 2015. The LEA will need to ensure classifications are in place prior to any fishery commencing Stock surveys, the results of which will indicate whether the fishery may be opened, are undertaken in March.

The three river channels are subject to different sources of contamination, and are partially separated in hydrological terms, so the following three classification zones are proposed.

Taf

Cockle stocks here can extend from Ginst Point up almost as far as Laugharne. The firing range at Ginst Point is not routinely accessible to sampling officers. The principle contaminating influence within this zone is land runoff from the wider catchment, and almost all of this arrives in the estuary upstream from the cockle beds. More locally, there are some minor freshwater inputs in the Laugharne area, as well as the Laugharne STW and three intermittent sewage discharges from this sewage catchment. It is therefore recommended that the RMP be located just south of Laugharne, adjacent to the drainage channel that the local inputs from Laugharne follow across the intertidal, as close to Laugharne as stocks extend. The classification status of this zone is temporarily declassified, and will require four samples taken not less than one week apart to be reclassified as no samples have been taken within this zone since 2012. Carmarthenshire Council indicate that access to anywhere in this zone is problematic, either due to the muddy nature of the substrate or the presence of the firing range. This zone may therefore have to remain declassified unless a safe and efficient way of accessing stocks in the Laugharne area can be found.

Tywi

Commercial cockle stocks here are located off Wharley Point. The principle contaminating influence within this zone is land runoff from the wider catchment, and almost all of this arrives in the estuary upstream from the cockle beds. There are also several sewage works discharging to this arm of the estuary, and again all of them are upstream of the cockle beds. The closest identified sources to the cockle bed are the Llanstephan STW and a small stream at Llanstephan, about 750 m upstream. It is therefore recommended that the RMP be located at the northern end of the cockle bed (Llansteffan South). To reinstate the classification monthly monitoring must be restarted as quarterly sampling has been maintained on this cockle bed.

Gwendraeth

This zone includes two areas of cockles, one of which lies in the central reaches of the Gwendraeth arm to the south of the main river channel, and another which lies off the caravan park on the north shore of the outer reaches of this zone. The principle sources of contamination within this zone are likely to be the two main rivers, both of which enter at the head of the estuary arm. The Kidwelly STW also discharges to the head of this zone. The saltmarsh that borders the south shore is grazed, so tidal inundation of this area is likely to mobilise significant amounts of contamination from livestock. There is a small sewage works (Llansaint STW) that discharges to the north shore just east of the caravan park via a small watercourse. There is also a relatively large private discharge serving the caravan park that discharges to the outer reaches of the main river channel. It is concluded that ideally, the RMP should be located at the eastern (upstream) end of the main central cockle bed to best capture contamination from the main sources at the head. However, access to the main bed is problematic due to the firing range. If access to the firing range cannot be negotiated, a reserve RMP off the caravan park will have to be used instead. This should be located as close to the main channel as possible, and at the eastern end of the cockle bed to best capture riverine inputs, and the Llansaint and caravan park discharges. Quarterly sampling has been maintained at the Gwendraeth RMP, so the start of monthly sampling at whichever RMP that is used will be sufficient for reclassification.

Sampling requirements

Sampled stock should be of a harvestable size (i.e. should not pass through a 19 mm square aperture) and sampling should be undertaken by hand. Sampling should be on a monthly basis. A tolerance of 100 m should be sufficient to allow repeated sampling.

2.2. Mussels

There are two minor mussel beds in the survey area which may be subject to occasional commercial harvesting.

St Ishmaels Point

There is a small mussel bed at St Ishmaels Point which is subject to commercial hand gathering from time to time. It is not thought to be commercially active at present, so Carmarthenshire Council may wish to consider temporarily declassifying it if the industry agrees. This area will be primarily influenced by upstream sources in the Tywi channel, as contamination from the Gwendraeth channel will tend to be carried out the estuary without coming into contact with the mussel bed. It is therefore recommended that the RMP be located at the most northerly part of the mussel bed.

Wharley Point

Ephemeral settlements of mussels occur from time to time off Wharley Point, extending towards the Taf channel, although there are no commercially viable stocks there at present. The exact extent of settlements is uncertain and likely to vary. Classification will only be required on request of the industry. This bed will be influenced by contamination delivered by both the Tywi and Taf channels. As settlements here are closer to the Taf channel, and may extend right up to this channel at low water, it is recommended that the RMP is located as close to the Taf channel as possible, and as far west as possible. Zone boundaries and RMP locations may require revision as there is considerable uncertainty about the possible extent of any future settlements here.

Sampling requirements

Monthly sampling will be required for a year round classification. Sampling should be via hand and stock sampled should be of a harvestable size (51 mm). A tolerance of 100 m should allow for repeated sampling.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Three Rivers
Cefas Main Site Reference	M071
Ordnance survey 1:25,000 map	Explorer 177
Admiralty Chart	1076

Shellfishery

Species/culture	Mussels	/	Wild
	Cockles	/	Wild
Seasonality of harvest	Year round		

Local Enforcement Authority

Name	Carmarthenshire County Council Ty Elwyn Town Hall Square Llanelli SA15 3AP
Environmental Health Officer	Mark Liley
Telephone number ☎	01554 742250
Fax number	01554 742115
E-mail	MLiley@carmarthenshire.gov.uk

3.2. Requirement for Review

The Guide to Good Practice for the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas (EU Working Group on the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas, 2010) indicates that sanitary assessments should be fully reviewed every 6 years, so this assessment is due a formal review in 2020. The assessment may require review in the interim should any significant changes in sources of contamination come to light, such as the upgrading or relocation of any major discharges.

Table 3.1: Number and location of representative monitoring points (RMPs) and frequency of sampling for classification zones within the Three Rivers estuary

Classification zone	RMP*	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Taf	B071L	Laugharne	SN 3107 1014	51° 45.863’ N 04° 26.964’ W	Cockles	Wild	Hand	Hand	100 m	Monthly	Requires 4 samples at least one week apart to reinstate classification.
Tywi	B071M	Llansteffan South	SN 3536 0989	51° 45.805’ N 04° 23.230’ W	Cockles	Wild	Hand	Hand	100 m	Monthly	Requires monthly sampling to start to reinstate classification.
Gwendraeth	B071N	Gwendraeth Upper	SN 3794 0659	51° 44.072’ N 04° 20.897’ W	Cockles	Wild	Hand	Hand	100 m	Monthly	**Preferred** RMP for Gwendraeth in public health protection terms. LEA have indicated that it is inaccessible due to the firing range. Requires monthly sampling to start for reclassification of this zone

Classification zone	RMP*	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
	B071I	Caravan Park	SN 3659 0684	51° 44.183' N 04° 22.076' W	Cockles	Wild	Hand	Hand	100 m	Monthly	**Reserve** RMP for the Gwendraeth to ensure there is a routinely accessible RMP for this zone. Not considered entirely suitable in public health protection terms. Requires monthly sampling to start for reclassification of this zone
St Ishmaels Point	B071J	St Ishmaels Point North	SN 3605 0775	51° 44.664' N 04° 22.570' W	Mussels	Wild	Hand	Hand	100 m	Monthly	
Wharley Point	B071K	Wharley Point West	SN 3321 0952	51°45.567' N 04°25.087' W	Mussels	Wild	Hand	Hand	100 m	Monthly	New zone and RMP. Will only require classification on industry request. The extent of the mussel bed when it forms is uncertain, so some revision to boundaries and RMP location may be required.

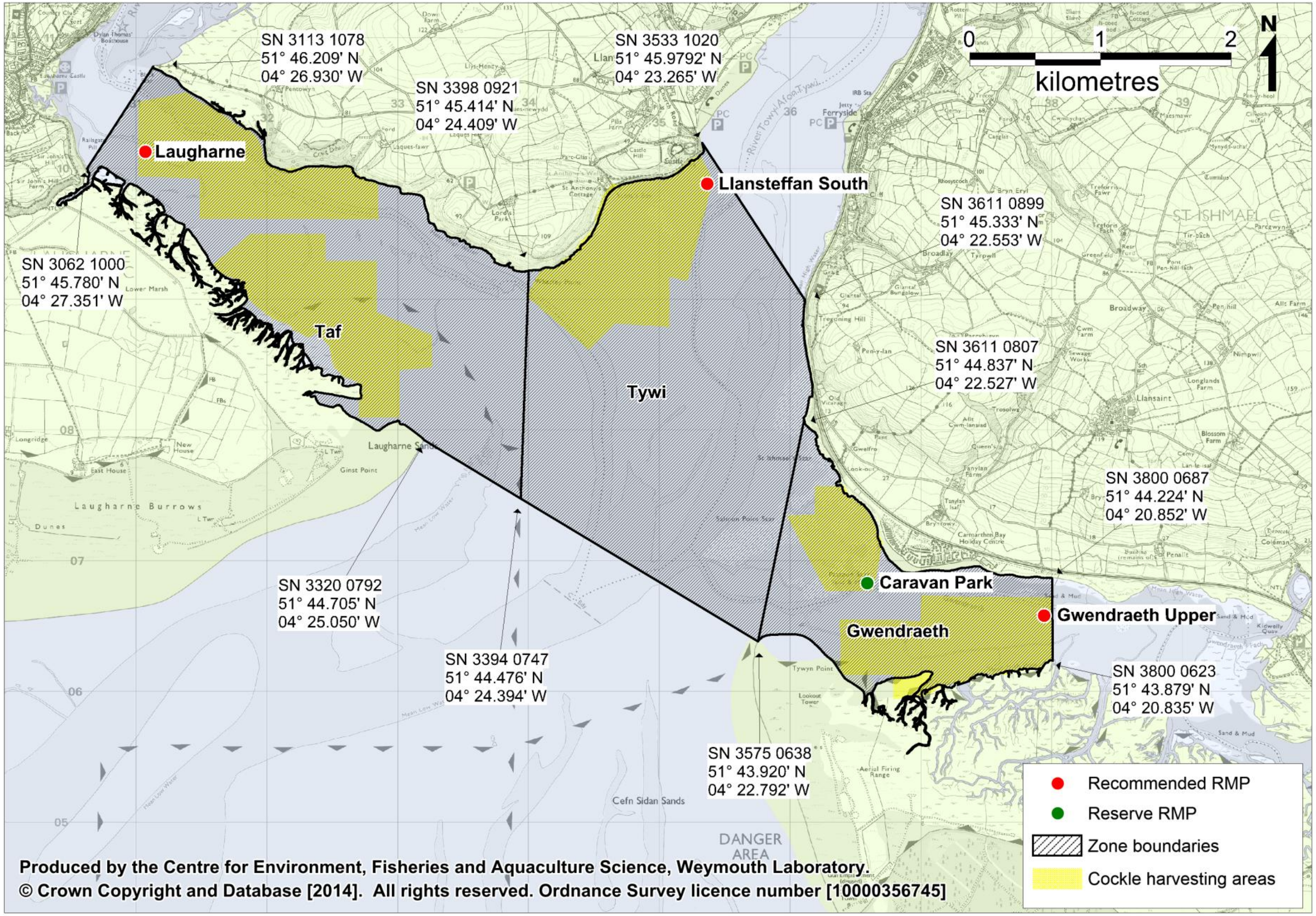


Figure 3.1: Recommended zoning and monitoring arrangements (cockles)

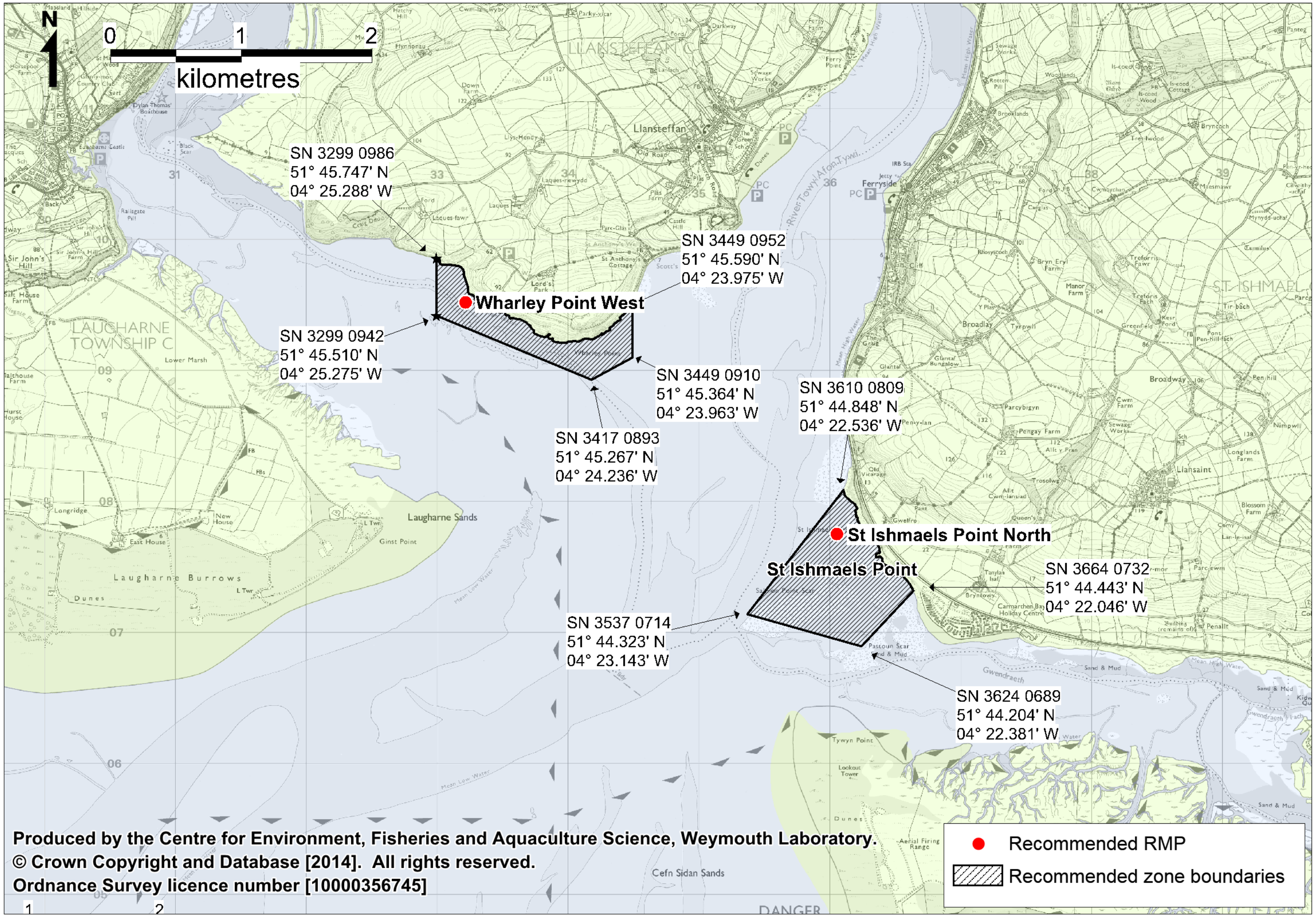


Figure 3.2: Recommended zoning and monitoring arrangements (mussels)

4. Shellfisheries

4.1. Description of fisheries

Periodically, the Three Rivers supports a major cockle fishery. There is also a mussel bed that is sometimes subject to commercial harvesting. Figure 4.1 shows the areas that Welsh Government Fisheries advise hold the main cockle stocks. It also shows the approximate areas where the mussel beds are located.

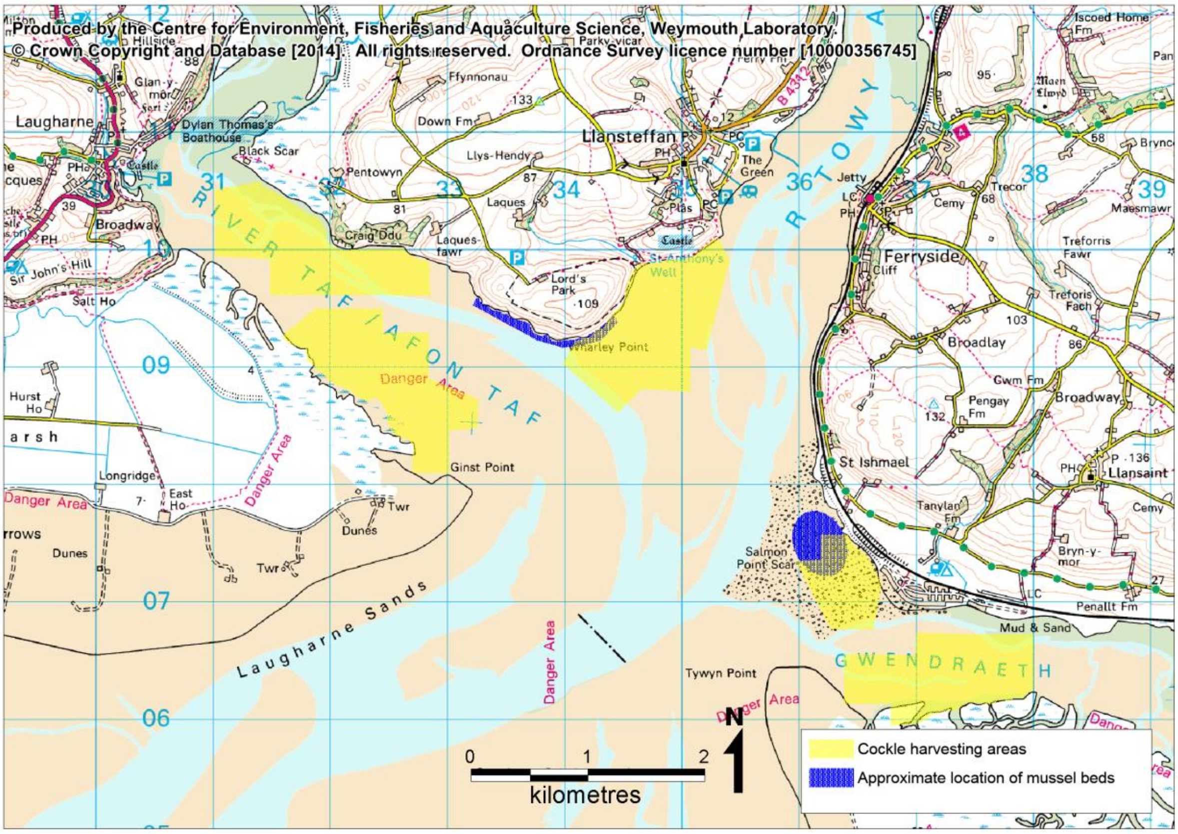


Figure 4.1: Commercial bivalve stocks in the Three Rivers estuary

Settlement of cockles occurs in all three arms of the estuary, with the main beds currently located in the areas indicated in Figure 4.1. Settlements have occurred in the past in the Tywi arm at Ferryside, but these are occasional and minor and Welsh Government Fisheries advise that this area will not require classification. The sandbanks in the mouth of the estuary are more exposed and do not support cockle beds. Cockle stocks in the Three Rivers estuary are naturally more variable than those in neighbouring Burry Inlet. As a consequence, there have been high levels of fishing effort in some years, and the fishery has been closed in other years when stocks have been deemed insufficient to support a fishery. The spring 2013 cockle surveys identified low stock levels (estimated at between 1 and 1105 tonnes) indicating poor recruitment in 2012, and the fishery is currently closed until 31st

March 2015. It will only reopen if surveys in spring 2015 indicate a significant increase in stocks. In contrast to the recent run of poor stocks, around 2,000 gatherers participated in a Three Rivers cockle fishery in August 2005 for example, during which 8,200 tonnes were landed (Otto *et al*, 2007).

There are two areas which support mussels of potential commercial interest, at St Ishmaels Point and at Wharley Point. The former is a more regular presence and the latter is more ephemeral. They sometimes yield harvestable quantities of marketable mussels, so may subject to limited commercial hand gathering from time to time. Neither has been surveyed in recent years, so the exact extent of the beds and the status of stocks therein are uncertain.

4.2. Fishery management

Cockle fisheries in the district are currently regulated under a series of byelaws. These include a minimum size (must not pass through a 19 mm square aperture), a restriction to hand gathering only, and a permit scheme specific to the Three Rivers estuary. Whilst there is no formal closed season, the fishery may be closed at any time for the preservation of stocks, as is currently the case. The management of cockle fisheries in Wales is currently under review but the outcome of this is yet to be decided (Welsh Government, 2013). Local byelaws also indicate that no closed season applies to mussels, and a minimum landing size of 51 mm applies.

4.3. Hygiene Classification

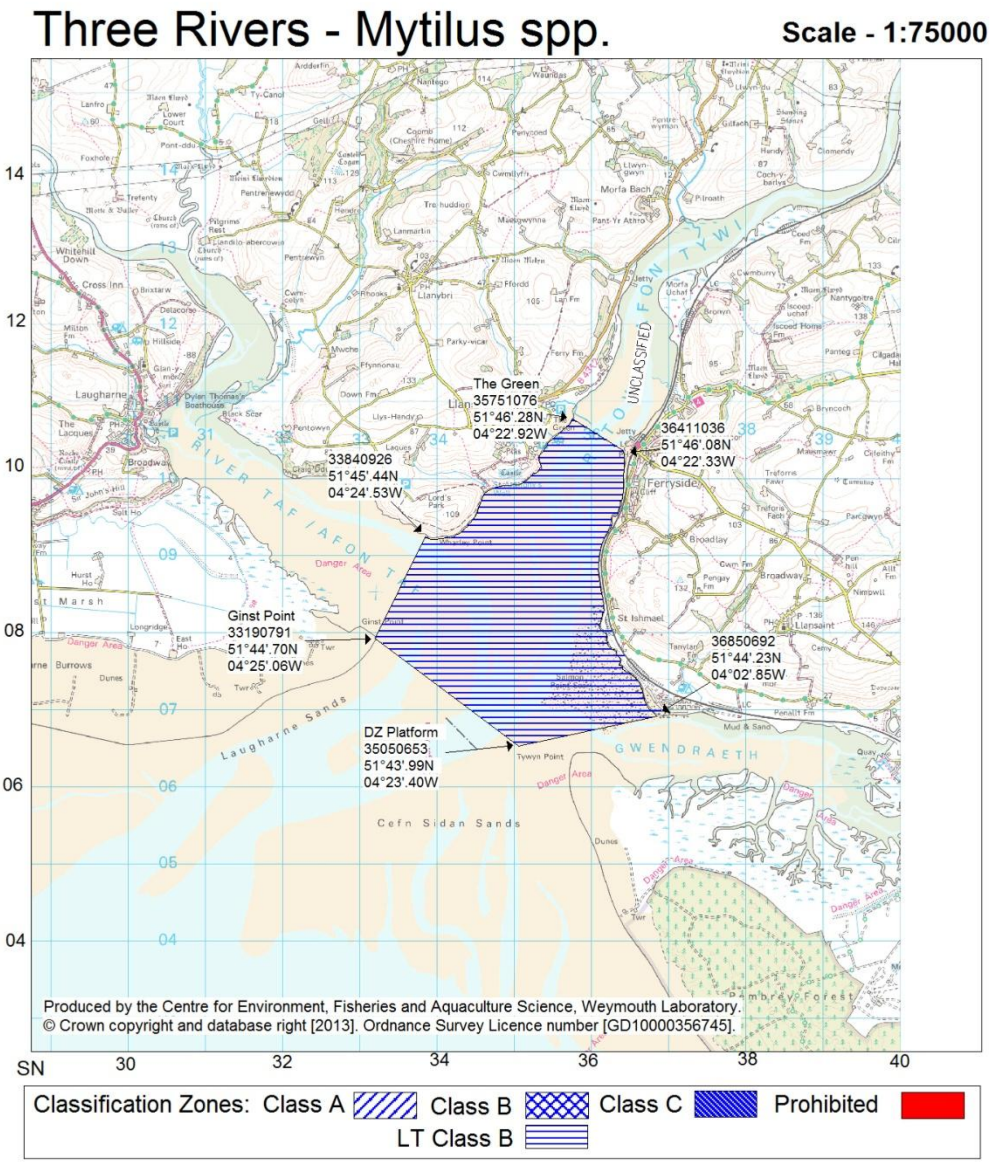
Table 4.1 lists all classifications within the survey area since 2005.

Table 4.1: Classification history for Three Rivers, 2005 onwards

Area	Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
St Ishmaels	Mussels	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Gwendraeth	Cockles	B	B	-	-	-	C	B	B	C	-
Wharley Point	Cockles	B-LT	B-LT	B-LT	B-LT	-	C	B	B	B	-
Ferryside	Cockles	B-LT	B-LT	B-LT	B-LT	-	-	-	-	-	-
Ginst Point	Cockles	-	B	B	B	-	-	B	B	-	-

LT denotes long term classification

All cockle zones are currently listed as being temporarily declassified. Quarterly sampling has continued at Gwendraeth and Wharley Point, but Ginst Point and Ferryside have not been sampled since 2012. To reinstate a classification at Gwendraeth and Wharley Point, a resumption of monthly sampling is required. To reinstate a classification at Ginst Point, four samples taken not less than a week apart would be required. The zones that these RMPs represent are not formally defined, but it is assumed that Gwendraeth represents the Gwendraeth arm, Wharley Point represents the cockle bed at Wharley Point, Ferryside represents the former Ferryside bed in the Tywi channel, and Ginst Point represents the Taf channel. Mussels have only been sampled at St. Ishmaels.



Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2013

The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

Further details on the classified species and the areas may be obtained from the responsible Food Authority. Enquiries regarding the maps should be directed to: Shellfish Microbiology, CEFAS Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset DT4 8UB.
(Tel: 01305 206600 Fax: 01305 206601)

N.B. Lat/Longs quoted are WGS84
Seperate map available for C. edule at Three Rivers

Food Authority: Carmarthenshire County Council

Figure 4.2: Current mussel classifications

Table 4.2: Criteria for classification of bivalve mollusc production areas.

Class	Microbiological standard[1]	Post-harvest treatment required
A[2]	Live bivalve molluscs from these areas must not exceed 230 Most Probable Number (MPN) of *E. coli* 100g^{-1} Fluid and Intravalvular Liquid (FIL)	None
B[3]	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution MPN test of 4,600 *E. coli* 100g^{-1} FIL in more than 10% of samples. No sample may exceed an upper limit of 46,000 *E. coli* 100g^{-1} FIL	Purification, relaying or cooking by an approved method
C[4]	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution Most Probable Number (MPN) test of 46,000 *E. coli* 100g^{-1} FIL	Relaying for, at least, two months in an approved relaying area or cooking by an approved method
Prohibited[6]	>46,000 *E. coli* 100g^{-1} FIL[5]	Harvesting not permitted

[1] The reference method is given as ISO 16649-3.
[2] By cross-reference from EC Regulation 854/2004, via EC Regulation 853/2004, to EC Regulation 2073/2005.
[3] From EC Regulation 1021/2008.
[4] From EC Regulation 854/2004.
[5] This level is not specifically given in the Regulation but does not comply with classes A, B or C. The competent authority has the power to prohibit any production and harvesting of bivalve molluscs in areas considered unsuitable for health reasons.
[6] Areas which are not classified and therefore commercial harvesting of LBMs cannot take place. This also includes areas which are unfit for commercial harvesting for health reasons e.g. areas consistently returning prohibited level results in routine monitoring and these are included in the FSA list of designated prohibited beds

5. Overall Assessment

5.1. Aim

This section presents an overall assessment of sources of contamination, their likely impacts, and patterns in levels of contamination observed in water and shellfish samples taken in the area under various programmes, summarised from supporting information in the previous sections and the Appendices. Its main purpose is to inform the sampling plan for the microbiological monitoring and classification of the bivalve mollusc beds in this geographical area.

5.2. Shellfisheries

The Three Rivers estuary contains commercially harvested stocks of both cockles and mussels. The cockle fishery is much larger than the mussel fishery, but due to the fluctuating nature of stocks within the area it does not support a fishery every year. The areas which support settlements are the lower reaches of the three estuary channels. The fishery is currently closed for reasons of stock preservation until at least the 31st March 2015. Its opening at this time will depend on the results of the spring cockle survey in March 2015. In good years the fishery can be very prolific, for example in August 2005 around 2,000 individuals participated and about 8,200 tonnes were landed. Cockle harvesting here is regulated under a series of byelaws, including a permit scheme, a restriction to hand gathering only, and a minimum size (they must not be able to pass through a 19 mm square aperture). There is no closed season for this species in the district.

Four RMPs have been used to classify the Three Rivers estuary for cockles. The zones that these RMPs represent are not formally defined, but it is assumed that Gwendraeth represents the Gwendraeth arm, Wharley Point represents the cockle bed at Wharley Point, Ferryside represents the Tywi channel, and Ginst Point represents the Taf channel. All cockle zones are currently listed as being temporarily declassified. Quarterly sampling has continued at Gwendraeth and Wharley Point, but Ginst Point and Ferryside have not been sampled since 2012. To reinstate a classification at Gwendraeth and Wharley Point, a resumption of monthly sampling is required. To reinstate a classification within the zone represented by Ginst Point, four samples taken not less than a week apart would be required. A classification is no longer required at Ferryside as further settlements here are considered unlikely.

There are mussel beds at St Ishmaels Point, where there is a suitable hard substrate for regular settlements, and at Whaley Point where the substrate is softer and the beds are more ephemeral. They sometimes yield harvestable quantities of marketable mussels, so are subject to limited commercial hand gathering from time to time. They have not been surveyed in recent years, so the exact extent of these beds and the status of stocks therein are uncertain. Carmarthenshire Council advise that the mussel fishery is not active at present.

The RMPs selected will need to be safely accessible from the shore, as well as containing sufficient stocks for regular sampling. Carmarthenshire Council has indicated that it is not possible to sample the Ginst Point area due to the Pendine firing range which is operational on weekdays. The Laugharne area also presents difficulties due to the soft substrate. There is another firing range at Pembrey which prevents sampling officers accessing the cockle beds to the south of the Gwendraeth estuary channel during the working week. This leaves only a small proportion of the cockle stocks within the Gwendraeth arm routinely accessible, and precludes access to any of the cockle beds in the Taf arm.

5.3. Pollution Sources

Freshwater Inputs

All rivers and streams carry some contamination from land runoff and so will require consideration in this assessment. A modelling study has indicated that the majority of faecal indicator flux into the estuary complex derives from land runoff rather than sewage, and accounts for almost all of it during high flow events. The impacts of freshwater inputs will be greatest where they enter the estuary, and within or immediately adjacent to any drainage channels they follow.

The Three Rivers estuary drains a catchment area of 2,052 km² within which the primary land use is pasture. Within this area there are effectively three separate sub-catchments draining to each of the three arms of the estuary. The largest watercourse is the Tywi, which is a major spate river that drains to the central arm of the estuary. Its upper reaches are of a high gradient, where land is a mixture of forestry and rough grazing, and its lower reaches have a gentler gradient, and are more meandering with extensive floodplain. There is a reservoir in the upper reaches which is used to maintain flows for abstraction further downstream, and controlled releases may occur in spring and late summer to assist the passage of migratory fish. The mean discharge recorded at the lowest gauging station on the Tywi is about 40 m^3/sec, and about 65 % of the Three Rivers catchment drains to this arm of the estuary, so the influence of land runoff is likely to be highest here. A water sample taken from the Tywi during the shoreline survey contained 2,000 *E. coli*/100ml.

River inputs to the Taf arm of the estuary are of a similar profile in terms of gradient and land use to the Tywi, but smaller, with about 25 % of the Three Rivers catchment draining to this channel. Water samples taken from one of the main inputs to the head of the Taf channel (the Cynin/Dewi Fawr) contained 12,000 *E. coli*/100ml, but the Taf itself was not sampled.

In contrast to the other main rivers, the Gwendraeth Fach and Fawr which drain to the eastern arm are more lowland in character, and of a medium-low gradient throughout their length. Samples taken from these two watercourses during the shoreline survey contained 600 and 1,700 *E. coli*/100ml respectively. Around 10 % of the catchment drains to this arm of the estuary.

In all three arms of the estuary, the principle freshwater inputs are to the head, although there are some smaller streams draining at regular intervals throughout. Underlying gradients of decreasing levels of faecal indicator bacteria associated with land runoff from the heads to the mouth of the estuary are anticipated. Therefore the influence of freshwater borne contamination is likely to be highest towards the up-estuary ends of the shellfish beds, so a general principle of locating RMPs at the up-estuary end of classification zones should be applied. Superimposed on this there may be more localised 'hotspots' associated with smaller freshwater inputs discharging in close proximity to the shellfish beds which should also be considered in the sampling plan.

Within the Taf arm, all significant freshwater inputs observed during the shoreline survey were up-estuary of the shellfish. This included a number of smaller watercourses discharging in the vicinity of Laugharne, and these may be of local influence to the cockle bed towards the western shore. A small and uncontaminated watercourse discharges to the southern end of a cockle bed at Ferryside in the Tywi arm. Its bacterial loading at the time of shoreline survey was only 1.8×10^9 *E. coli*/day. Apart from this all, significant freshwater inputs observed during the shoreline survey within the Tywi arm were up-estuary from the shellfish. No significant freshwater inputs were observed in the immediate vicinity of shellfish resources in the Gwendraeth arm, and all important freshwater inputs were to its head.

Volumes of runoff are generally higher in the late autumn and winter, although high flow events may occur at any time of the year. Increased levels of runoff are likely to result in an increased bacterial loading carried into coastal waters, particularly as river levels rise when heavy rain occurs following a dry period (the 'first flush'). Most rivers are likely to respond rapidly to rainfall so the bacterial loadings they deliver to the estuary are likely to fluctuate greatly in response to rainfall. The modelling study predicted a five-fold increase in fluxes of faecal indicator bacteria into the estuary during high river flow events.

Human Population

Total resident population within census areas contained within or partially within the catchment area was approximately 153,000 at the time of the last census in 2011. The largest settlement in the area is Carmarthen, which had a population of about 16,000. Most of the population resides around the Carmarthen area, and in the Gwendraeth catchment. Some urban runoff will enter coastal waters from these built up areas, but the pattern of impacts from sewage will depend on the nature of the sewerage infrastructure serving the population. Carmarthenshire attracts significant tourism, with about 3 million visitors recorded in 2010. The majority of visits were from April to October, peaking in July and August. It is therefore concluded that sewage works in the area are likely to be serving a larger population during the summer.

Sewage Discharges

There are 61 continuous water company sewage treatment works within the Three Rivers hydrological catchment. The majority of these are relatively small works serving the rural areas of the catchment that discharge to watercourses which subsequently drain to the estuary, although there are a small number which discharge directly to the estuary.

There are two sewage works discharging directly to tidal waters in the Taf arm of the estuary. The Laugharne STW discharges just to the north of an area of cockle beds. Although it provides UV treatment bacteriological testing of the effluent indicates that this is not particularly effective, and the average loading it has generated in recent years has been 5.6×10^{11} faecal coliforms/day. The St Clears STW discharges about 7 km upstream of Laugharne. It provides secondary treatment for a consented dry weather flow of 987 m^3/day and generates an estimated bacterial loading of 3.3×10^{12} faecal coliforms/day. There are a further 11 inland sewage works within the Taf estuary catchment, all of which discharge to watercourses which feed into the estuary upstream of the shellfisheries. They are estimated to generate a combined bacterial loading in the approximate order of 4×10^{12} faecal coliforms/day, although some die-off will occur on transit. All of these sewage inputs are upstream of the shellfisheries, so their impacts will be most acute at the upstream ends of the shellfish beds.

The only sewage works discharging directly to the Tywi estuary is Parc Y Splotts STW, which is the largest sewage discharge in the survey area. It provides secondary treatment for a consented dry weather flow of 7000 m^3/day and generates an estimated bacterial loading of 2.3×10^{13} faecal coliforms/day. Although the discharge is located at some distance from the shellfisheries, its large size means it is likely to have widespread impacts. Other discharges to the Tywi include Ferryside STW, Llanstephan STW, and Pantyrathro WWTW, all of which are much smaller than Parc Y Splotts STW and provide secondary treatment. These three works generate estimated bacterial loadings of 1.1 $x10^{12}$, 5.2 $x10^{11}$ and 3.8 $x10^{11}$ faecal coliforms/day respectively. They discharge to short watercourses which subsequently drain to the middle reaches of the estuary between 0.5 and 3 km upstream of the nearest shellfish resources. As well as the sewage works in coastal areas, there are a further 33 inland discharges which generate an estimated combined bacterial loading of about $1x10^{13}$ faecal coliforms/day. These all discharge to watercourses draining to the head of the estuary. As for the Taf channel, all these sewage works discharge up-estuary from the shellfisheries.

The only sewage works discharging directly to tidal waters in the Gwendraeth arm of the estuary is Kidwelly STW. This discharges to the Gwendraeth Fach channel near the head of the estuary, and is estimated to generate a bacterial loading of around $5.4x10^{12}$ faecal coliforms/day. The Gwendraeth Fach also receives effluent from two inland works (Llanddarog and Llangynderyn STWs) which are estimated to contribute a bacterial loading of around $1.1x10^{12}$ faecal coliforms/day. The Gwendraeth Fach watercourse receives effluent from four works which are estimated to generate a combined bacterial loading of about $2.3x10^{13}$ faecal coliforms/day. The majority of this derives from Pontyberem WWTW, which is about 12 km upstream of the tidal limit. As well as the above, which all discharge up-estuary of the shellfish beds in this arm of the estuary, Llansaint STW discharges to a short watercourse which then discharges to the north shore at the western end of the Carmarthen Bay Holiday Centre in close proximity to the mussel and cockle beds here. It is a relatively small works, and generates an estimated bacterial loading of only 3.17 $x10^{11}$, but its proximity to the shellfisheries may result in a small hotspot of contamination within them.

In addition to the continuous sewage discharges, there are 34 permitted intermittent overflow discharges associated with the sewer networks within 2 km of the tidal limits of the estuary. The main cluster is at Carmarthen, and there are a five at Kidwelly, three at Laugharne and two at the north end of Ferryside, four around St Clears as well as one at the Llansaint STW. One year of spill records (2012 or 2013) was available for 13 of these in summary form. These indicate that some of the monitored outfalls in the Carmarthen and St Clears sewerage catchments were the most frequent spillers, with up to 177 events recorded in one year. In the Laugharne area, one outlet (Laugharne Sewerage) spilled 41 times during a year. In the Kidwelly catchment the main spiller was the Tycoch SPS which spilled 38 times. In the Ferryside area, the sewage works overflow recorded only 14 spill events in a year. The Llansaint STW overflow was not monitored. The results of a sewer modelling study was also available for consideration. In the Carmarthen catchment the estimated annual spill volume was large (436,654 m^3) but none of the individual outlets were predicted to spill for more than 5 % of the time. Within the St Clears catchment the predicted annual spill volume was 235,068 m^3, and the storm tanks at the sewage works were predicted to spill for almost 50 % of the time. In the

Laugharne catchment annual spill volumes were relatively low at 25,604 m^3, and the main spiller was active for 1.9 % of the time. Similarly, the Kidwelly catchment was only predicted to spill 25,126 m^3/year and the main spiller was active for 3.4 % of the time. Neither the Ferryside or Llansaint STW catchments were modelled.

Intermittent discharges create issues in management of shellfish hygiene however infrequently they spill. Their impacts' are not usually captured during a year's worth of monthly monitoring from which the classification is derived as they only operate for a small fraction of the time. Thus when they do have a significant spill, heavily contaminated shellfish may be harvested under a better classification than the levels of *E. coli* within them may merit. A reactive system alerting relevant parties to spill events in real time may therefore convey better public health protection.

Although the vast majority of the survey area is served by water company sewerage infrastructure, there are also 54 permitted private sewage discharges within 2 km of the estuary, of which 33 discharge to water and 21 discharge to soakaway. Where specified, these are generally treated by small treatment works such as package plants. Those discharging to soakaway should not impact on coastal water assuming they are functioning correctly. Those discharging to watercourses will generally make a minor contribution to the bacterial loadings carried by the receiving water, but will have little bearing on the sampling plan. The exception to this is a caravan park discharge which has a maximum consented flow of 320 m^3 /day of effluent with an unspecified treatment level, although this is likely to be secondary treatment of some kind. This discharge is to the outer reaches of the Gwendraeth Fach channel, in close proximity to the shellfisheries. There may also be a seasonal variation in the volume of effluent discharged, with peak volumes in the summer.

Agriculture

Most of the land within the hydrological catchment is used for agriculture, and almost all of this is pasture. The upper reaches of the catchment support extensive sheep grazing, whilst the lower reaches are more a mix of dairy and livestock farming. Livestock census data indicates that sheep farming is widespread, with over 660,000 animals within the catchment, with highest densities present in the upper eastern areas. Large number of cattle are also present (163,000) and highest densities of these were in the lower western parts of the catchment. Some poultry are raised in the area, the majority of which are within the Gwendraeth sub-catchment. Small numbers of pigs are also farmed, mainly within the Taf catchment. During the shoreline survey livestock were observed in most areas visited.

The primary mechanism for mobilisation of faecal matter from agricultural land is via land runoff, so the geographical pattern of impacts will therefore be similar to that previously described for freshwater inputs. Fluxes of livestock related contamination into the estuary will be highly rainfall dependent. Rainfall and river flows are generally higher during the winter months, although high rainfall events may occur at any time of the year. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the 'first flush'). Numbers of sheep and cattle will increase significantly in the spring, with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. The seasonal pattern in application of manures and slurries to agricultural land is uncertain. Cattle may be housed indoors during the winter, so applications of slurry collected from such operations is likely to be spread in the late winter and spring, depending on the storage capacities of each farm.

Grazing of some areas of saltmarsh that fringe the estuary are of potential local significance to the shellfisheries. The most significant of these is to the south of the Gwendraeth estuary channel, where around 100 cattle were observed during the shoreline survey. The smaller areas of saltmarsh around the Taf estuary channel are also reported to be grazed to various extents. The main area between Laugharne and Ginst Point is reported to be only lightly grazed, whereas the other areas are grazed more intensively. Contamination deposited in the intertidal areas will be carried into the estuary via tidal inundation which is a particularly direct and predictable mechanism, the risk of which is greater during spring tides. The saltmarsh drainage channels cutting through the cockle beds in the Gwendraeth arm of the estuary are likely to be most affected by saltmarsh grazing.

In summary, the upper reaches of the three estuary arms will be most impacted by contamination of livestock origin. Therefore RMPs situated towards the up-estuary ends of the shellfish beds and by the drainage channels crossing intertidal areas are likely to capture peak levels of livestock related contamination. It is likely that the saltmarsh grazing within the Gwendraeth arm makes a significant contribution at times. Livestock numbers are highest during summer and autumn so some seasonality in impacts may be anticipated. Whilst the flux of contamination from pastures will be highly rainfall dependent, peak fluxes from grazing marsh may be anticipated on spring tides.

Boats

Boats may make overboard sewage discharges, so require consideration in this assessment. There are no ports or marinas within the survey area, but there are areas of moorings for small yachts in the Tywi channel opposite Llanstefan, and about 2 km north of Llanstefan, and in the middle reaches of the Gwendraeth arm. A small fishing fleet operates from the estuary, with 9 under 10 m vessels listed as having their home port as the Three Rivers area. A further 40 small vessels operate from nearby Burry Port and Saundersfoot. Their fishing patterns are uncertain, but in general their use of the Three Rivers estuary is likely to be limited to navigating in and out of it.

It is therefore concluded that boat traffic within the area is minor and mainly consists of pleasure craft and small fishing vessels. It is likely that the larger private vessels (yachts, cabin cruisers, fishing vessels) which have onboard toilets make overboard discharges from time to time. This may occur whilst boats are in passage, and it is quite likely that any boats in overnight occupation on the moorings will make a discharge at some point during their stay. Levels of overnight occupancy on the moorings are uncertain however. As such, the estuary channels and the mooring areas described above may be most at risk. Peak pleasure craft activity will arise in the summer, so any associated impacts are likely to follow this seasonal pattern. However, it is difficult to be more specific without any firm information about the locations, timings and volumes of such discharges, and as such boating will have little material bearing on the sampling plan.

Wildlife

The survey area encompasses a range of estuarine habitats and these attract aggregations of wildlife, some of which may be an influence on shellfish hygiene. The most significant of these is likely to be the waterbirds (wildfowl and waders) populations which overwinter in the area. Over the five winters up until 2010/11 an average total count of 37,923 overwintering birds and wildfowl were recorded within Carmarthen Bay, which includes the Three Rivers estuary. On the shoreline survey flocks of birds were observed throughout, in particular large numbers, around 500, oystercatchers were recorded on a sand bank off Wharley Point where the Taf and Twyi converge. Waders feeding on intertidal invertebrates will defecate directly on the intertidal areas in which the shellfish beds are located. They may tend to aggregate in certain areas holding the highest densities of their preferred size and species of prey, but this may vary from year to year. They will therefore represent a diffuse input and whilst they may be a significant contaminating influence at times, they will not influence the positioning of any RMPs. Grazing waterbirds such as ducks and geese will mainly frequent areas of saltmarsh and coastal grasslands, where their faeces will be carried into coastal waters via runoff into tidal creeks or through tidal inundation. RMPs positioned in or by creeks and channels draining from such areas would be best positioned to capture contamination from these.

Although the majority of waterbirds migrate elsewhere to breed, other species such as gulls and terns are present throughout the entire year. No seabird breeding colonies were reported within the estuary during a seabird survey undertaken in 2000. Seabirds will forage widely throughout the area, but in the absence of a nesting colony no particular part of the estuary is likely to be consistently subject to heavier impacts.

The closest seal colony to the Three Rivers, of up to around 60 grey seals is at Caldey Island about 20 km to the southwest. They are known to enter the estuary from time to time to hunt returning salmon and sea trout, for which the peak period of upstream migration is summer and autumn. It is quite likely that they haul out on mid estuary sandbanks on occasion, and if this coincides with a cockle bed there is the potential for them to create a localised hotspot of contamination. However, no firm information on regular haul-out sites could be found. Given their small numbers and the large area they are likely to forage over their impacts are likely to be minor, and unpredictable in spatial terms, although it is likely that the estuary is more attractive to them during the summer and autumn. The estuary also supports a small otter population. For both seals and otters impacts are likely to be minor, and unpredictable in spatial terms, so neither species will influence the sampling plan.

Domestic animals

Dog walking takes place on beaches and paths adjacent to the shoreline of the survey area and could represent a potential source of diffuse contamination to the near shore zone. The intensity of dog walking is likely to be higher closer to the more urban areas such as Laugharne and Ferryside. As a diffuse source, this will have little influence on the location of RMPs.

Summary of Pollution Sources

An overview of sources of pollution likely to affect the levels of microbiological contamination to the shellfish beds is shown in Table 5.1 and Figure 5.1.

Table 5.1: Qualitative assessment of seasonality of important sources of contamination.

Pollution source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural runoff	red	red	red	red	red	red	red	red	red	red	red	red
Continuous sewage discharges	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange
Intermittent sewage discharges	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange
Urban runoff	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow
Waterbirds	orange	orange	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	orange	orange
Boats	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow

Red - high risk; orange - moderate risk; yellow - lower risk;

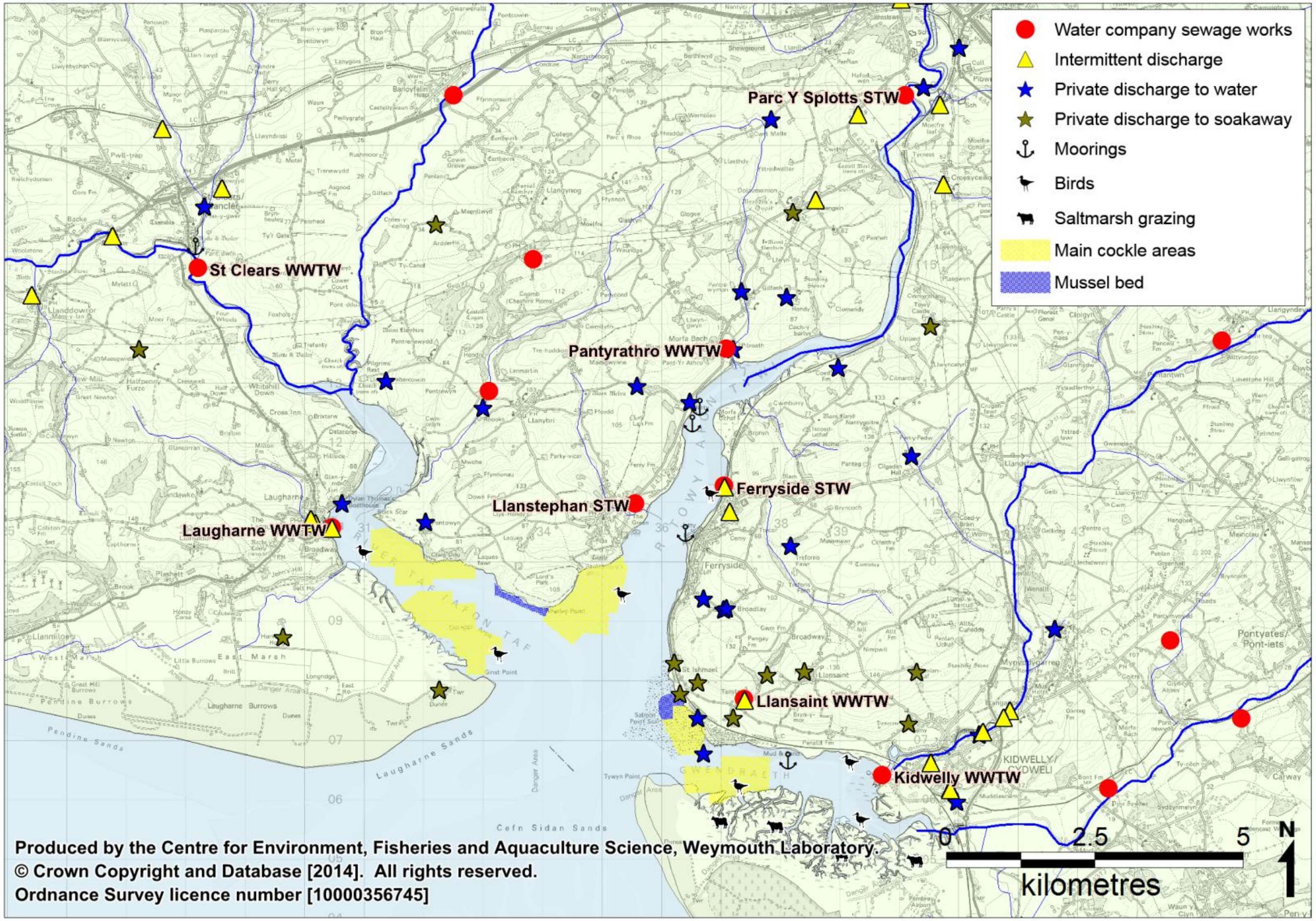


Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The Three Rivers estuary is a double spit enclosed estuary which faces south west and drains into Carmarthen Bay. It covers an area of around 37 km^2, most of which is intertidal, so a large proportion of water will be exchanged on each tide but the dilution potential will be quite low away from the main channels. It has a relatively wide mouth, and from this three separate arms extend inland. These are all characterised by a central river channel bisecting intertidal areas, and the main freshwater inputs are to the heads of these three channels. The Tywi channel extends about 20 km inland from Wharley Point to its tidal limit. It becomes progressively narrower, with the upper 14 km not generally exceeding 200 m in width. The Taf estuary channel has a similar profile to the Tywi, although it is only about 13 km in length from Wharley Point to its tidal limit. These two channels both lie in quite steep sided valleys. Patches of saltmarsh are present in both, but these are more extensive within the Taf channel. The shape of these channels, coupled with the location and size of the main freshwater inputs will result in a marked gradient of increasing levels of runoff borne contamination towards their upper reaches. The Gwendraeth arm is slightly different in character, being a relatively uniform 1 km in width throughout its lower 3.5 km. It then splits into two narrow tidal river channels which extend a further 2-3 km to their tidal limits. Hills border the north shore, but the south shore is low lying with extensive saltmarshes. Tidal deltas have formed around the mouth of the estuary complex. South of the estuary mouth, the bathymetry gently slopes into Carmarthen Bay.

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. Tidal range in the outer estuary is large, at 6.6 m on spring tides at Ferryside, and this drives extensive water movements through the area. Current velocities are reported to exceed 1 m/s on spring tides but are considerably lower away from the main channels. The flood tide will convey relatively clean water originating from Carmarthen Bay into the estuary, whereas the ebb tide will carry contamination from shoreline sources out through the estuary. On a flood tide the principal tidal stream flows into the estuary and progresses up the three main channels with the opposite occurring on the ebb. As these channels fill, the tidal flow will fill the creeks and spread over the intertidal areas. Shoreline sources of contamination will therefore primarily impact up and down tide of their locations along the bank to which they discharge. Their impacts will decrease with distance travelled, as the plume becomes progressively more diluted. At lower states of the tide contamination from some shoreline sources such as watercourses will be carried through the intertidal drainage channels where the dilution potential is low. Relatively high concentrations of indicator bacteria may arise in these channels at such times. The three arms of the estuary will be primarily influenced by sources of contamination discharging directly to them. There is the potential for some impacts from major sources in other channels carried back up the estuary on the subsequent flood tide, although they will be subject to significant dilution during travel. Eddies can form around high water on spring tides in the mouth of the estuary and these may assist the exchange of water between the three estuary channels.

Freshwater inputs may modify the circulation of water around estuaries via density effects. Freshwater inputs to the estuary are significant but low relative to the volumes exchanged tidally. This suggests that the system as a whole is well mixed, and that density effects are unlikely to significantly modify circulation in the outer reaches of the estuary where the shellfish are located. Salinity measurements indicate that salinity in the mouth of the estuary is usually approaching that of full strength seawater, although much lower salinities were recorded here from time to time. There is a slight gradient of decreasing average salinity towards the up-estuary ends of the shellfish beds in the Taf and the Tywi channels. Further upstream in the Tywi channel, the average salinity drops off to around 10 ppt at Pantyrathro, and is less than 5 ppt at all points north of here. Salinities are also likely to drop off rapidly in the upper narrow reaches of the Taf estuary. The only salinity measurements taken in the Gwendraeth arm were in its very outer reaches, but there is likely to be a decrease in average salinity towards its upper reaches. The shape of the estuary suggests that this is unlikely to be as steep as that observed where the Tywi estuary narrows. Salinity may be considered a proxy for levels of runoff borne contamination, and was strongly negatively correlated with levels of faecal coliforms in the Three Rivers estuary. Therefore it is concluded that the influence of contamination carried into the estuary by land runoff will increase significantly towards the up-estuary ends of the fishery. Zoning and monitoring arrangements should reflect this overall principle.

Strong winds drive surface water currents, and these will create return currents lower in the water column or along sheltered margins. Effects of wind upon tide are highly dynamic and variable making firm predictions difficult. The prevailing south westerly winds will tend to push surface water up the estuary, with the likely exception of the Taf arm. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action. Where these waves break contamination held in intertidal sediments may be resuspended. The Three Rivers estuary is quite exposed to the south westerly winds but due to the sandbanks off the estuary mouth the wave energy will be dissipated before it enters the estuary.

5.5. Summary of Existing Microbiological Data

The survey has been subject to considerable microbiological monitoring over recent years, consisting of Bathing and Shellfish Waters monitoring programmes and shellfish flesh monitoring for hygiene classification purposes. Figure 5.2 shows the locations of the monitoring points referred to in this assessment. Results from 2003 onwards are considered in the analyses.

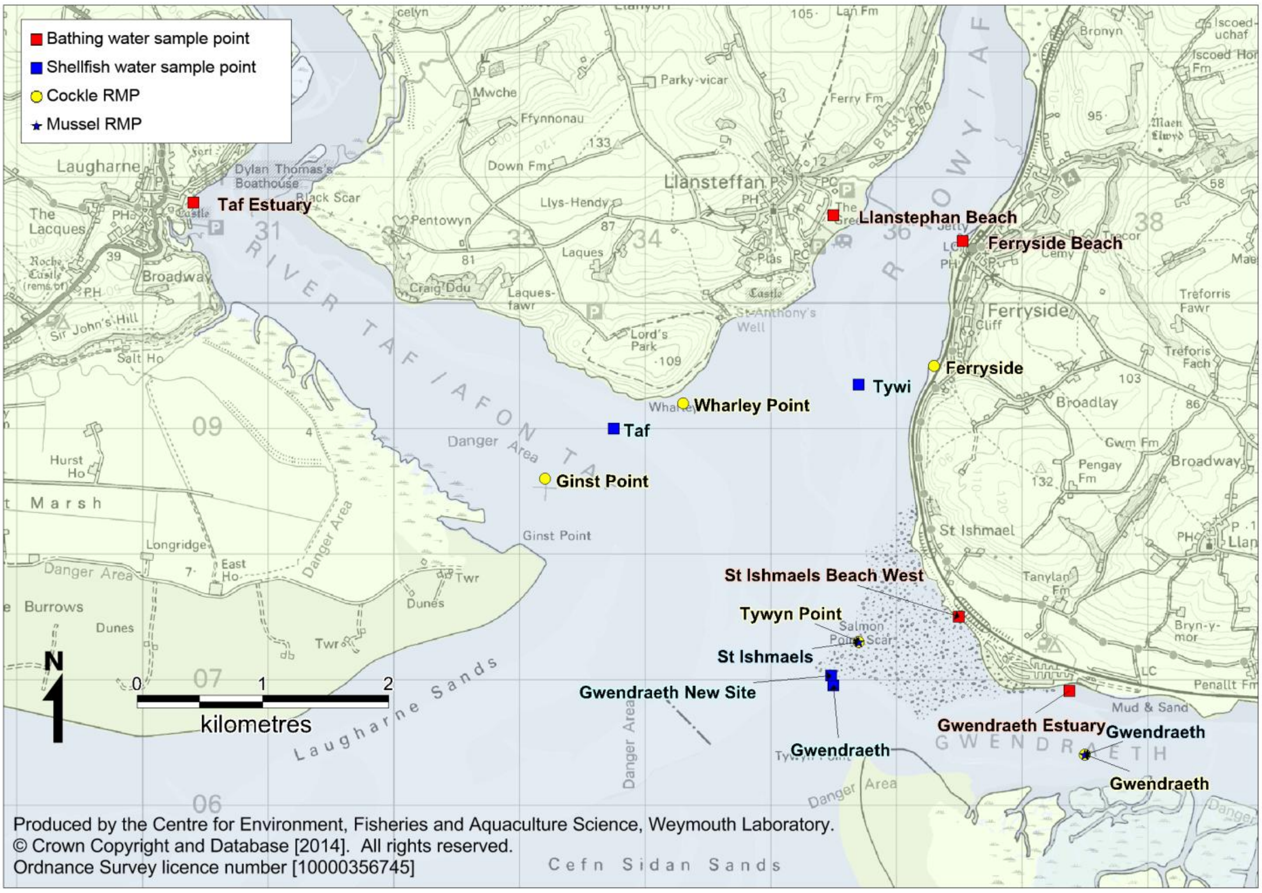


Figure 5.2: Microbiological sampling sites

Bathing waters

There are five sites where Natural Resources Wales monitors bathing water quality in the Three Rivers estuary. Around twenty water samples were taken from each of these locations during the May to September bathing season and enumerated for faecal coliforms. The levels of faecal coliforms recorded at all sites were quite high, with geometric means ranging from 74.7 to 189.7 cfu/100ml, and at least 10% of results exceeded 1,000 cfu/100ml at all five. There were no statistically significant differences in average result between the five sites. Paired (same day sample) comparisons showed strong correlations in results between Ferryside Beach and Llanstephan Beach, and between St Ishmaels Beach West and Gwendraeth Estuary. There was also a significant correlation between Gwendraeth Estuary and Llanstephan Beach. This suggests that these site pairings share similar sources of contamination. No significant correlation was found between Llanstephan Beach and St. Ishmaels Beach West however, and no comparisons with Taf Estuary could be undertaken due to the low number of samples from here.

A statistically significant influence of the high/low tidal cycle was found at Llanstephan Beach and Gwendraeth Estuary, but these were relatively weak, sampling was targeted towards high water, and no strong patterns were apparent when the data was plotted. Stronger correlations were found between the spring/neap tidal cycle and faecal coliform results at Llanstephan Beach, Ferryside Beach and St Ishmaels Beach West. At all three sites faecal coliform concentrations tended to be lower on neap tides and the few days before neap tides. Levels of faecal coliforms were strongly influenced by antecedent rainfall at all sites, which is unsurprising due to the large amount land runoff the estuary receives.

Shellfish waters

There are four shellfish waters monitoring points within the survey area, where water samples are taken on a quarterly basis and enumerated for faecal coliforms. Two of these (Gwendraeth and Gwendraeth New Site) are in very close proximity to one another. Results were considerably lower on average than at the bathing waters sites, with geometric mean results raging from 8.7 to 35.6 faecal coliforms/100ml. It is likely that this is a consequence of their more offshore location rather than a seasonal effect as results were higher during the autumn and winter. A statistically significant difference in average results was found with the Tywi having significantly higher results than the Taf. Paired (same day sample) comparisons showed that results from all site pairings significantly correlated, suggesting they are all subject to similar contamination sources.

Since 2003, results at all four sites have been reasonably stable with the exception of Gwendraeth which had an increase in average faecal coliform levels between 2008 and 2012. The seasonal pattern of results was similar at all sites, with higher results on average during the autumn and winter, and was statistically significant in all cases. A significant influence of the high/low tidal cycle was detected at Tywi and Gwendraeth New Site. Although sampling was targeted towards high water, an increase in average result was apparent once the tide had started to ebb at both, suggesting up-estuary sources are an influence. A statistically significant influence of recent rainfall was detected for all sites, but this was weaker at Gwendraeth, even though it was very strong at the nearby Gwendraeth New Site. Strong negative correlations between salinity and faecal coliform concentrations were found at three of the sites, and there was insufficient salinity data available to undertake comparisons with the fourth (Gwendraeth). The strong effect of rainfall and salinity suggests that land runoff is a major contaminating influence.

Shellfish hygiene

There are a total of seven RMPs in the Three Rivers production area that have been sampled between 2003 and 2013 for the purposes of shellfish hygiene classification, of which five are for cockles and two are for mussels. One of the mussel RMPs (Gwendraeth) was only sampled on two occasions and one of the cockle RMPs (Tywyn Point) was only sampled on six occasions and so are not considered in the statistical analyses. Also, is believed that the last few samples from the Gwendraeth cockle RMP may have originated from the St Ishmaels Point area rather than the location shown in Figure 5.2, although this could not be confirmed at the time of writing.

Across the four main cockle RMPs, no significant difference was found in average result. The RMP showing the highest results was Gwendraeth, where the geometric mean was 619 *E. coli* MPN/100g, 19.3% of samples exceeded 4,600 MPN/100g, and the only prohibited level result was recorded. The proportion of results exceeding 4,600 *E. coli* MPN/100g was also over 10% (10.4%) at Wharley Point, but not at the other cockle RMPs. Paired (same day sample) comparisons showed significant correlations between all cockle RMP pairings, suggesting that they share similar contamination sources. At the mussel RMP at St Ishmaels, 8.5% of samples exceeded 4,600 *E. coli* MPN/100g so class B compliance here is borderline at times.

Since 2003, *E. coli* levels appear to have generally increased at all cockle sites. At Wharley Point and Ginst Point, levels rose until 2008 and have remained fairly stable since. *E. coli* levels at Gwendraeth appear to have increased sharply from 2011 to present. At the St Ishmaels mussel RMP, *E. coli* levels have risen by around one order of magnitude since 2003. Across the four main cockle RMPs there was a general tendency for higher results in the summer and autumn. At the St Ishmaels mussel RMP results were highest on average during the autumn and winter. Seasonal variation was statistically significant in all cases.

A statistically significant influence of the high/low tidal cycle was detected at three of the cockle RMPs. However, sampling was necessarily targeted to low water and no patterns were apparent when the data was plotted. A significant influence of the spring/neap tidal cycle was found for all four of the main cockle RMPs as well as the main mussel RMP. Plots of the data showed that higher results tended to occur more around spring tides in all cases. All of the main RMPs showed strong correlations between *E. coli* levels and antecedent rainfall in the week running up to sampling.

Bacteriological survey

No bacteriological survey was undertaken because there is a significant microbiological monitoring history. Also, it was not possible to complete a bacteriological survey within the contractual timescales within which this report had to be produced.

Appendices

Appendix I. Human Population

Figure I.1 shows population densities in census output areas within or partially within the Three Rivers catchment area, derived from data collected from the 2011 census.

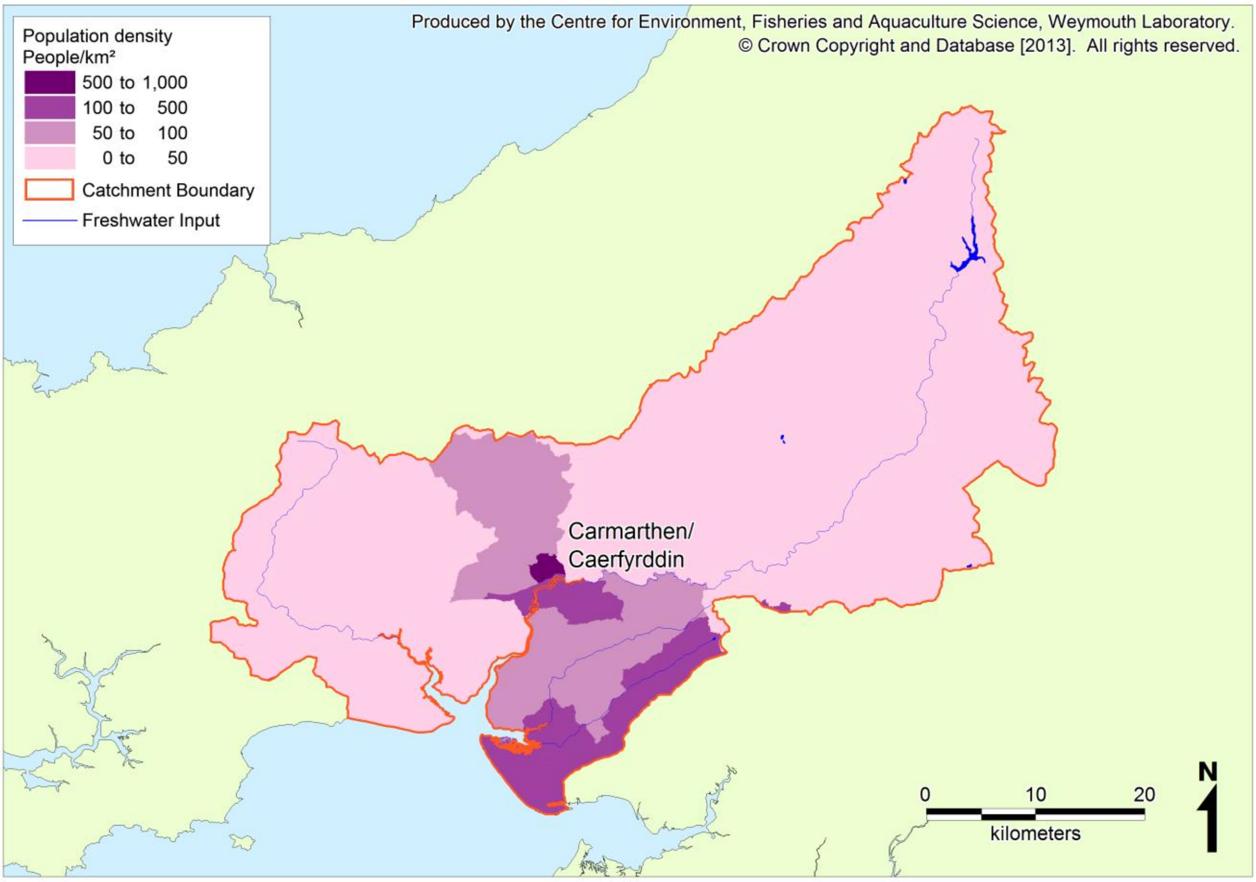


Figure I.1: Human population density in census areas in the Three Rivers catchment.

Total resident population within census areas contained within or partially within the catchment area was approximately 153,000 at the time of the last census. The largest settlement in the area is Carmarthen, which had a population of about 16,000. Most of the population resides around Afon Tywi near Carmarthen, and in the south of the catchment around Afon Gwendraeth.

Carmarthenshire, which accounts for around 87 % of the catchment attracted approximately 3 million visitors in 2010 (GTS, 2011) and so there will be some seasonality in population within the survey area. Figure I.2 shows the variation in visitor numbers to Carmarthenshire in 2010.

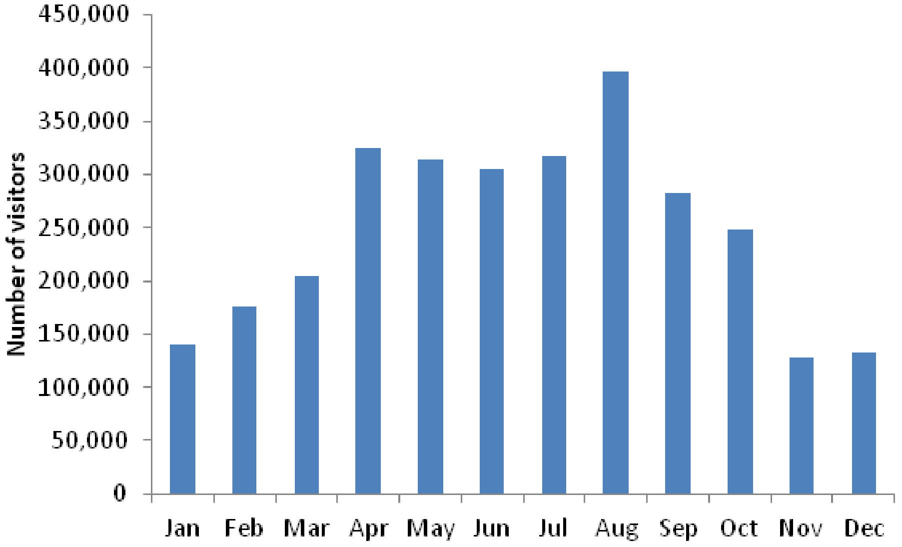


Figure I.2: Numbers of tourists visiting Carmarthenshire in 2010 by month.
Data from GTS, 2011

From spring to autumn there was an influx of visitors which peaked in August. The seasonal variation in population levels in the catchment will result in corresponding seasonal variations in the amount of sewage effluent received by sewage treatment works serving the areas, and the bacterial loadings they generate may be expected to fluctuate accordingly.

Appendix II. Sources and Variation of Microbiological Pollution: Sewage Discharges

Details of all consented sewage discharges in the Three Rivers hydrological catchment were taken from the most recent update of the Natural Resources Wales national permit database (March 2013). The locations of all water company owned sewage treatment works are shown in Figure II.1, with further details in Table II.1. Given the very large hydrological catchment draining to the Three Rivers, only the intermittent and private discharges within 2 km of the Three Rivers tidal limit are considered in this report.

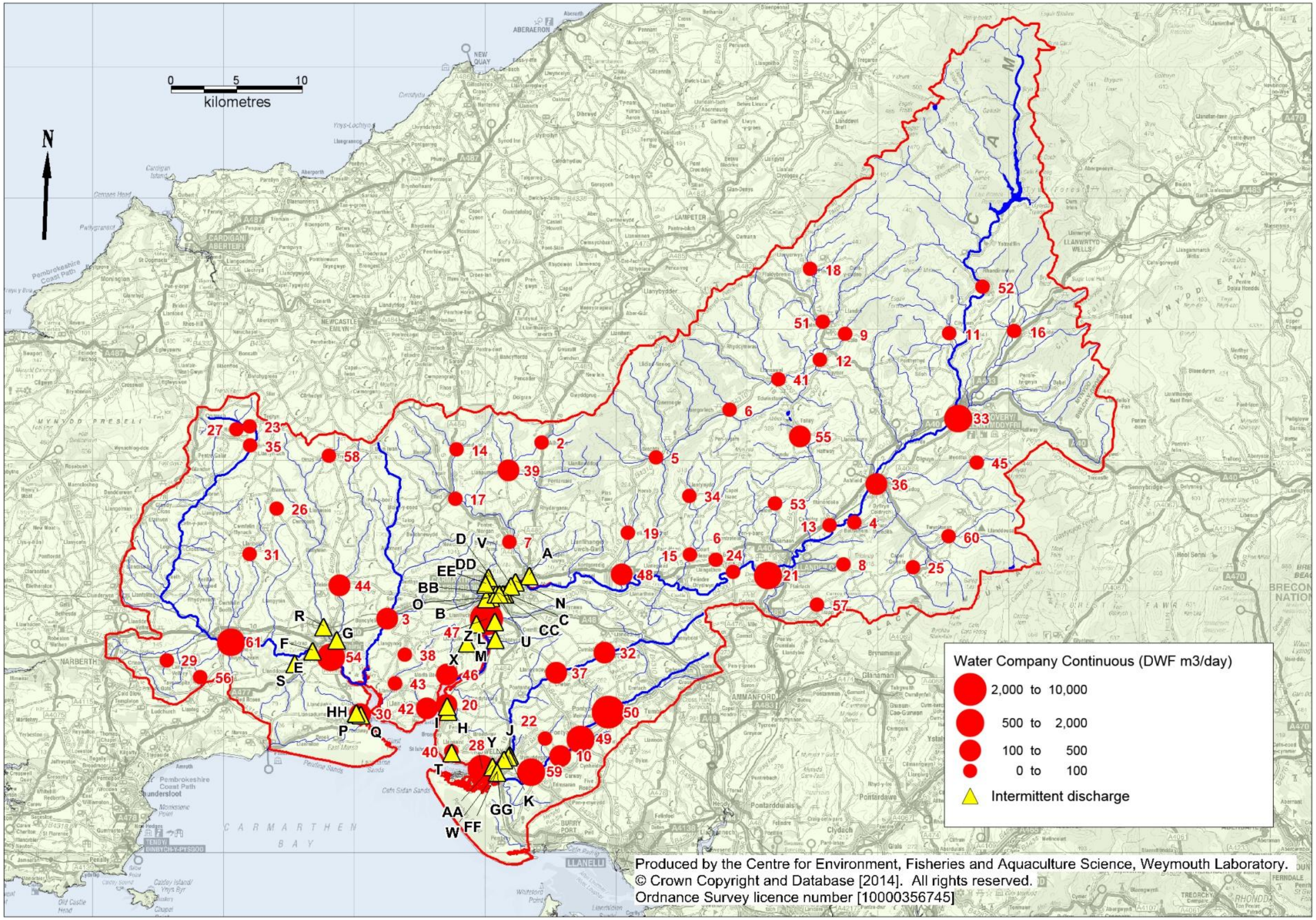


Figure II.1: All water company continuous discharges in catchment and intermittent sewage discharges within a 2 km buffer of the Three Rivers

Table II.1: Details of continuous water company sewage works

No	Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
1	Abergorlech WWTW	SN5867 133790	Biological Filtration	25.7	8.48 $x10^{10}$	Afon Gorlech
2	Alltwalis STW	SN4430 031300	Unspecified	19.9***	6.57 $x10^{10}$	Nant Alltwalis
3	Bancyfelin STW	SN3251 017840	Biological Filtration	142	4.69 $x10^{11}$	River Cywyn
4	Bethlehem STW	SN6818 625190	Unspecified	12	3.96 $x10^{10}$	Afon Ceidrych
5	Brechfa STW	SN5305 030150	Unspecified	43.6	1.44 $x10^{11}$	Afon Marlais
6	Broad Oak WWTW	SN5761 222336	Biological Filtration	10.9	3.60 $x10^{10}$	Nant Lash
7	Bronwydd STW	SN4182 023700	Unspecified	92	3.04 $x10^{11}$	Gwili
8	Bryngwyn WWTW	SN6735 121995	Biological Filtration	6	1.98 $x10^{10}$	Afon Y Cwm
9	Caio STW	SN6750 039600	Unspecified	21.8	7.19 $x10^{10}$	Afon Annell
10	Carway WWTW	SN4576 507359	Tertiary Biological	103.8	3.43 $x10^{11}$****	Trib Gwendraeth Fawr
11	Cilycwm WWTW	SN7545 039629	Biological Filtration	38	1.25 $x10^{11}$	Afon Gwenlais
12	Crugybar STW	SN6558 037620	Package Treatment Plant	12***	3.96 $x10^{10}$	Afon Annell
13	Cwm Ifor STW	SN6629 024940	Unspecified	92.5	3.05 $x10^{11}$	Afon Tywi
14	Cwmduad STW	SN3779 630745	Package Treatment Plant	33	1.09 $x10^{11}$	Afon Duad
15	Cwrt Henri STW	SN5565 022700	Biological Filtration	40.4	1.33 $x10^{11}$	Afon Dulas
16	Cynghordy WWTW	SN8041 939810	Biological Filtration	22	7.26 $x10^{10}$	River Bran
17	Cynwyl Elfed WWTW	SN3768 926996	Biological Filtration	50	1.65 $x10^{11}$	Afon Duad
18	Farmers STW	SN6480 044550	Unspecified	17	5.61 $x10^{10}$	Afon Twrch
19	Felingwm WWTW	SN5086 924399	High Rate Biological	22	7.26 $x10^{10}$	Nant Mynachdy
20	Ferryside STW	SN3706 011270	Biological Filtration	317	1.05 $x10^{12}$	The Ferryside Stream
21	Ffairfach STW	SN6159 021170	High Rate Biological	847	2.80 $x10^{12}$	Afon Tywi
22	Four Roads STW	SN4457 008670	Biological Filtration	32	1.06 $x10^{11}$	River Clydach
23	Glogue STW	SN2200 032530	High Rate Biological	13.2	4.36 $x10^{10}$	Afon Taf
24	Golden Grove	SN5891	Tertiary Biological	10.8	3.56 $x10^{10}$****	The Afon Towy

No	Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
	WWTW	921384				
25	Gwynfe STW	SN7266 021760	Unspecified	unknown	unknown	Afon Clydach
26	Heol Shon WWTW	SN2405 426247	Biological Filtration	12.5	4.13 x10^{10}	Trib Of The Afon Gronw
27	Hermon STW	SN2099 032310	Biological Filtration	41	1.35 x10^{11}	Trib of River Taf
28	Kidwelly WWTW	SN3971 506405	Biological Filtration	1642	5.42 x10^{12}	Gwendraeth Fach Estuary
29	Lampeter Velfrey STW	SN1564 014650	Biological Filtration	27.2	8.98 x10^{10}	Unnamed Trib of Afon Marlais
30	Laugharne WWTW	SN3046 010567	UV Disinfection	320	8.96 x10^{8}**	Taf Estuary
31	Llanboidy WWTW	SN2198 522765	Biological Filtration	65	2.15 x10^{11}	Afon Gronw
32	Llanddarog WWTW	SN4913 515239	High Rate Biological	207	6.83 x10^{11}	River Gwendraeth Fach
33	Llandovery WWTW	SN7613 033180	Biological Filtration	705	2.33 x10^{12}	Afon Bran
34	Llanfynydd STW	SN5560 027200	Unspecified	68	2.24 x10^{11}	Afon Sannen
35	Llanfyrnach WWTW	SN2204 531053	Biological Filtration	77.6	2.56 x10^{11}	Afon Taf
36	Llangadog STW	SN6989 028140	High Rate Biological	427	1.41 x10^{12}	River Sawdde
37	Llangynderyn WWTW	SN4543 413711	Biological Filtration	138	4.55 x10^{11}	Gwendraeth Fach
38	Llangynog STW	SN3385 015080	Biological Filtration	9	2.97 x10^{10}	Llanbri Stream
39	Llanpumpsaint PS	SN4180 029200	Biological Filtration	117.8	3.89 x10^{11}	River Gwil
40	Llansaint WWTW	SN3739 507690	High Rate Biological	96	3.17 x10^{11}	Llansaint Stream
41	Llansawel WWTW	SN6239 536140	High Rate Biological	57	1.88 x10^{11}	Afon Marlais
42	Llanstephan STW	SN3556 010980	Biological Filtration	158.4	5.23 x10^{11}	Trib of Afon Towy
43	Llanybri STW	SN3310 012860	Biological Filtration	31	1.02 x10^{11}	Nant Twlch Filiast
44	Meidrim STW	SN2890 020400	Biological Filtration	111	3.66 x10^{11}	Afon Dewi Fawr
45	Myddfai WWTW	SN7753 529762	Biological Filtration	28	9.24 x10^{10}	Afon Bran
46	Pantyrathro WWTW	SN3709 213580	Biological Filtration	114	3.76 x10^{11}	Fernhill Brook
47	Parc Y Splotts STW	SN4010 017840	Biological Filtration	7000	2.31 x10^{13}	River Tywi
48	Pont-Ar-Gothi & Nantgaredig	SN5044 621217	Biological Filtration	171	5.64 x10^{11}	Afon Cothi

No	Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
	WWTW					
49	Pontyates WWTW	SN4727 408662	Biological Filtration	696	2.30 $x10^{12}$	Gwendraeth Fawr
50	Pontyberem WWTW	SN4938 110722	Chemical - Phosphate Stripping	5159	1.70 $x10^{13}$	Gwendraeth Fawr
51	Pumpsaint STW	SN6580 040500	Unspecified	16.5	5.45 $x10^{10}$	Afon Cothi
52	Rhandirmwyn STW	SN7800 043200	Unspecified	unknown	unknown	Afon Tywi
53	Salem STW	SN6212 026640	Activated Sludge	56	1.85 $x10^{11}$	Afon Myddyfi
54	St Clears WWTW	SN2820 214939	Biological Filtration	987	3.26 $x10^{12}$	Afon Taf
55	Talley WWTW	SN6405 031782	Biological Filtration	128	4.22 $x10^{11}$	Nant Ddu
56	Tavernspite STW	SN1822 013350	Biological Filtration	80	2.64 $x10^{11}$	Afon Cwm Wuan Gron
57	Trapp STW	SN6536 018900	Unspecified	3.3	1.09 $x10^{10}$	River Cennen
58	Trelech STW	SN2805 030290	Unspecified	23	7.59 $x10^{10}$	Unnamed Trib of Afon Cynin
59	Trimsaran WWTW	SN4352 206180	Biological Filtration	914	3.02 $x10^{12}$	Gwendraeth Fawr
60	Twynllanan STW	SN7538 024110	Unspecified	unknown	unknown	Afon Sawde
61	Whitland WWTW	SN2055 516071	Biological Filtration	522	1.72 $x10^{12}$	River Taf

Data from Natural Resources Wales
*faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs (Table II.2).
** faecal coliforms (cfu/day) based on geometric mean final effluent testing data (Table II.3)
***No DWF provided, so Max Flow used instead
**** Probably an overestimate as reference values for secondary treatment used but this works has an additional nutrient removal step.

Table II.2: Summary of reference faecal coliform levels (cfu/100ml) for different sewage treatment levels under different flow conditions.

Treatment Level	Flow			
	Base-flow		High-flow	
	n	Geometric mean	n	Geometric mean
Storm overflow (53)	-	-	200	$7.2x10^6$
Primary (12)	127	$1.0x10^7$	14	$4.6x10^6$
Secondary (67)	864	$3.3x10^5$	184	$5.0x10^5$
Tertiary (UV) (8)	108	$2.8x10^2$	6	$3.6x10^2$

Data from Kay et al. (2008b).
n - number of samples.
Figures in brackets indicate the number of STWs sampled.

Three of the continuous water company discharges (Carway WWTW, Golden Grove WWTW and Laugharne WWTW) undergo tertiary treatment of some description. Of these, effluents from Carway and Golden Grove WWTWs receive additional biological treatment for nutrient removal rather than disinfection. Laugharne WWTW receives UV disinfection and is located approximately 3.8 km from the shellfisheries. Table II.3 summarises the results of bacteriological testing of the final effluent from this works, and Figure II.2 presents boxplots of the instantaneous bacterial loadings recorded at this works, derived from effluent testing and spot flow measurements.

Table II.3: Summary statistics for final effluent testing data from Laugharne WwTW, a UV treated works, January 2011 to September 2013

Sewage works	No.	Geometric mean result (faecal coliforms cfu/100ml)	Minimum	Maximum
Laugharne WWTW	71	87,951	48	$4.9x10^{6}$

Data from Dwr Cymru

Bacteriological testing results for the final effluent at Laugharne WWTW indicate that disinfection is not effective. The geometric mean faecal coliform concentration in the final effluent is over two orders of magnitude higher than the reference value given in Table II.2, and less than one order of magnitude lower than that for secondary works.

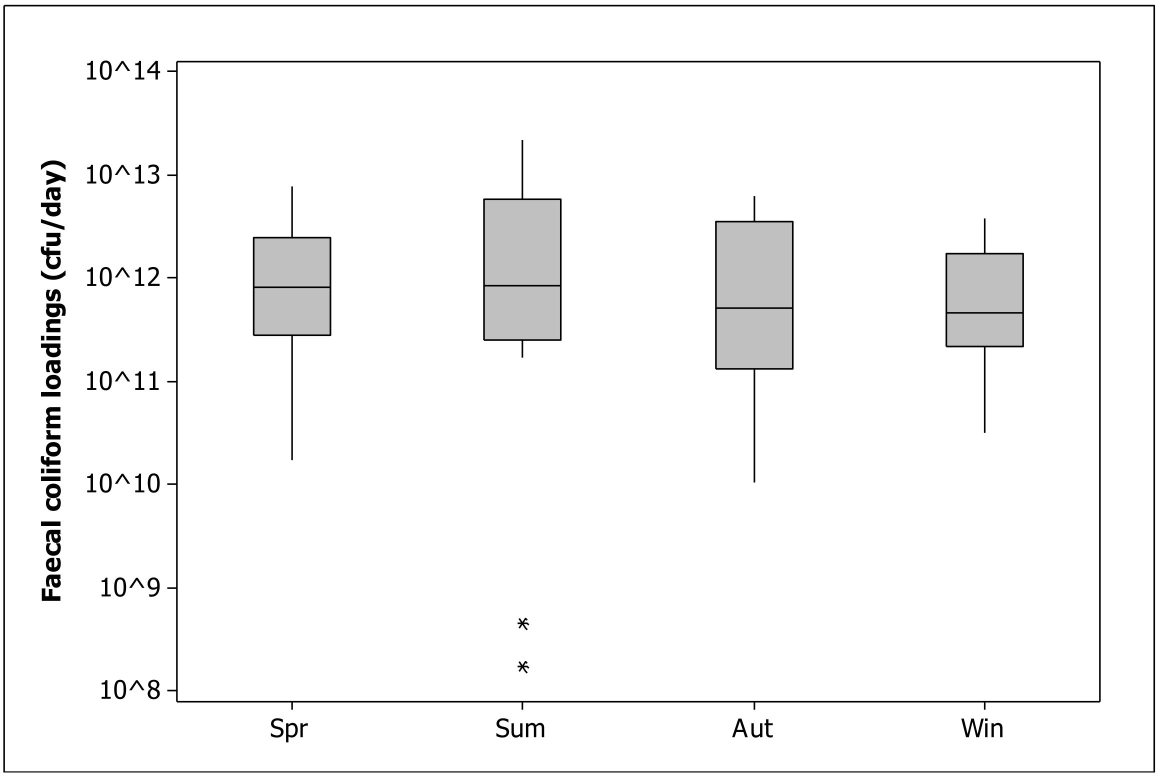


Figure II.2: Boxplot of measured instantaneous faecal coliform loadings by season at Laugharne WWTW

Data from the Dwr Cymru

There is little seasonal variation in the bacterial loading this works generates, which is generally between 10^{11} and 10^{13} faecal coliforms/day throughout the year.

There are 61 continuous water company discharges within the Three Rivers hydrological catchment. The majority of these are relatively small works serving the rural areas of the catchment which discharge to watercourses which subsequently drain to the estuary, although there are a small number which discharge directly to tidal waters. Continuous water company discharges to the Tywi include Parc Y Splotts STW which is the largest treatment works in the Three Rivers catchment with a consented Dry Weather Flow (DWF) of 7000 m^3/day. It discharges biologically treated effluent to the tidal reaches near Carmarthen about 10 km upstream of the nearest shellfish bed. Although the discharge is located at some distance from the shellfisheries, its large size means it is likely to have widespread impacts. Other discharges to the Tywi include Ferryside STW, Llanstephan STW, and Pantyrathro WWTW with consented DWFs of 317 m^3/day, 159 m^3/day and 114 m^3/day. These four works provide secondary treatment and discharge to short watercourses which subsequently drain to the middle reaches of the estuary between 0.5 and 3km upstream from the nearest shellfish resources. As well as the sewage works in coastal areas, there are a further 33 inland discharges which are consented to discharge a combined dry weather flow of 3162 m^3/day of mainly secondary treated effluent. These all discharge to watercourses draining to the head of the estuary.

The only sewage works discharging directly to The Gwendraeth arm of the estuary is Kidwelly STW. This discharges to the Gwendraeth Fach channel near the head of the estuary, and is consented to discharge 1642 m^3/day of secondary treated effluent. The Gwendraeth Fach also receives effluent from two inland works (Llanddarog and Llangynderyn STWs) which are consented to discharge a total of 345 m^3/day of secondary treated effluent. The Gwendraeth Fach watercourse receives effluent from four works (Carway, Four Roads, Pontyates, Pontyberem and Trimsaran STWs) which are consented to discharge a combined dry weather flow of 6905 m^3/day. Most of this originates from Pontyberem WWTW, which is consented to discharge 5159 m^3/day about 12 km upstream of the tidal limit. It provides secondary treatment with an additional phosphate stripping step. Llansaint STW discharges to a short watercourse which then discharges to the north shore of the Gwendraeth arm at the western end of the Carmarthen Bay Holiday Centre in close proximity to the mussel and cockle beds here. It provides secondary treatment for a consented dry weather flow of 96 m^3/day.

There are two sewage works discharging directly to tidal waters in the Taf arm of the estuary. The Laugharne STW is consented to discharge a dry weather flow of 320 m^3/day of UV treated effluent immediately to the north of an area of cockle beds. Despite the UV treatment, the average concentration of faecal coliforms in the effluent is approaching that which may be expected from secondary treated discharges. The St Clears STW discharges to the upper reaches of the estuary, about 7km upstream of Laugharne. It provides secondary treatment for a consented dry weather flow of 987 m^3/day. There are a further 11 inland sewage works within the Taf estuary catchment, all of which discharge to watercourses which feed into the estuary upstream of the shellfisheries. Their combined consented dry weather flow is 1,114.5 m^3/day, and all, where specified, provide secondary treatment.

These discharges, entering the various pathways to the shellfisheries will contribute significantly to the microbiological loading in the classification zones and thereby contribute to water quality at the shellfisheries. The closer the discharges are located to the classification zone and the larger they are, the greater the microbiological impact will be. Depending on how long the effluent takes to reach the shellfisheries some natural die-off of micro-organisms will take place between the point of discharge and the shellfisheries. More die-off will tend occur for those discharges that are located further inland.

In addition to the continuous sewage discharges, there are various intermittent water company discharges associated with the sewerage networks also shown on Figure II.1. Details of those within 2 km of the Three Rivers or considered to be potentially significant are shown in Table II.4.

Table II.4: Intermittent discharges potentially impacting on the shellfisheries (within 2km of the Three Rivers and/ or in the EA Pollution Reduction Plans)

No.	Name	Grid reference	Receiving water	Type
A	Abergwili PS Near Rugby Field	SN4333021230	River Gwili	Storm Overflow
B	Brickyard Lane PS	SN4040019550	Tawelan Brook	Storm Overflow/ Storm Tank
C	Carmarthen - Station Road Pump	SN4150019800	River Towy	Storm Overflow
D	Castle Hill Drainage Area	SN4130019800	River Tywi	Storm Overflow
E	Craigwen PS Tenby Road St Clears	SN2676315494	River Taf	Pumping Station
F	Craigwen PS Tenby Road St Clears	SN2676315494	River Taf	Storm Overflow/ Storm Tank
G	C'then Rd.PS St.Clears Emergency	SN2860016300	Tributary Of Afon Dewi Fawr.	Storm Overflow
H	Ferryside PS	SN3714010860	Ferryside Stream	Storm Overflow
I	Ferryside STW	SN3706011270	Ferryside Stream	Storm Overflow
J	Garreg SPS Llangadog	SN4185207511	Gwendraeth Fach	Pumping Station
K	Housing Dev At Meinciau Rd	SN4175007400	Gwendraeth Fach	Storm Overflow
L	Idole Cwmffrwd Sewerage Scheme	SN4068017700	Tributary Of Nant Pibwr	Storm Overflow
M	Idole Cwmffrwd Sewerage Scheme	SN4074016360	Nant Cwm Croes Y Ceiliog	Storm Overflow
N	Jewsons CSO Tanerdy	SN4229020760	Tywi Estuary	Storm Overflow
O	Johnstown C'marthen SWO	SN4002019480	Towy	Storm Overflow
P	Laugharne Sewerage System	SN3017010670	The River Coran	Storm Overflow
Q	Laugharne WWTW	SN3045010580	Taf Estuary	Storm Overflow/ Storm Tank
R	Llanboidy Road PS	SN2760017300	Afon Cymin	Storm Overflow
S	Llanddowror Village PS	SN2540014500	Nant Hedfron,Trib Of River Taf	Storm Overflow
T	Llansaint WWTW	SN3739507690	Llansaint Stream	Storm Overflow/ Storm Tank
U	Morfa Lane Carmarthen	SN4080019800	River Towy	Storm Overflow
V	Old Priory Row CSO Parc Hinds PS	SN4194020440	Tywi Estuary	Storm Overflow
W	Parc Stephens SPS	SN4085706205	Undesignated Water	Storm Overflow

No.	Name	Grid reference	Receiving water	Type
X	Pencoed Farm SPS Llangain No 1	SN3858816104	Unnamed Trib. Of River Towy	Pumping Station
Y	PS Adj Glangwendreath	SN4140107157	Gwendreath Fach	Pumping Station
Z	Pwntan SPS	SN3929717541	Nant Pwntan	Pumping Station
AA	SSO At Station Road PS	SN4053006640	Gwendraeth Fach Estuary	Storm Overflow
BB	SSO Pothouse Wharf P.S.	SN4103819823	River Towy	Pumping Station
CC	SSO Pothouse Wharf P.S.	SN4103819823	River Towy	Storm Overflow
DD	Trevaughan SWO	SN4020021100	Tawelan Brook	Storm Overflow
EE	Trinity Grange SPS Carmarthen	SN4000020565	Unnamed Trib Tawelan Brook	Pumping Station
FF	Tycoch SPS	SN4085806204	Trib. Of Gwendraeth Fach	Pumping Station
GG	Tycoch SPS	SN4085006188	Trib. Of Gwendraeth Fach	Pumping Station
HH	Wogan Mews CSO	SN3009210736	Culverted Mackerel Lake Stream	Storm Overflow

Data from Dwr Cymru

Those discharges highlighted in yellow have spill event duration monitoring, the results from which are summarised in Table II.5. These are reported in numbers of spill events, with no information on their durations or the volumes of effluent involved. There are several clusters of intermittent discharges associated with the sewerage network at Carmarthen, Kidwelly and St Clears, with other intermittent discharges located at the larger sewage treatment works throughout the catchment. The most concentrated area of intermittent discharges is at Carmarthen and as such microbiological loadings arising from this area will potentially impact at the shellfisheries approximately 12 km downstream. Of those intermittent discharges that have event duration monitoring, several spill noticeably more frequently than others. Pothouse Wharfe PS, located at Carmarthen and spilling to the Afon Tywi, spilled 177 times in between December 2011- November 2012. Data for the remaining assets was available for the whole of 2013. Also contributing to microbiological loads in the Afon Tywi at Carmarthen were Morfa Lane, which spilled 83 times in 2013 and Jewsons CSO which spilled 64 times. Intermittent discharges to the Afon Taf that spilled frequently included Craigwen PS which spilled 167 times in 2013 and Laugharne Sewerage System which spilled 41 times. Intermittent discharges of note contributing load to the Gwendraeth Fach include Garreg SPS which spilled 52 times in 2013; Tycoch SPS which spilled 38 times. Together these assets, together with others that are also spilling several times per year, will contribute significantly to microbiological loadings in receiving waters in association with these spill events. No spill information was available for the Llansaint STW overflow.

Table II.5: Summary of numbers of spill events, 2013 (2011-12 for Pothouse Wharfe PS)

Discharge	Type	Permit number	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Total 2013
Carmarthen- Station road Pump	Storm Overflow	BH0053409	0	0	0	0	0	0	0		0	1	0	5	
Craigwen PS Tenby Road St Clears	Pumping Station	BH0053403	32	28	26	13	14	3	2	1	7	14	14	13	167
Ferryside STW	Storm Overflow	BN0169301	4	1	0	0	0	0	0	0	0	5	0	4	14
Garreg SPS Llangadog Kidwelly	Pumping Station	BW2202801	7	2	3	0	3	3	1	2	1	9	9	12	52
Jewsons CSO Tanerdy Carmarthen	Storm Overflow	BP0209801	7	3	5	1	4	1	2	5	4	12	7	13	64
Laugharne Sewerage System	Storm Overflow	BH0060004			0	0	2	1	2	5	1	8	6	16	41
Laugharne Sewerage System	Storm Overflow	BH0060004	0	0	0	0	0	0	0	1	0	0	0	0	1
Morfa Lane Carmarthen	Storm Overflow	BH0053406	12	5	8	5	7	4	3		4	13	7	15	83
Old Priory Row CSO Parc Hinds PS	Storm Overflow	BH0053405	0	0	0	0	0	0	0	1	1	0	0	5	7
SSO At Station Rd PS Kidwelly	Storm Overflow	BF0147004			0	0	1		0	1	0	1	0	0	3
Tycoch Sewage Pumping Station Kidwelly	Pumping Station	BW2203001	15	4	0	1	1	0	0	5	2	10	0	0	38
Wogan Mews CSO Laugharne	Storm Overflow	BP0209601											1	3	4
Pothouse Wharfe PS*			**Dec 11**	**Jan 12**	**Feb 12**	**Mar 12**	**Apr 12**	**May 12**	**Jun 12**	**Jul 12**	**Aug-12**	**Sep-12**	**Oct-12**	**Nov-12**	**Total 12 mths**
	Storm Overflow	BH0053407	21	9	4	8	14	15	23	20	14	25	24	21	177

Data from Dwr Cymru

*2013 data not available, so most recently available data used

In addition to the actual spill data discussed above, the performance of the intermittent discharges impacting on Shellfish Waters were investigated by a modelling study (Metoc, 2008). This report covered the coastal sewerage catchments only, and presented modelled data rather than actual spill records. Some of the predicted annual spill volumes and percentage of time spill durations are considerably higher than others. Modelled annual spill volumes for the cluster of eight intermittent discharges contributing microbiological load to the Afon Taf at Laugharne and St Clears totalled 260,672 m^3. For those discharges from the Carmarthen area, impacting on the Afon Tywi the modelled total annual spill volume was 436,654 m^3 from 22 assets and for those from the Kidwelly area, contributing to the Gwendraeth Fach, the total was 25,126 m^3 from 2 assets.

Within each of these areas, some individual assets spilled more frequently than others. Discharging at Carmarthen to the Afon Tywi, Pothouse Wharfe CSO (presumably the same discharge also referred to as Pothouse Wharfe PS) was modelled to spill 117 times per year, with a modelled annual spill volume of 262,690m^3. Brickyard Lane PS, also at Carmarthen, was modelled to spill 64 times per annum, with a total annual spill volume of 105,870 m^3. St Clears WwTW storm overflow was modelled to spill 350 times per year with a modelled annual volume of 102,420 m^3. However, this discharge is no longer on the EA national discharges database and as such may no longer be in operation. Various other intermittent discharges were modelled to spill frequently, contributing to the totals for each river catchment detailed above.

Although the vast majority of the survey area is served by water company sewerage infrastructure, there are also a number of private discharges in the area. Where specified, these are generally treated by small treatment works such as package plants. Table II.6 details private discharges >3 m^3/day (max daily flow) within 2 km of the coast. All these private discharges and the other smaller private discharges will contribute to background levels of microbiological contamination in the various water sources impacting on the shellfisheries in the Three Rivers. Within the wider catchment, most of the larger watercourses draining to the Three Rivers also receive inputs from private discharges.

Table II.6: Details of private discharges over 3 m^3/day within 2 km of the Three Rivers

Label	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	99 Ferry Road	SN4014707306	Septic Tank	4.0	Ground Via Infiltration System
B	Bwythyn-Y-Felin	SN3733314569	Package Treatment Plant	3.6	Fernhill Brook
C	Carmarthen Bay Holiday Park	SN3670006800	Unspecified	320	Tidal Gwendraeth Fach
D	Carmarthen Leisure Centre	SN4040018000	Unspecified	4.6	Tributary Of River Tywi
E	Cwm Tawer	SN4370020000	Septic Tank	5.0	To Land
F	Cysgod Y Bedol	SN3810014470	Package Treatment Plant	5.0	Trib Of Fernhill Brook
G	Dolau Farm (The Coach House)	SN3558412982	Package Treatment Plant	5.0	Afon Twyi
H	Dylan Thomas Boathouse	SN3062011000	Unspecified	4.5	River Taf
I	Glanyrafon STW	SN4628021570	Unspecified	9.3	Afon Annell
J	Hurst House Farm	SN2961908757	Package Treatment Plant	23.7	Groundwater Via Soakaway
K	Pilroath Farm	SN3720013600	Unspecified	11.2	Fernhill Brook
L	RAF Pembrey Sands	SN4070003800	Package Treatment Plant	5.0	Swan Pool Drain
M	SW.Pool & Boiler Plant Caravan Park	SN3660007400	Unspecified	5.7	Unnamed Trib Gwendraeth Fach
N	Tanylan Farm Touring Site	SN3720007400	Unspecified	4.8	Into Land
O	Towy Castle Residential Home	SN4051813987	Package Treatment Plant	15	Ground Waters, Via Soakaway

Data from Natural Resources Wales

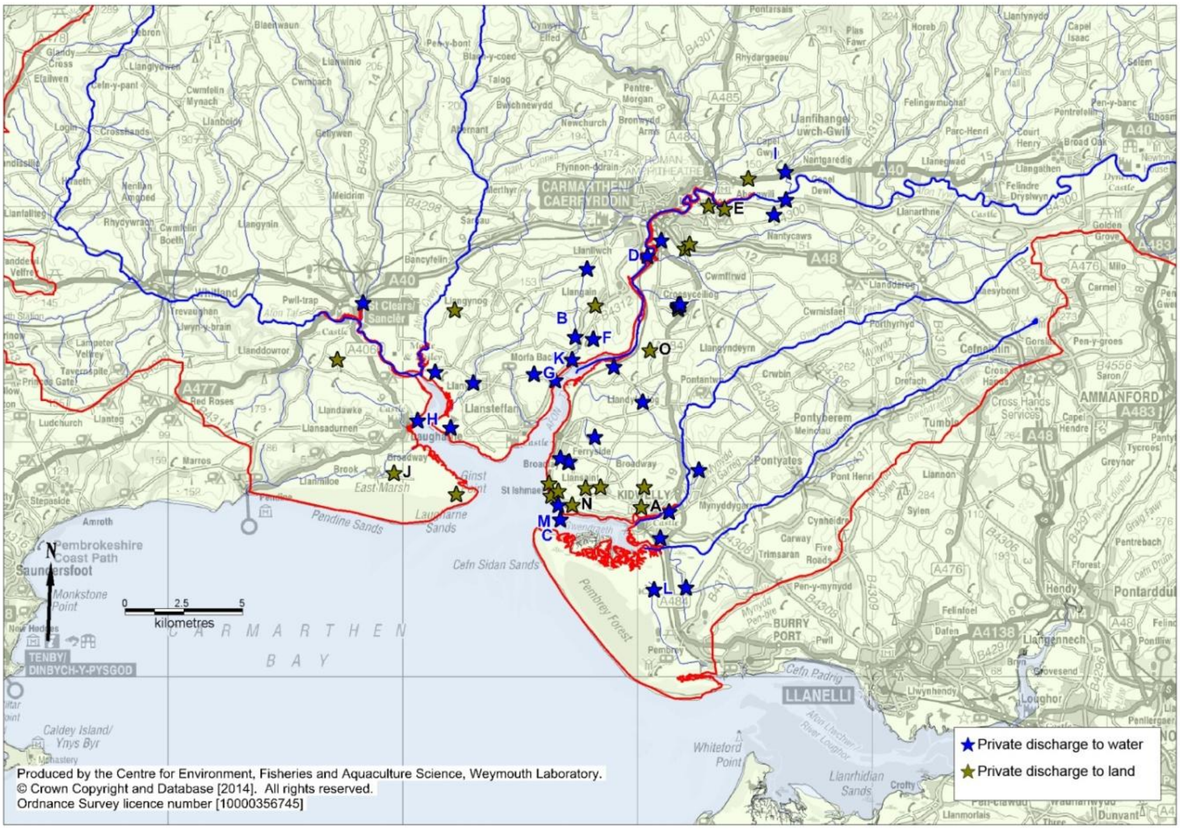


Figure II.3: Private discharges within 2 km of the Three Rivers estuary
Data from Natural Resources Wales.

Of the private discharges located within 2 km of the estuary, the largest discharge is from Carmarthen Bay Holiday Park (C) which has a maximum consented flow of 320 m^3 /day of effluent with an unspecified treatment level, although this is likely to be secondary treatment of some kind. This discharge is to the Gwendraeth Fach channel, in close proximity to the shellfisheries here. There may also be a seasonal variation in the volume of effluent discharged, with peak volumes in the summer. Other private discharges are considerably smaller, and most are located further from the shellfisheries. They will therefore make a minor contribution to the bacterial loadings carried by some watercourses, but will have little bearing on the sampling plan.

Appendix III. Sources and variation of microbiological pollution: Agriculture

Most of the land within the hydrological catchment is used for agriculture, and almost all of this is pasture (Figure 1.2). Numbers and overall densities of livestock as recorded in the 2012 agricultural census are presented in Figure III.1 and Table III.1.

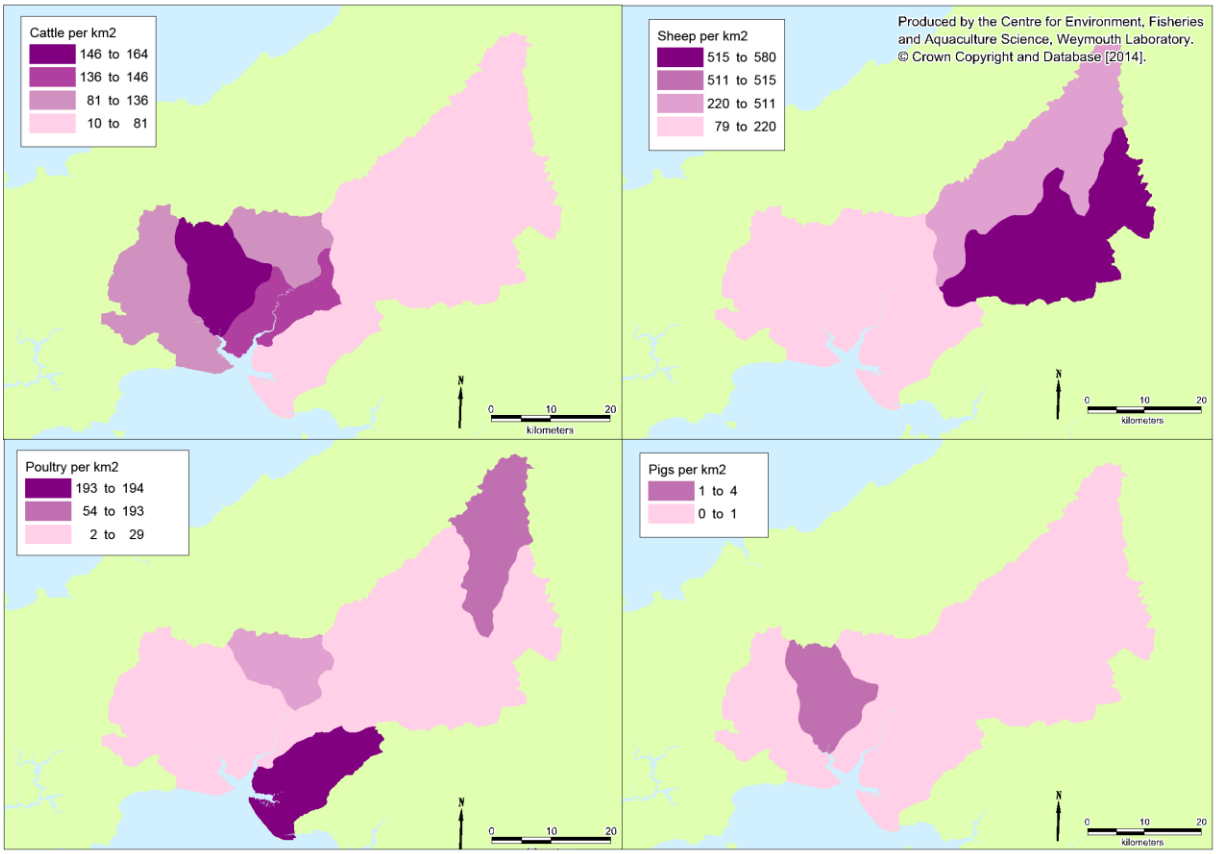


Figure III.1: Livestock densities in 2012 across the Three Rivers sub-catchments
Data from Welsh Government.

Table III.1: Summary statistics from 2012 livestock census within the survey catchment

Subcatchment	Total number				Density (no/km^2)			
	Cattle	Sheep	Poultry	Pigs	Cattle	Sheep	Poultry	Pigs
Bran & Gwydderig	3,358	78,327	396	26	24.9	579.8	2.9	0.2
Cothi	9,999	156,594	2,051	87	32.6	510.6	6.7	0.3
Gwendraeth Fach & Fawr	16,947	16,626	40,438	152	80.9	79.4	193.1	0.7
Gwili	14,996	32,162	4,284	74	102.4	219.7	29.3	0.5
Taf East	30,433	27,358	1,671	678	163.2	146.7	9.0	3.6
Taf West	39,586	60,979	3,603	182	135.9	209.3	12.4	0.6
Tywi d/s Nantgaredig	20,536	22,876	1,415	35	145.7	162.4	10.0	0.2
Tywi u/s Llandovery Bran	2,325	55,306	12,266	25	10.3	244.7	54.3	0.1
Tywi, Cothi to Llandovery Bran	24,854	212,286	3,469	285	60.4	515.5	8.4	0.7
Total	**163,034**	**662,514**	**69,593**	**1,544**	**79.4**	**322.5**	**33.9**	**0.8**

Data from Welsh Government

The concentration of faecal coliforms excreted in the faeces of animals and humans and corresponding loads per day are summarised in Table III.2.

Table III.2: Levels of faecal coliforms and corresponding loads excreted in the faeces of warm-blooded animals.

Farm Animal	Faecal coliforms (No. g^{-1} wet weight)	Excretion rate (g day^{-1} wet weight)	Faecal coliform load (No. day^{-1})
Chicken	1,300,000	182	2.3×10^{8}
Pig	3,300,000	2,700	8.9×10^{8}
Human	13,000,000	150	1.9×10^{9}
Cow	230,000	23,600	5.4×10^{9}
Sheep	16,000,000	1,130	1.8×10^{10}

Data from Geldreich (1978) and Ashbolt et al. (2001).

The upper reaches of the catchment favours sheep farming, whilst the lower reaches are more a mix of dairy and livestock farming. Some maize is grown in the more fertile areas (Environment Agency, 2006). Livestock census data indicates that sheep farming is widespread, with over 660,000 animals within the catchment. Highest densities were present in the upper eastern areas of the catchment. Large number of cattle are also present (163,000) and highest densities of these were in the lower western parts of the catchment. Some poultry are raised in the area, the majority of which are within the Gwendraeth Fach & Fawr sub-catchment. Small numbers of pigs are also farmed, mainly within the Taf catchment. During the shoreline survey livestock were observed in most areas visited.

Faeces from grazing animals will be deposited directly onto pastures, and subsequently washed into nearby watercourses. The main watercourses enter at the heads of the three estuary channels, so an underlying gradient of increasing contamination towards the heads of the estuary are anticipated on this basis. Cattle may be housed indoors at certain times of the year, and at these times slurry will be collected and stored for use as a fertilizer. Manure from pig and poultry operations is typically collected, stored and spread tactically on nearby farm land (Defra, 2009). Sewage sludge may also be used as fertilizer, but no information on local practices was available at the time of writing. There may therefore be some impacts arising from the periodic application of organic fertilizers to pastures and crops.

The primary mechanism for mobilisation of faecal matter deposited or spread on farmland to coastal waters is via land runoff, so fluxes of livestock related contamination into the survey will be highly variable and depend on rainfall. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the 'first flush'). Most, if not all significant watercourses will be impacted to some extent by agriculture. The largest and most consistent fluxes of indicator bacteria into coastal waters are anticipated to arise from grazed areas where animals have access to watercourses, particularly if this is in close proximity to the coast.

As well as being carried into the estuary via land runoff, faecal matter deposited on saltmarshes may be washed in through tidal inundation. Creeks draining saltmarsh areas will carry associated faecal contamination into coastal waters either via runoff or through tidal inundation. An Environment Agency study found a significant increase in levels of faecal coliforms within such creeks in the Ribble estuary as the tide started to ebb following saltmarsh inundation (Dunhill, 2003). Impacts will be greatest in the vicinity of any drainage channels cutting across the intertidal, and the fluxes are likely to be much greater on large spring tides when much more of the marsh is covered. Around 100 cattle were observed on the saltmarsh to the south of the Gwendraeth estuary channel. The smaller areas of saltmarsh around the Taf estuary channel are also reported to be grazed to various extents. The main area between Laugharne and Ginst Point is only lightly grazed, whereas the other areas are grazed more intensively (CCW, 2002).

As well as significant day to day variation driven by rainfall there is likely to be some seasonal differences in the fluxes of faecal indicator bacteria of agricultural origin into the survey area. Numbers of sheep and cattle will increase in the spring with the birth of lambs and calves, and then decrease in the autumn as they are sent to market. In warmer weather, grazing animals are more likely to access watercourses to cool off and drink. It is likely that sheep are moved from the higher pastures to more sheltered areas during the colder months. The seasonal pattern of saltmarsh grazing is uncertain. During winter cattle may be transferred from pastures to indoor sheds, and at these times slurry will be collected and stored for later application to fields. Timing of these applications is uncertain, although farms without large storage capacities are likely to spread during the winter and spring. Poultry/pig manure and sewage sludge may be spread at any time of the year. Therefore peak levels of contamination from sheep and cattle may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised basis if wet weather follows a slurry application which is more likely in winter or spring.

Appendix IV. Sources and variation of microbiological pollution: Boats

The discharge of sewage from boats is a potential source of bacterial contamination to shellfisheries within the Three Rivers survey area. Boat traffic in the area includes fishing boats, yachts, cabin cruisers and smaller leisure craft such as sailing dinghies and kayaks. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources.

Figure IV.1 Boating activity in the Three Rivers survey area

There are no ports or marinas within the Three Rivers survey area. The closest marina, Burry Port Harbour is situated in Burry Inlet approximately 15 km east where there are 450 berths (Reeds Almanac, 2012). Saundersfoot Harbour situated approximately 19 km west of the survey area holds around 174 berths for pleasure craft plus additional drying moorings for fishing boats (Saundersfoot Harbour website, 2014). Sewage pump out facilities are not available at either of these marinas, the closest facility is located in Swansea marina approximately 55 km east of the survey area (The Green Blue, 2010). Within the survey area the largest area of moorings is on the River Towy (or Tywi), offshore from the River Towy Yacht Club and The Towy Boat Club. Both clubs offer a variety of watersports including; rowing, power boating, yachting and dinghy sailing. A few moorings are also situated on the Taf channel at St Clears and in the middle reaches of the Gwendraeth estuary.

There is a fishing fleet in the area, of which 9 vessels are listed as having a home port as the Three Rivers area. A further 28 vessels operate from Burry Port, and 12 vessels operate from Saundersfoot (MMO, 2013). All are under 10 m in length. Their fishing patterns are uncertain, but in general their use of the Three Rivers estuary is likely to be very limited.

It is therefore concluded that boat traffic in the estuary is limited to small numbers of pleasure craft and fishing vessels, so the impacts from boat traffic are likely to be minor at most. Smaller pleasure craft such as kayaks and sailing dinghies will not have onboard toilets and so are unlikely to make overboard discharges. Only the larger yachts and fishing vessels are therefore likely to make overboard discharges. This may occur when boats are at anchor, particularly if they are in overnight occupation, or whilst a vessel is navigating through the area. As such, the areas of moorings and the river channels are probably most at risk. Peak pleasure craft activity is anticipated during the summer, so associated impacts are likely to follow this seasonal pattern. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Appendix V. Sources and Variation of Microbiological Pollution: Wildlife

The Three Rivers estuary encompasses a variety of habitats including sand dunes, intertidal mudflats and sandflats, and saltmarsh. Consequently, Carmarthen Bay and estuaries have been classified as a Special Area of Conservation (SAC). The survey area is also protected by several other international and national environmental legislations including: five Special Sites of Scientific Interest (SSSI) and a Local Nature Reserve (LNR), Glan Yr Afon.

The most significant wildlife aggregation in terms of shellfish hygiene is likely to be the large numbers of overwintering waterbirds (wildfowl and waders) which use the estuary. Studies in the UK have found significant concentrations of microbiological contaminants (thermophilic campylobacters, salmonellae, faecal coliforms and faecal streptococci) from intertidal sediment samples supporting large communities of birds (Obiri-Danso and Jones, 2000). Over the five winters up until 2010/11 an average total count of 37,923 overwintering birds and wildfowl were recorded (Holt *et al*, 2012) within Carmarthen Bay, which includes the Three Rivers estuary. On the shoreline survey flocks of birds were observed throughout in particularly large numbers, around 500 oystercatchers were recorded on a sand bank off Wharley Point where the Taf and Twyi converge.

Grazers such as geese and ducks will frequent the saltmarsh and coastal pastures, where their faeces will be carried into coastal waters via runoff into tidal creeks or through tidal inundation. Therefore RMPs within or near to the drainage channels from saltmarsh areas will be best located to capture contamination from this source. Waders, such as dunlin and oystercatchers forage upon shellfish and so will forage (and defecate) directly on any shellfish beds on the intertidal. They may tend to aggregate in certain areas holding the highest densities of bivalves of their preferred size and species, but this will probably vary from year to year. Contamination via direct deposition may be patchy, with some shellfish containing high levels of *E. coli* while others a short distance away are unaffected. At high tide waders are likely to frequent the saltmarsh and the perimeter of the estuary. Due to the diffuse and spatially unpredictable nature of contamination from wading birds it is difficult to select specific RMP locations to best capture this, although they may well be a significant influence during the winter months.

In addition to overwintering and wildfowl flocks, gulls and terns are also likely to be widespread within the survey area all year round; exact numbers are not available although numbers are likely to be considerably lower. No records of breeding seabirds were listed in a survey of breeding seabirds undertaken in 2000 (Mitchell *et al*, 2004) so it can be concluded that there are no significant breeding colonies in the area. These seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse away from any nesting aggregations.

There are about 5000 grey seals in west Wales and their main stronghold is the Pembrokeshire coast. The closest colony to the Three Rivers, of up to around 60 seals, is at Caldey Island (Kiely *et al*, 2000) about 20 km to the southwest. They are known to enter the estuary from time to time to hunt returning salmon and sea trout, for which the peak period of upstream migration is summer and autumn. It is quite likely that they haul out on mid estuary sandbanks on occasion, and if this coincides with a cockle bed there is the potential for them to create a localised hotspot of contamination. However, no firm information on regular haul-out sites could be found. Given their small numbers and the large area they are likely to forage over their impacts are likely to be minor, and unpredictable in spatial terms, although it is likely that the estuary is more attractive to them during the summer and autumn.

Otters are present within the survey area and are known to breed 1 km inland on the Gwendraeth Fach particularly (Countryside Council for Wales, 2009) and within the Afon Tywi SSSI (Countryside Council for Wales, 1998). No information on numbers was available but the population is likely to be small. Otters generally tend to favour the more secluded areas with access to watercourses. However, given their likely wide distribution and small numbers otters have no material bearing on the sampling plan.

Appendix VI. Meteorological Data: Rainfall

The Johnstown weather station, received an average of 1299 mm per year between 2003 and 2012. Figure VI.1 presents a boxplot of daily rainfall records by month at Johnstown.

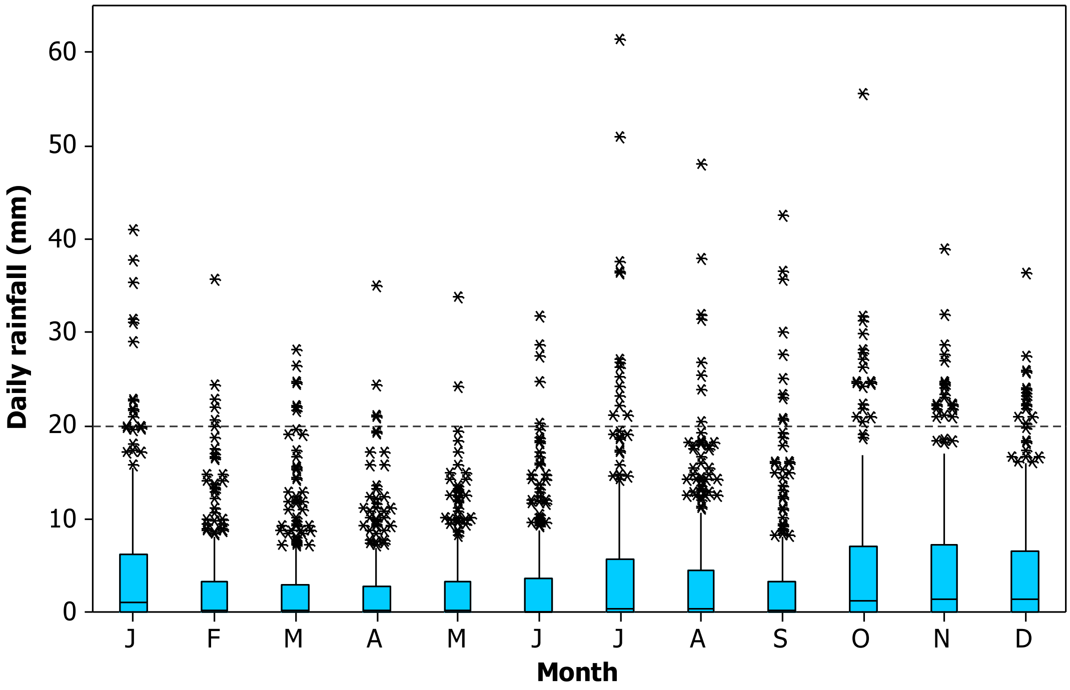


Figure VI.1: Boxplot of daily rainfall totals at Johnstown, January 2003 to December 2012.
Data from Natural Resources Wales

Rainfall records from Johnstown, which is representative of conditions in the vicinity of the shellfish beds, indicate some seasonal variation in average rainfall with more rainfall through the winter. Rainfall was lowest on average in March and highest on average in October. A secondary peak is apparent in July as a result of a series of wet Julys from 2007 to 2010, but this pattern is not apparent in long term averages for the region (Met Office 2012). Daily totals of over 20 mm were recorded on 3.25 % of days and only 39 % of days were dry. High rainfall events occurred in all months, but were more numerous and intense in the second half of the year. The catchment area for Three Rivers is relatively large, and extends into the Cambrian Mountains. Rainfall in the upper catchment is likely to be higher than in the lower catchment.

Rainfall may lead to the discharge of raw or partially treated sewage from combined sewer overflows (CSOs) and other intermittent discharges as well as runoff from faecally contaminated land (Younger *et al*., 2003). Representative monitoring points located in parts of shellfish beds closest to rainfall dependent discharges and freshwater inputs will reflect the combined effect of rainfall on the contribution of individual pollution sources. Relationships between levels of *E. coli* and faecal coliforms in shellfish and water samples and recent rainfall are investigated in detail in Appendices XI and XII.

Appendix VII. Meteorological Data: Wind

Wales is one of the windier parts of the UK, particularly its west facing coasts. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest in the winter half of the year, especially from November to February, and this is when mean speeds and gusts are strongest (Met Office, 2012).

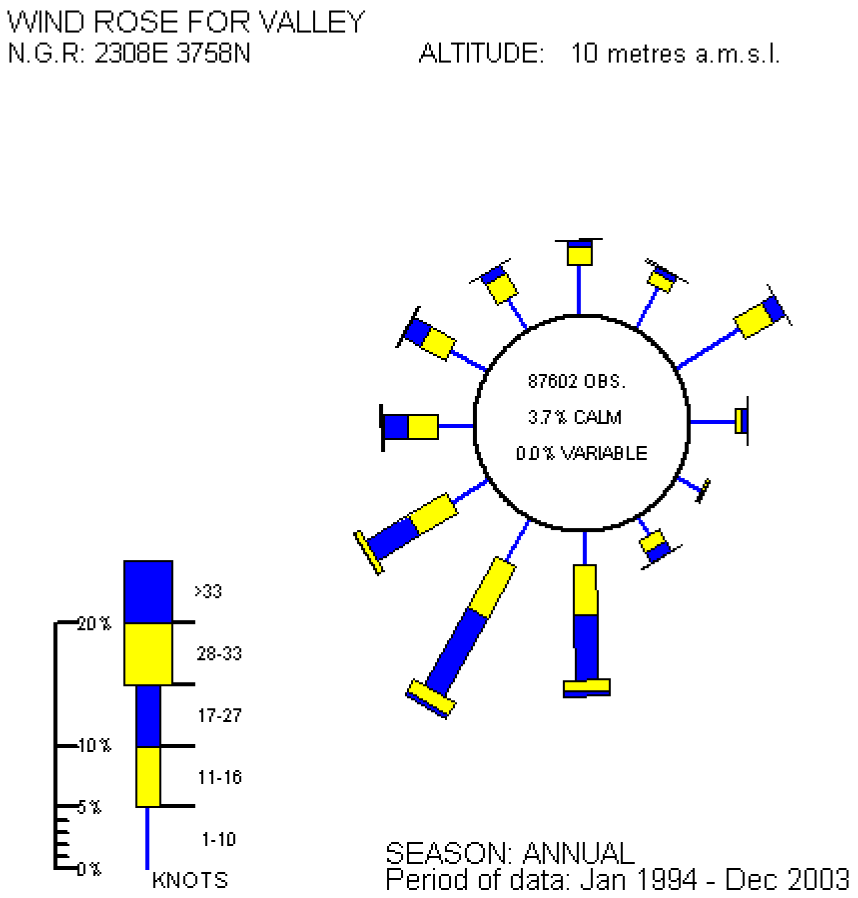


Figure VII.1 ***Wind rose for Valley.***
Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The wind rose for Valley (Anglesey) is typical of coastal locations in Wales. The prevailing wind direction is from the south west and the strongest winds usually blow from this direction. A higher frequency of north easterly winds occurs during spring. The Three Rivers estuary faces south west and therefore will be exposed to the prevailing winds and swells, in its outer reaches at least.

Appendix VIII. Hydrometric Data: Freshwater Inputs

Five main watercourses drain the Three Rivers hydrological catchment, which covers an area of around 2,052 km². The Taf and the Cywyn drain to the western estuary channel, the Tywi drains to the central channel, and the Gwendraeth Fach and Gwendraeth Fawr drain to the eastern channel. They all drain to the heads of their respective estuary channels, so the influence of land runoff is likely to increase towards the upper reaches of the three channels. There are also numerous other smaller watercourses draining to the estuary at regular intervals which may create more localised hotspots of contamination.

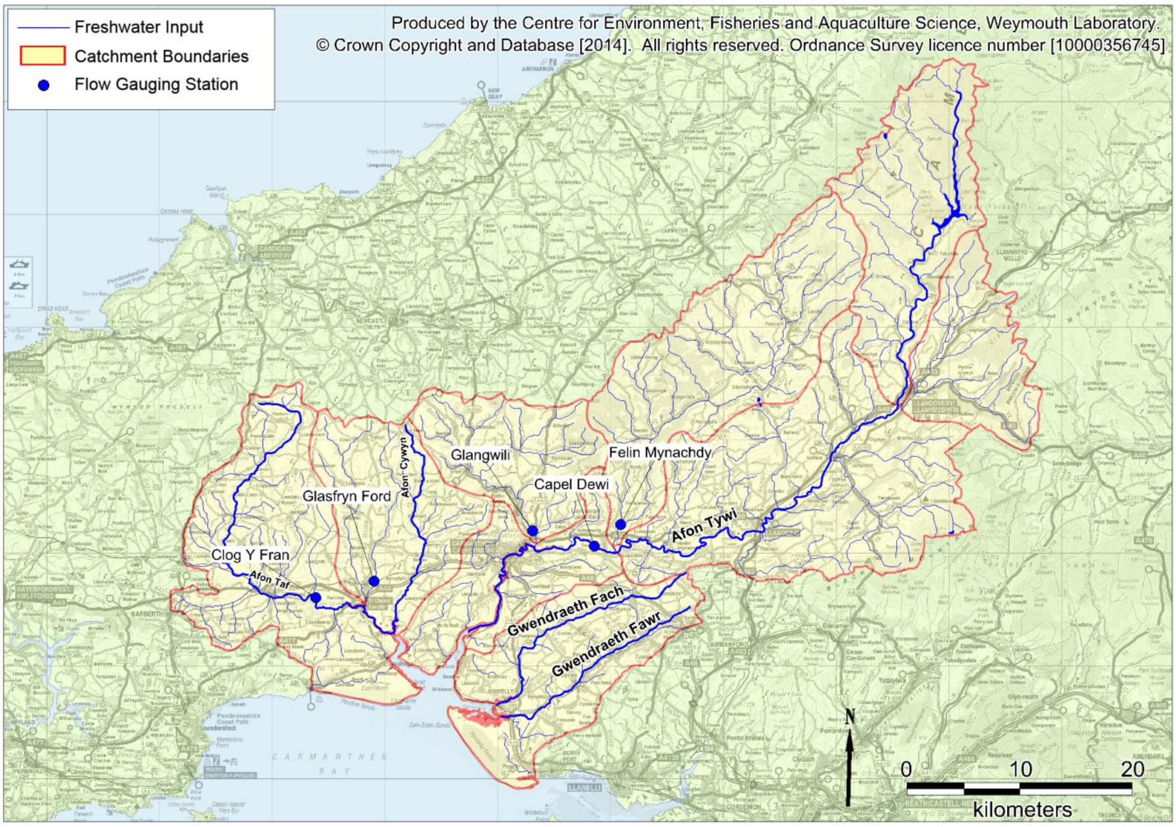


Figure VIII.1 Freshwater inputs to the Three Rivers estuary

The Afon Twyi is the principle freshwater input into the estuary. It is a major spate river of 96 km in length from source to tidal limit. The gradient is high in the upper reaches, whereas the lower reaches downstream of Llandovery are of a lower gradient with a more meandering channel and an extensive floodplain. There is a reservoir in the upper reaches which is used to maintain flows for abstraction further downstream, and controlled releases may occur in spring and late summer to assist the passage of migratory fish. Around 65 % of the whole catchment area drains to the Tywi arm of the estuary. The profile of the Taf/Cywyn is similar to that of the Tywi, with steep gradients in the upper reaches and more meandering with a less steep gradient in the lower reaches. Around 25 % of the catchment drains to the Taf arm of the estuary. In contrast to the other main rivers, the Gwendraeth Fach and Fawr are more lowland in character, with a medium-low gradient throughout their length. About 10 % of the Three Rivers catchment drains to the Gwendraeth arm of the estuary.

The topography and geology of the Three Rivers catchment is such that there will generally be relatively high rates of runoff and the rivers will respond rapidly to rainfall. They all drain rural land, with sheep farming and forestry at higher elevations and a mix of sheep and cattle in the lower reaches, so significant agricultural inputs are anticipated. The principle watercourses also all receive significant sewage inputs. Summary statistics for five flow gauging stations in the Three Rivers hydrological catchment are presented in Table VIII.1. Data for mean flow, Q95 and Q10 cover the period from January 2003 to January 2014.

Table VIII.1:
Summary flow statistics for five gauging stations draining into Three Rivers (2003-2014)

Station Name	Water course	Catchment Area (Km²)	Mean Annual Rainfall 1961-1990 (mm)	Mean Flow (m³s-1)	Q95[1] (m^3s^{-1})	Q10[2] (m^3s^{-1})
Clog Y Fran	Taf	217.3	1420	7.94	1.17	17.20
Glasfryn Ford	Dewi Fawr	36.7	1475	1.28	0.16	2.98
Glangwili	Gwili	129.5	1602	5.06	0.70	11.90
Capel Dewi	Tywi	1090.4	1534	40.51	5.63	96.02
Felin Mynachdy	Cothi	297.8	1551	12.14	1.13	28.33

[1]Q95 is the flow that is exceeded 95% of the time (i.e. low flow). [2]Q10 is the flow that is exceeded 10% of the time (i.e. high flow). Data from NERC, 2012 and Natural Resources Wales

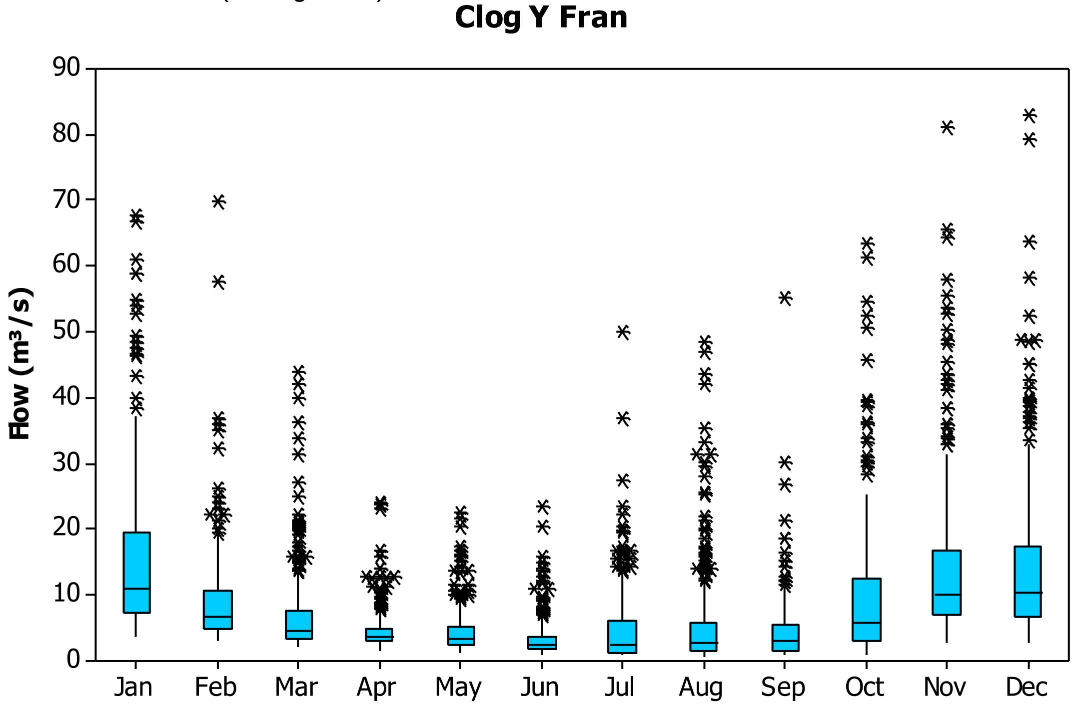


Figure VIII.2 Boxplots of mean daily flow records from the Clog Y Fran gauging station on the Taf watercourse (2003-2014)
Data from Natural Resources Wales

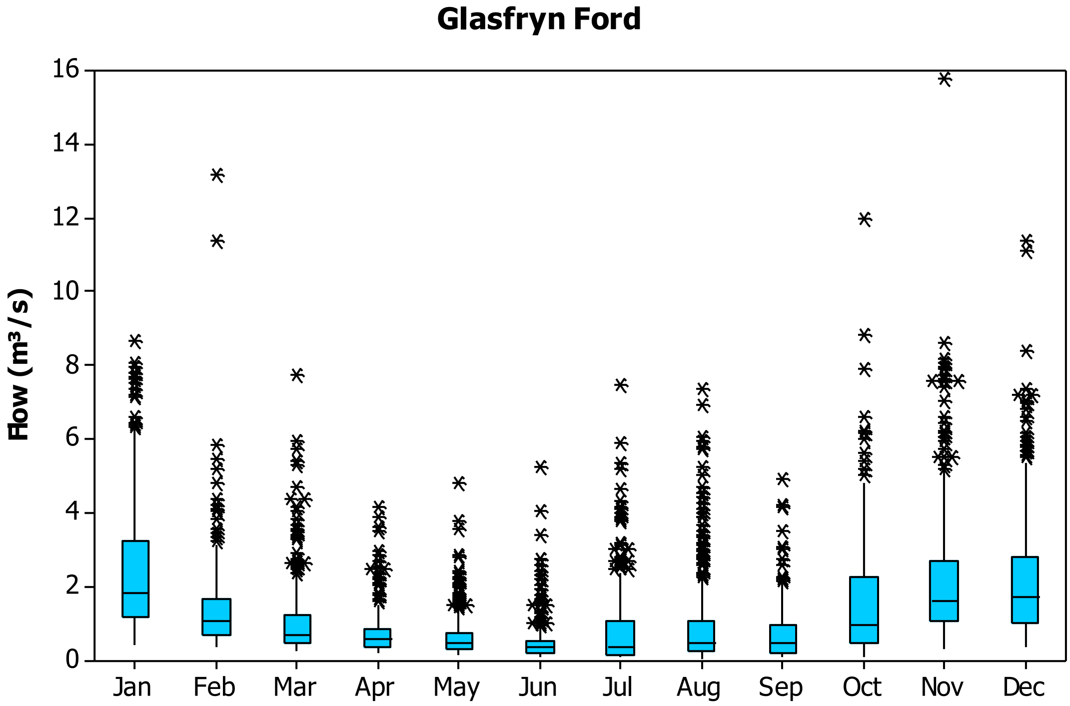


Figure VIII.3 Boxplots of mean daily flow records from the Glasfryn Ford gauging station on the Dewi Fawr watercourse (2003-2014)

Data from Natural Resources Wales

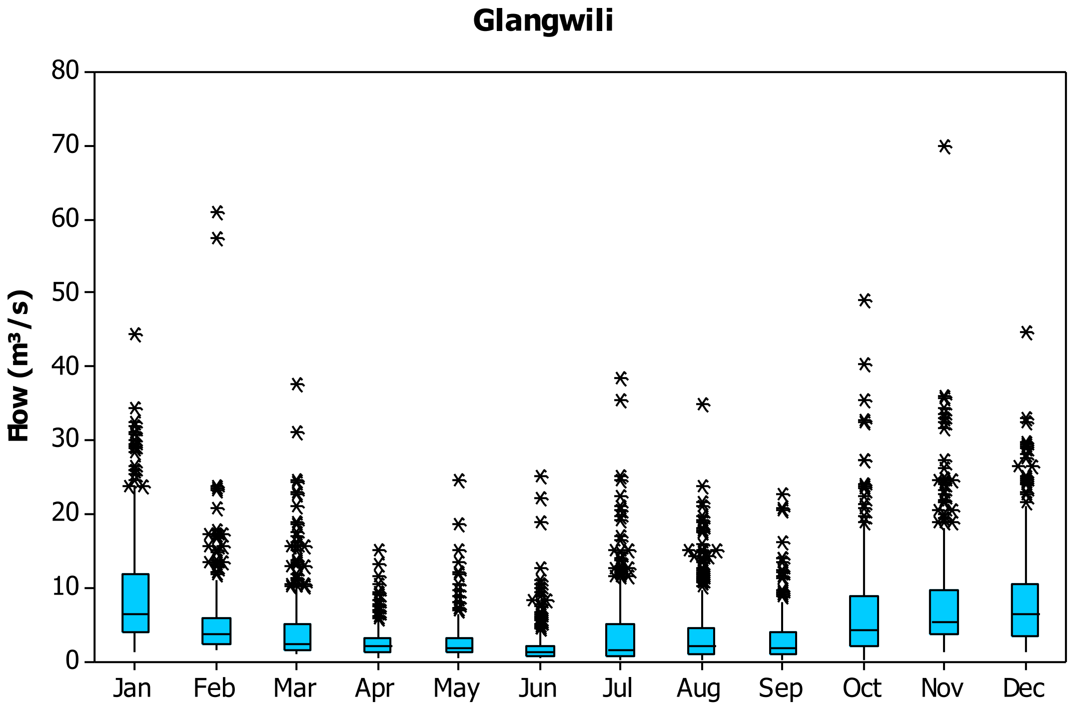


Figure VIII.4 Boxplots of mean daily flow records from the Glangwili gauging station on the Gwili watercourse (2003-2014)

Data from Natural Resources Wales

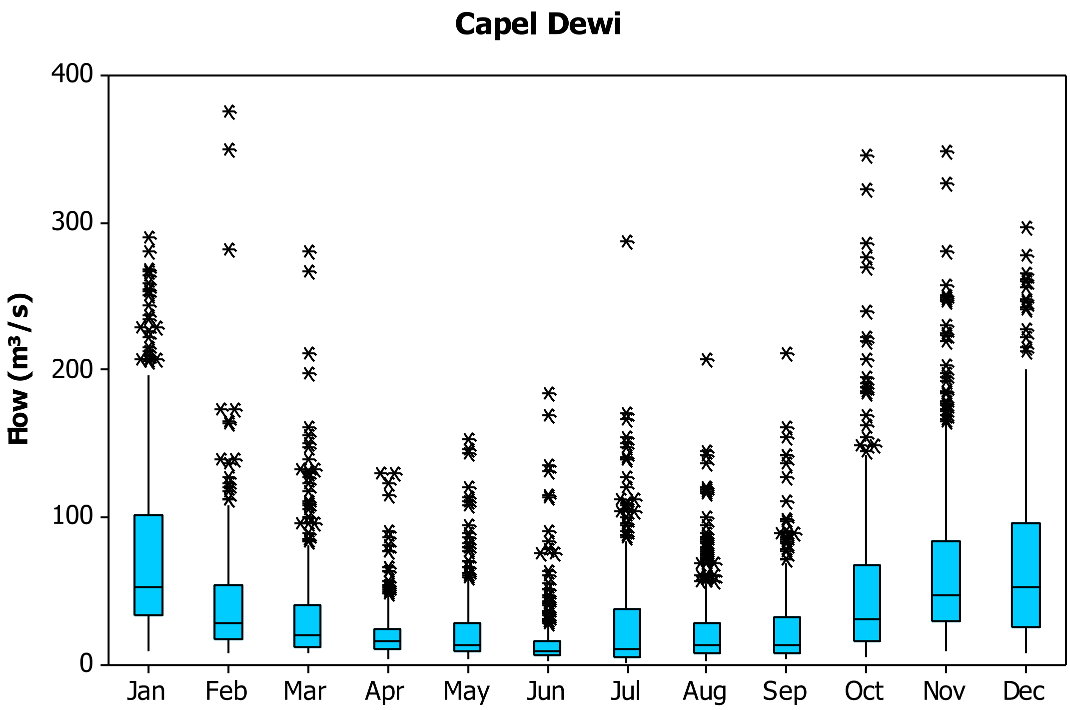


Figure VIII.5 Boxplots of mean daily flow records from the Capel Dewi gauging station on the Tywi watercourse (2003-2014)
Data from Natural Resources Wales

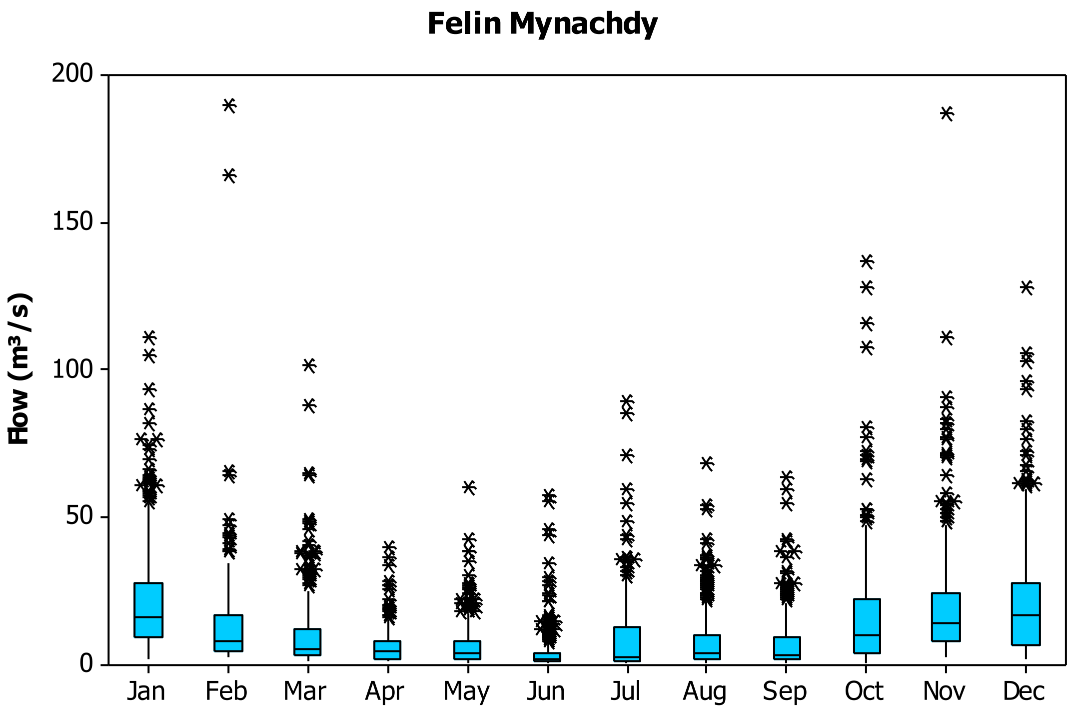


Figure VIII.6 Boxplots of mean daily flow records from the Felin Mynachdy gauging station on the Cothi watercourse (2003-2014)
Data from Natural Resources Wales

Highest discharge volumes by some margin were recorded on the Tywi, so the Tywi estuary channel is likely to be the most heavily influenced by land runoff. Flows were highest on average from October to January on all five gauged watercourses. A secondary peak in flows can be seen in July, although this is likely to be due to the unusual series of wet Julys during the period presented (Appendix VI). The seasonal pattern of flows is not entirely dependent on rainfall as during the colder months there is less evaporation and transpiration, leading to a higher water table. This in turn leads to a greater level of runoff immediately after rainfall. Increased levels of runoff are likely to result in an increase in the amount of microorganisms carried into coastal waters. Additionally, higher runoff will decrease residence time in rivers, allowing contamination from more distant sources to have an increased impact during high flow events.

During the shoreline survey, which was conducted under both dry and wet conditions watercourses and drainage systems which could be safely accessed were sampled for *E. coli* and spot flow measurements were made. The results and locations are presented in Table VIII.2 and Figure VIII.7. Due to the inaccessibility of the majority of larger watercourses their flow rate could not be measured and consequently the *E. coli* loading per day could not be calculated.

Table VIII.2 *E. coli* sample results, measured discharge and calculated *E. coli* loadings

Ref.	Date	Watercourse	*E. coli* concentration (CFU/100 ml)	Flow (m^3s^{-1})	*E. coli* loading (CFU/day)
A	17/12/2013	Marsh drainage	660	0.549	$3.13x10^{11}$
B	17/12/2013	Gwendraeth Fawr	1,700	Not accessible	
C	17/12/2013	Marsh drainage	120	0.136	$1.41x10^{10}$
D	17/12/2013	Gwendraeth Fach	600	7.000	$3.63x10^{12}$
E	17/12/2013	Stream	110	0.019	$1.81x10^{9}$
F	17/12/2013	Stream	1,600	0.140	$1.93x10^{11}$
G	17/12/2013	Afon Pibwr	350	1.400	$4.23x10^{11}$
H	17/12/2013	Afon Tywi	2,000	Not accessible	
I	18/12/2013	Stream	2,200	0.087	$1.65x10^{11}$
J	18/12/2013	Stream	14,000	0.248	$2.99x10^{12}$
K	18/12/2013	Stream	15,000	2.000	$2.59x10^{13}$
L	18/12/2013	Afon Cywyn	4,700	Not accessible	
M	18/12/2013	Afon Cynin/Afon Dewi Fawr	12,000	Not accessible	
N	18/12/2013	Ground water	16,000	Not accessible	
O	18/12/2013	Stream	2,300	0.092	$1.82x10^{11}$
P	18/12/2013	Stream	1,500	0.009	$1.15x10^{10}$
Q	18/12/2013	Marsh drainage	300	Not accessible	
R	18/12/2013	Marsh drainage	440	0.028	$1.05x10^{10}$

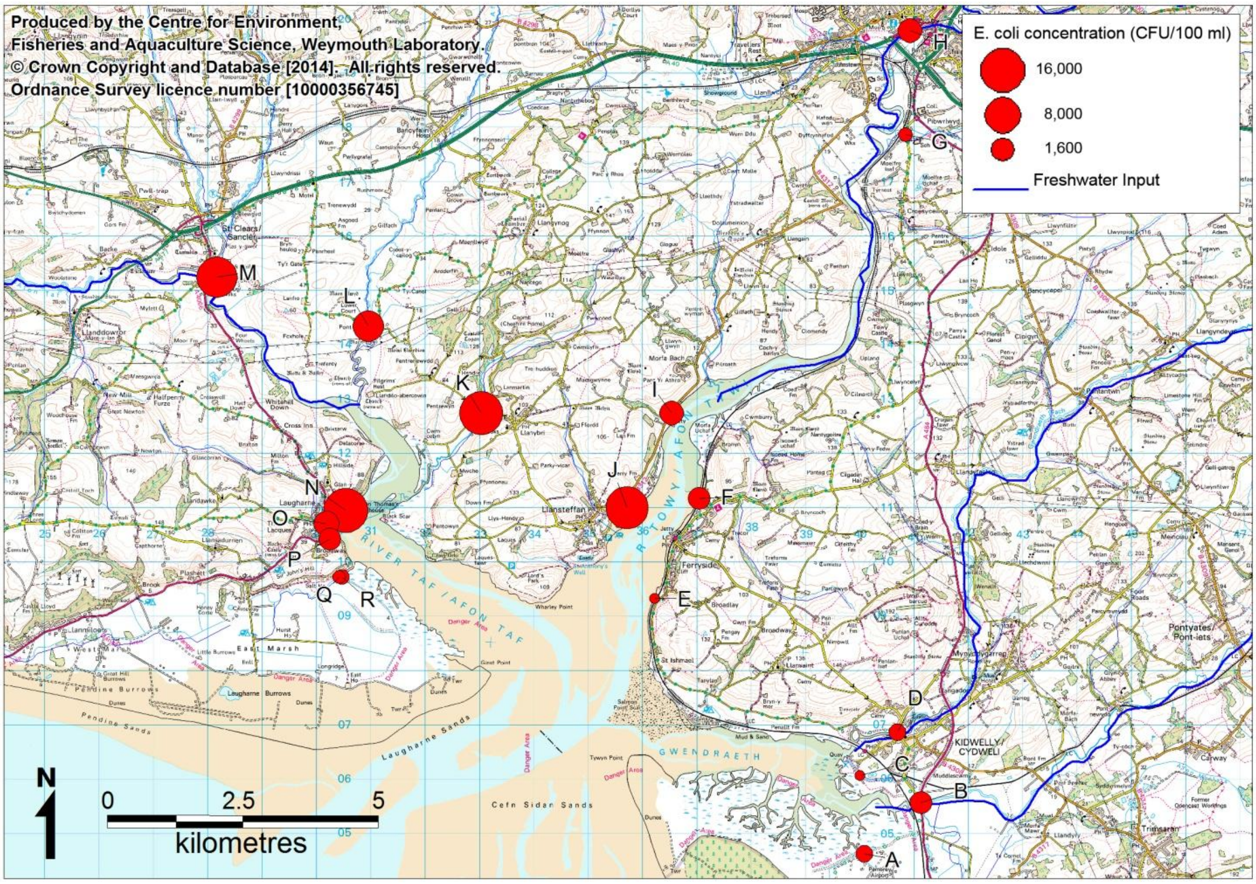


Figure VIII.7 Locations of shoreline survey stream observations, Three Rivers Estuary

Within the Taf arm, a number of smaller watercourses discharge in the vicinity of Laugharne, and these may be of local influence to the cockle bed. Their influence, together with other freshwater inputs to this channel will be more acute at the upper end of this shellfish bed. A small and uncontaminated watercourse discharges to the southern end of a cockle bed at Ferryside in the Tywi arm, but apart from this all significant freshwater inputs are up-estuary from the shellfish. No significant freshwater inputs were observed in the immediate vicinity of shellfish resources in the Gwendraeth arm, and all significant freshwater inputs were to its head. The *E. coli* concentrations carried by the majority of these watercourses on the eastern side of the survey area were not particularly high, ranging from 110 to 2,000 *E. coli* CFU/100ml. On the west of the survey area *E. coli* concentrations ranged from 1,500 to 16,000 *E. coli* cfu/100ml. This marked difference in *E. coli* concentrations between the west and east of the survey area could be as a result of the heavy rainfall that fell on the second half of the survey, which is when the western arm was sampled.

The results of a modelling study of the estuary indicated that land runoff accounts for the majority of contamination delivered to the estuary even at low flows. During high river flow events the loadings the estuary receives increases about fivefold (Wyer *et al*, 2005). Of potential relevance to the sampling plan, this study also predicted that at low flows, the bacterial loading delivered by the Gwendraeth Fawr was about 15 times that delivered by the Gwendraeth Fach, but at high flows the two delivered a similar bacterial loading.

Table VIII.3: Modelled *E. coli* budgets for the three estuary channels

		Low flow	High Flow
Taf	*E. coli* loading/day	$2.37x10^{15}$	$1.72x10^{16}$
	% from runoff	94.9%	99.7%
Tywi	*E. coli* loading/day	$5.82x10^{15}$	$2.88x10^{16}$
	% from runoff	64.6%	96.7%
Gwendraeth	E. coli loading/day	$1.07x10^{15}$	$6.87x10^{15}$
	% from runoff	83.4%	98.9%

Reproduced from Wyer et al*, 2005.*

It is therefore concluded that the land runoff will deliver a significant proportion of the faecal indicator loading the estuary receives. All three channels will be impacted, particularly the Tywi channel, and as all the major inputs are up-estuary from the fisheries, their upstream ends will be most heavily impacted.

Appendix IX. Hydrography

IX.1. Bathymetry

The Three Rivers estuary is a double spit enclosed estuary which faces south west and drains into Carmarthen Bay. It covers an area of around 37 km², of which 91% is intertidal, so a large proportion of water will be exchanged on each tide but the dilution potential will be quite low away from the main channels. Figure IX.1 illustrates the bathymetry of the outer reaches of the estuary in which the shellfisheries are located.

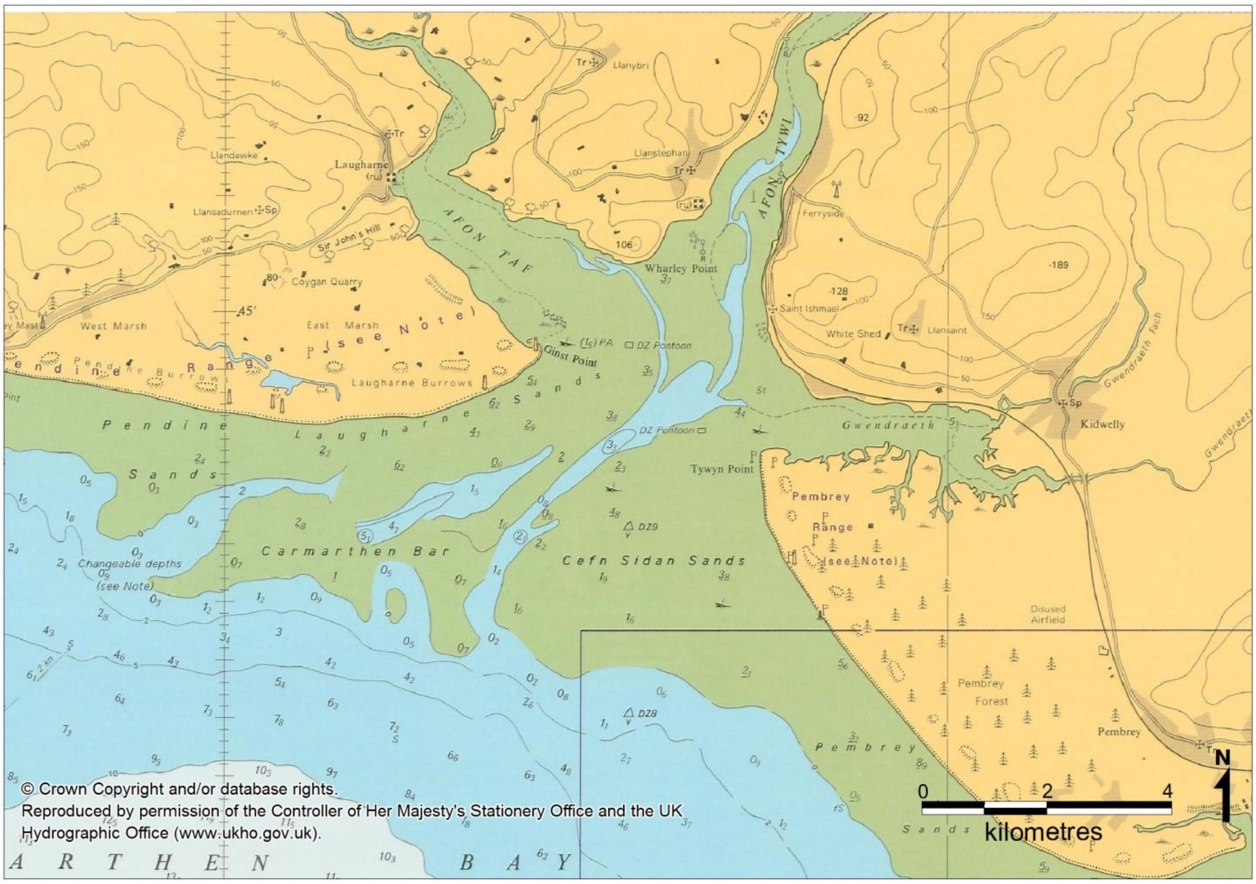


Figure IX.1: Bathymetry of the Three Rivers estuary

Three shallow arms extend from a wide mouth (4 km) representing the estuaries of the Taf extending north west, the Twyi extending north and the Gwendraeth extending east. These are characterised by central river channels bisecting the intertidal areas, and all three receive their main freshwater inputs at their head. The Tywi channel extends about 20 km inland from Wharley Point to its tidal limit. It becomes progressively narrower, with the upper 14 km not generally exceeding 200 m in width. The Taf estuary channel has a similar profile to the Tywi, although it is only about 13 km in length from Wharley Point to its tidal limit. These two channels both lie in quite steep sided valleys. Patches of saltmarsh are present in both, but these are more extensive within the Taf channel. The shape of these channels, coupled with the location and size of the main freshwater inputs will result in a marked gradient of increasing levels of runoff borne contamination towards their upper reaches. The Gwendraeth arm is slightly different in character, being a relatively uniform 1 km in width throughout its lower 3.5 km. It then splits into two narrow tidal river channels which extend a further 2-3 km to their tidal limits. Hills border the north shore, but the south shore is low lying with extensive saltmarshes. Tidal deltas have formed around the mouth of the estuary complex. South of the estuary mouth, the bathymetry gently slopes into Carmarthen Bay.

IX.2. Tides and Currents

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The Three Rivers estuary is macrotidal with a tidal range of 6.6 m at Ferryside on spring tides. The tidal amplitude decreases further inland, and high water springs at Carmarthen are 2.6 m. There are no tidal diamonds within the Three Rivers estuary complex.

Table IX.1: Tide levels and ranges within the Three Rivers estuary

	Height above chart datum (m)				Range (m)	
Port	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Ferryside	6.7	4.5	0.8	0.1	6.6	3.7
Carmarthen	2.6	0.4	-	-	-	-

Data from Admiralty Totaltide

The estuarine system is flood dominant (Futurecoast, 2002), with a shorter duration faster moving flood tide in the outer estuary. There are no tidal diamonds within the survey area. Current velocities are reported to exceed 1 m/s on spring tides in places, but are considerably lower away from the main channels (May, 2003; Metoc, 2008).

Advection of pollutants by tidal currents is the main mode of contaminant transport in the Three Rivers estuary. The flood tide will convey relatively clean water originating from Carmarthen Bay into and up the estuary, whereas the ebb tide will carry contamination from shoreline sources out through the estuary. On a flood tide the principal tidal stream flows in a north easterly direction into the estuary and progresses up the three main channels with the opposite occurring on the ebb. As these channels fill, the tidal flow will fill the creeks and spread over the intertidal areas. Shoreline sources of contamination will therefore primarily impact up and down tide of their locations along the bank to which they discharge. Their impacts will decrease with distance travelled, as the plume becomes progressively more diluted. At lower states of the tide contamination from some shoreline sources such as watercourses will be carried through the intertidal drainage channels where the dilution potential is low. Relatively high concentrations of indicator bacteria may arise in these channels at such times.

The three main channels will be primarily influenced by sources of contamination discharging directly to them. There is the potential for some impacts from major sources in other channels to be carried back up the estuary on the subsequent flood tide, although they will be subject to significant dilution during travel. Due to the shallow nature of the estuary anticlockwise eddies can form around high water on spring tides in the mouth of the estuary (Metoc, 2008), and these may assist the exchange of water between the three estuary arms.

Superimposed on tidally driven currents, are the effects of freshwater inputs and wind. River flows are high, especially from the River Twyi but due to the size of the estuary and volumes exchanged tidally the flow ratio (freshwater input:tidal exchange) is low (Futurecoast, 2002). This suggests that the system as a whole is well mixed, and that density effects are unlikely to significantly modify circulation in the outer reaches of the estuary where the shellfish are located. Repeated salinity measurements were taken between 2003 and 2013 at 13 points within the estuary (Figure IX.2 and Figure IX.3).

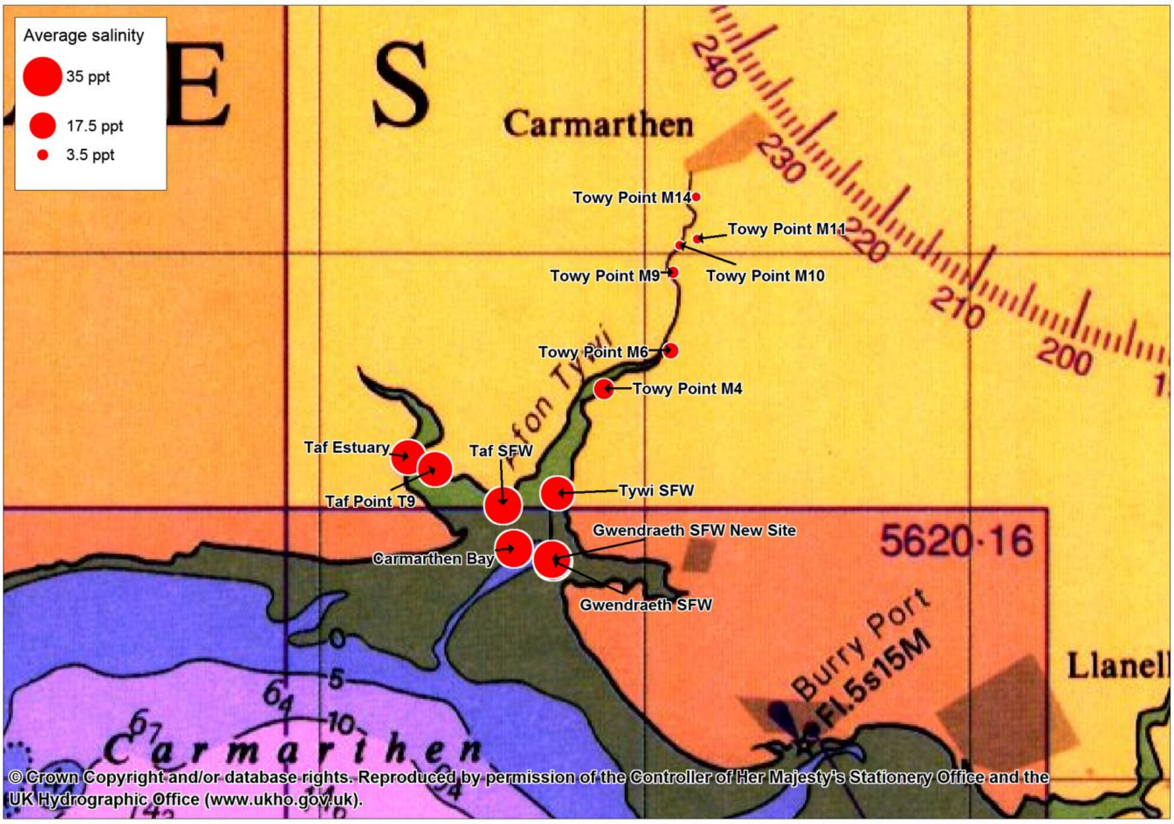


Figure IX.2: Locations of Salinity Sampling Locations
Data from Natural Resources Wales

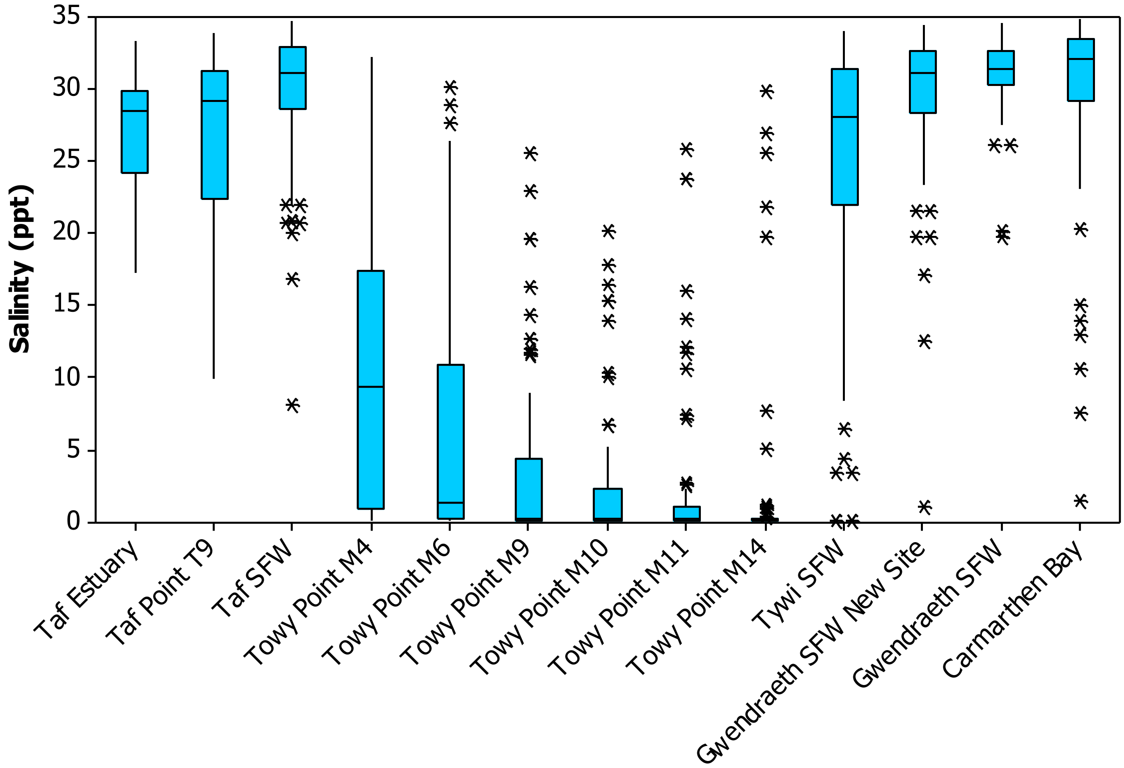


Figure IX.3 Boxplot of salinity readings taken from 13 locations in the Three Rivers Estuary
(2003 - 2013 at Taf SFW, Tywi SFW & Carmarthen Bay; 2004 – 2013 at Towy Points M4, M6, M9, M10, M11 & M14; 2003 - 2009 at Gwendraeth SFW; 2005 - 2013 at Gwendraeth SFW New site; 2006 – 2009 at Taf Point T9 and 2006 – 2013 Taf Estuary).
Data from Natural Resources Wales

The salinity measurements indicate that salinity in the mouth of the estuary is usually approaching that of full strength seawater, although much lower salinities were recorded here from time to time. The results also indicate that there is a slight gradient of decreasing average salinity towards the up-estuary ends of the shellfish beds in the Taf and the Tywi channels. Further upstream in the Tywi channel, the average salinity drops off to 10.4 ppt at Towy Point M4, and is less than 5 ppt at all points north of here. Salinities are also likely to drop off rapidly in the upper narrow reaches of the Taf estuary. The only sampled point in the Gwendraeth arm is in its very outer reaches, but there is likely to be a decrease in average salinity towards its upper reaches. The shape of the estuary suggests that this is unlikely to be as steep as that observed where the Tywi estuary narrows. Salinity may be considered a proxy for levels of runoff borne contamination, and was strongly negatively correlated with levels of faecal coliforms at both sites (Figure X.9). Therefore it is concluded that the influence of contamination carried into the estuary by land runoff will increase significantly towards the up-estuary ends of the fishery.

Strong winds drive surface water currents 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 0.5 m/s. This will create return currents lower in the water column or along sheltered margins. Effects of wind upon tide are highly dynamic and variable making firm predictions difficult. The prevailing south westerly winds will tend to push surface water up the estuary, with the likely exception of the Taf arm. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action. Where these waves break contamination held in intertidal sediments may be resuspended. The Three Rivers estuary is quite exposed to the south westerly winds and has a large fetch of over 4000 km consequently it is exposed to wave conditions from the Atlantic (May, 2003). However, due to the shallow nature offshore from the estuary, the wave energy will be dissipated before it reaches the mouth of the Three Rivers estuary (Metoc, 2008).

Appendix X. Microbiological Data: Seawater

X.1. Bathing Waters

There are five sites where Natural Resources Wales monitor bathing water quality in the Three Rivers estuary, but none of these are designated under the Directive 76/160/EEC (Council of the European Communities, 1975).

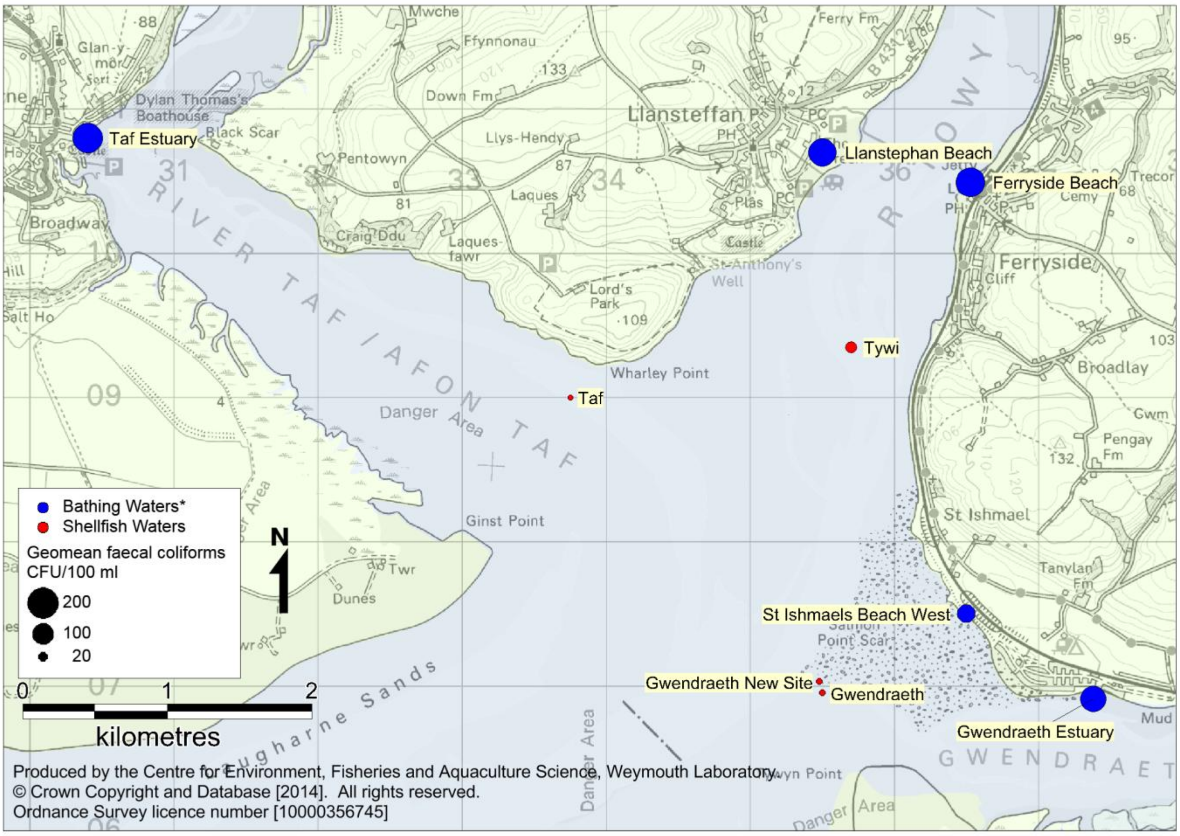


Figure X.1: Location of bathing waters and shellfish waters monitoring points.

Around twenty water samples were taken from each of the bathing waters sites during each bathing season, which runs from the 15th May to the 30th September. Faecal coliforms were enumerated in all these samples. Summary statistics of all results by bathing water are presented in Table X.1, and Figure X.2 presents box plots of these data.

Table X.1: Summary statistics for bathing waters faecal coliforms results, 2003-2011 (cfu/100 ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000	% over 10,000
Taf Estuary	11	21/12/2011	03/10/2012	189.7	<10	3200	54.5	18.2	0.0
Llanstephan Beach	102	07/05/2003	22/09/2009	162.6	2	8800	63.7	22.5	0.0
Ferryside Beach	102	07/05/2003	22/09/2009	178.1	2	10400	62.7	25.5	1.0
St Ishmaels Beach West	40	07/05/2003	15/09/2004	74.7	4	5200	47.5	10.0	0.0
Gwendraeth Estuary	62	01/05/2007	23/09/2009	143.3	<2	16000	48.4	29.0	1.6

Data from Natural Resources Wales

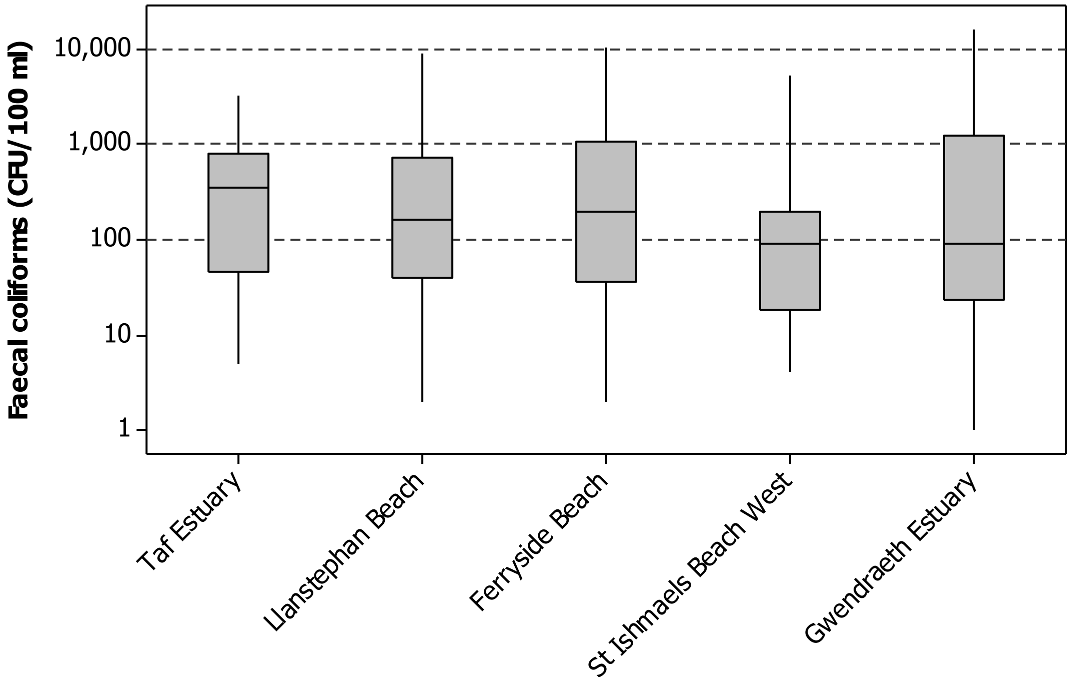


Figure X.2: Box-and-whisker plots of all faecal coliforms results by site
Data from Natural Resources Wales

All sites had results exceeding 1000 faecal coliforms/100 ml, but only Ferryside Beach and Gwendraeth Estuary had samples exceeding 10,000 CFU/100 ml. While Taf Estuary had the highest geometric mean of faecal coliform CFU/100 ml, Gwendraeth Estuary had the highest individual result of 16,000 cfu/100 ml and had the greatest proportion of results over 1,000 cfu/100 ml. One-way ANOVAs showed that there were no significant differences between faecal coliform levels between sites ($p = 0.243$).

Comparisons of sites were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared sampling dates, and therefore environmental conditions, on at least 20 occasions. No comparisons between Taf Estuary and the other sites were possible as it was only sampled on 11 occasions. St Ishmaels Beach West and Gwendraeth Estuary were not sampled on the same day on 20 or more occasions and there was no significant correlation ($p>0.05$) between

Llanstephan Beach and St. Ishmaels Beach West. Ferryside Beach correlated significantly ($p<0.05$) with Llanstephan Beach, St Ishmaels Beach West and Gwendraeth Estuary. There was also a significant correlation between Gwendraeth Estuary and Llanstephan Beach. These significant correlations suggest that these sites are influenced by similar sources.

Overall temporal pattern in results

There were not enough data to determine any overall temporal trends at the bathing waters sites.

Influence of tides

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of these bathing waters sampling points. Correlation coefficients are presented in Table X.2, with statistically significant correlations highlighted in yellow.

Table X.2: Circular linear correlation coefficients (r) and associated p values for faecal coliform results against the high low and spring/neap tidal cycles

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Llanstephan Beach	0.196	0.022	0.307	<0.001
Ferryside Beach	0.052	0.769	0.323	<0.001
St Ishmaels Beach West	0.182	0.295	0.610	<0.001
Gwendraeth Estuary	0.325	0.002	0.185	0.134

Data from Natural Resources Wales

Correlations were found for both tidal cycles at all four sites. Figure X.3 presents polar plots of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle. High water at Ferryside is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

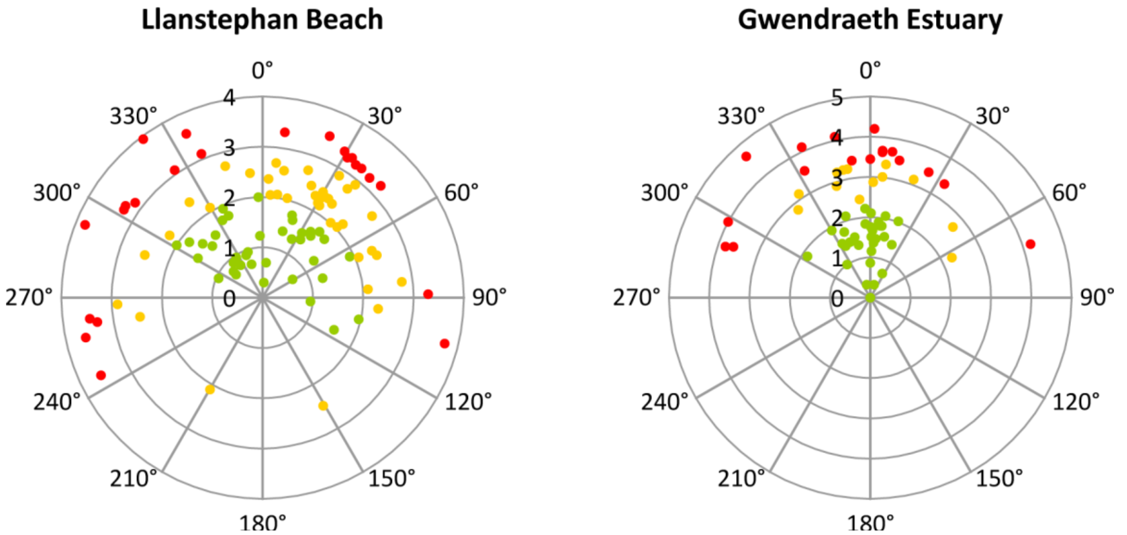


Figure X.3: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations
Data from Natural Resources Wales

Most samples were taken around high tide so only a part of the tidal cycle is represented, and there are no strong patterns apparent in either of the polar plots.

Figure X.4 presents polar plots of faecal coliform results against the lunar spring/neap 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 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

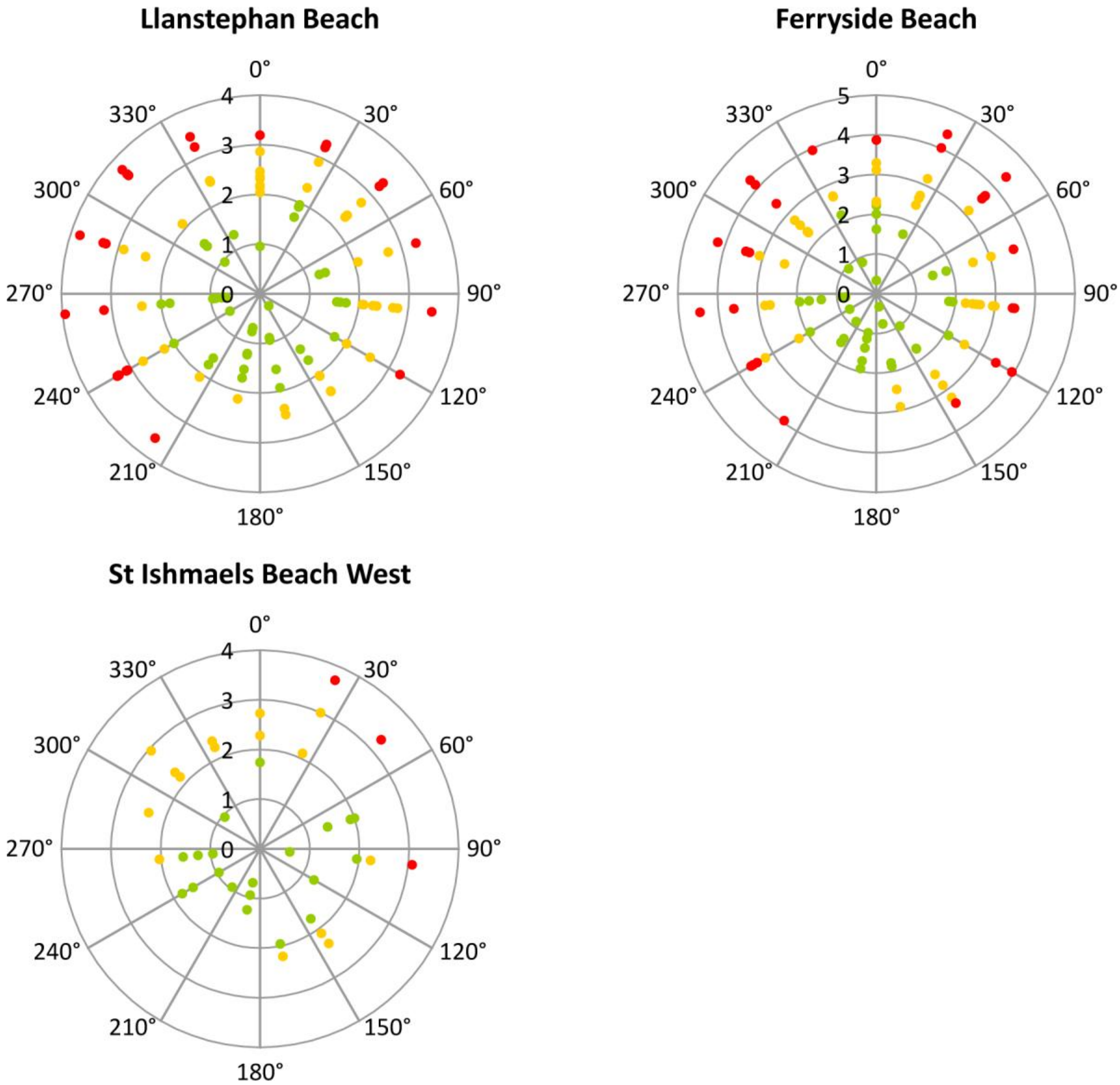


Figure X.4: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from Natural Resources Wales

At all three sites faecal coliform concentrations tended to be lower on neap tides and the few days before neap tides.

Influence of Rainfall

To investigate the effects of rainfall on levels of contamination at the bathing waters sites Spearman's rank correlations were carried out between rainfall recorded at the Johnstown weather station (Appendix VI for details) over various periods running up to sample collection and faecal coliform results. These are presented in Table X.3 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.3: Spearmans Rank correlation coefficients for faecal coliforms results against recent rainfall

		Taf Estuary	Llanstephan Beach	Ferryside Beach	St Ishmaels Beach West	Gwendraeth Estuary
	Site / n	11	102	102	40	62
24 hour periods prior to sampling	1 day	0.325	0.219	0.412	0.203	0.535
	2 days	0.670	0.257	0.434	0.466	0.536
	3 days	0.801	0.323	0.394	0.324	0.402
	4 days	0.447	0.383	0.449	0.311	0.558
	5 days	-0.092	0.393	0.421	0.213	0.376
	6 days	0.010	0.332	0.391	0.497	0.319
	7 days	0.768	0.311	0.284	0.051	0.332
Total prior to sampling over	2 days	0.542	0.223	0.430	0.256	0.605
	3 days	0.767	0.312	0.482	0.334	0.668
	4 days	0.764	0.370	0.524	0.395	0.725
	5 days	0.745	0.424	0.541	0.403	0.717
	6 days	0.764	0.452	0.551	0.423	0.684
	7 days	0.818	0.501	0.573	0.380	0.693

Data from Natural Resources Wales

Levels of *E. coli* were strongly influenced by antecedent rainfall at all sites. This is unsurprising due to the large amount of freshwater in the system from the rivers.

X.2. Shellfish Waters

There are four shellfish waters monitoring sites designated under Directive 2006/113/EC (European Communities, 2006) in the Three Rivers estuary. Figure X.1 shows the location of these sites. Table X.4 presents summary statistics for bacteriological monitoring results and Figure X.5 presents a boxplot of faecal coliform levels from the monitoring point.

Table X.4: Summary statistics for shellfish waters faecal coliform results, 2003 to 2013 (cfu/100ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Taf	42	23/01/2003	18/02/2013	8.7	<2	580	14.3	0.0
Tywi	42	23/01/2003	18/02/2013	35.6	<2	2880	35.7	7.1
Gwendraeth New Site	33	16/02/2005	18/02/2013	12.3	<2	1360	15.2	3.0
Gwendraeth	29	23/01/2003	18/02/2013	10.9	<2	1560	13.8	3.4

Data from Natural Resources Wales

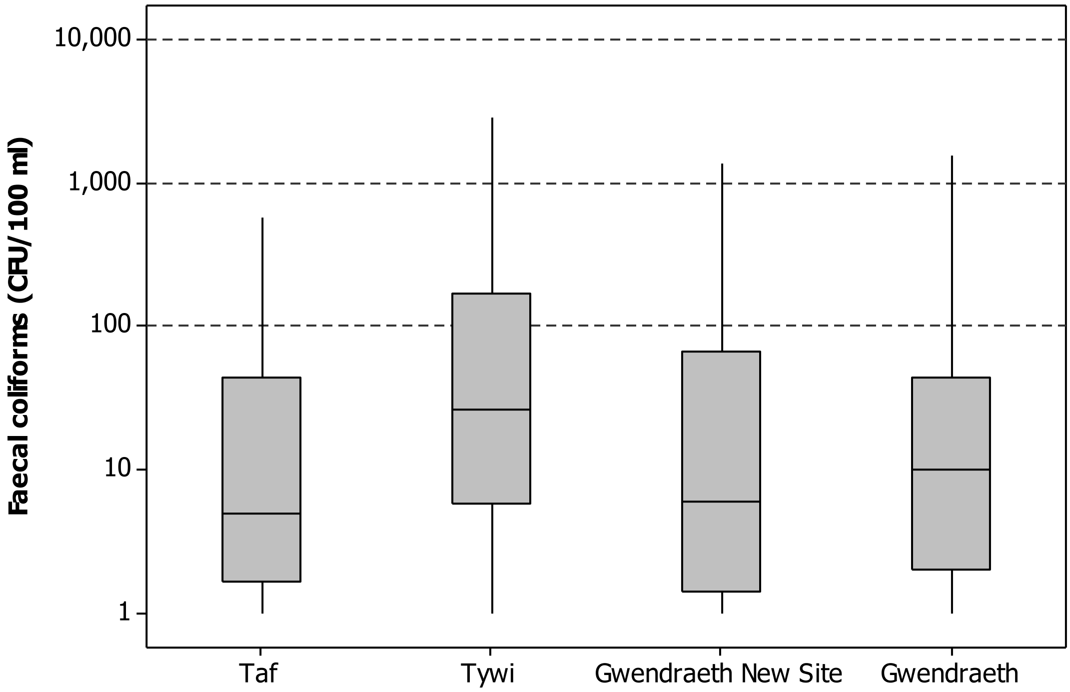


Figure X.5: Box-and-whisker plots of all faecal coliforms results
Data from Natural Resources Wales

All sites had samples with more than 100 faecal coliform cfu/100 ml, and Taf was the only site to not have any samples that exceeded 1,000 cfu/100 ml. One-way ANOVA tests showed that there were significant differences in faecal coliform levels between sites (p=0.009). Post ANOVA Tukey tests showed that Tywi had significantly higher *E. coli* levels than Taf.

Comparisons of sites were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared sampling dates, and therefore environmental conditions, on at least 20 occasions. Results from all site pairings significantly correlated suggesting that they are all subject to similar contamination sources.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at shellfish water sites over time is shown in Figure X.6.

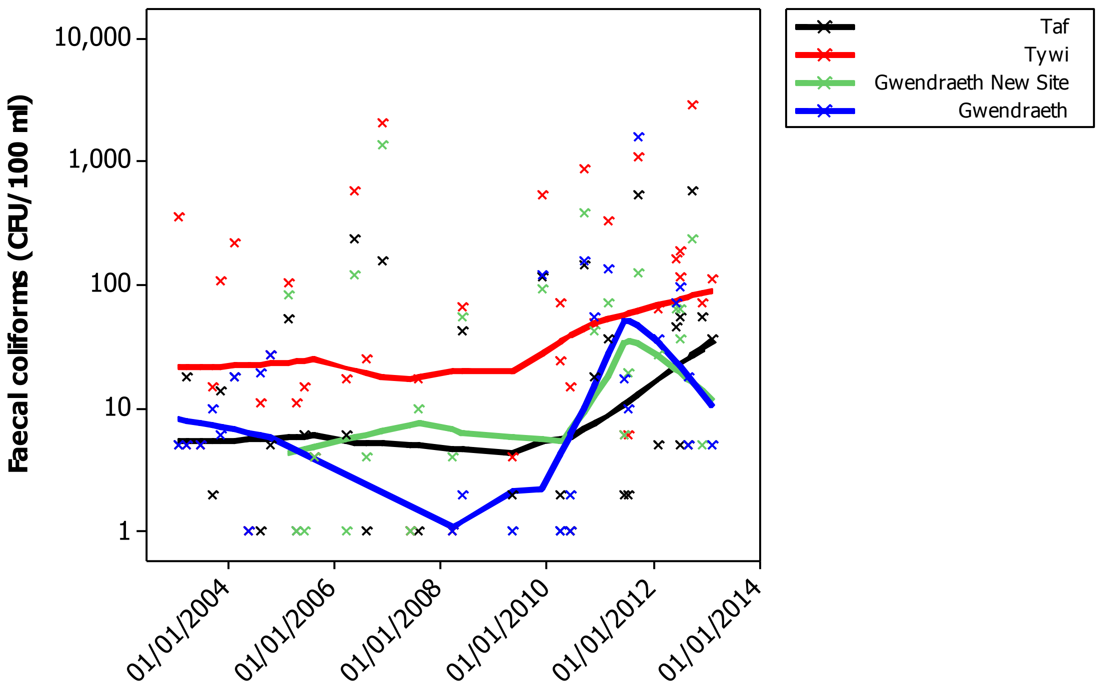


Figure X.6: Scatterplot of faecal coliform results by date, overlaid with loess lines
Data from Natural Resources Wales

In 2003 all four sites had similar levels of faecal coliforms. Faecal coliform levels have remained stable at all sites except Gwendraeth, which had an increase in faecal coliform levels between 2008 and 2012.

Seasonal patterns of results

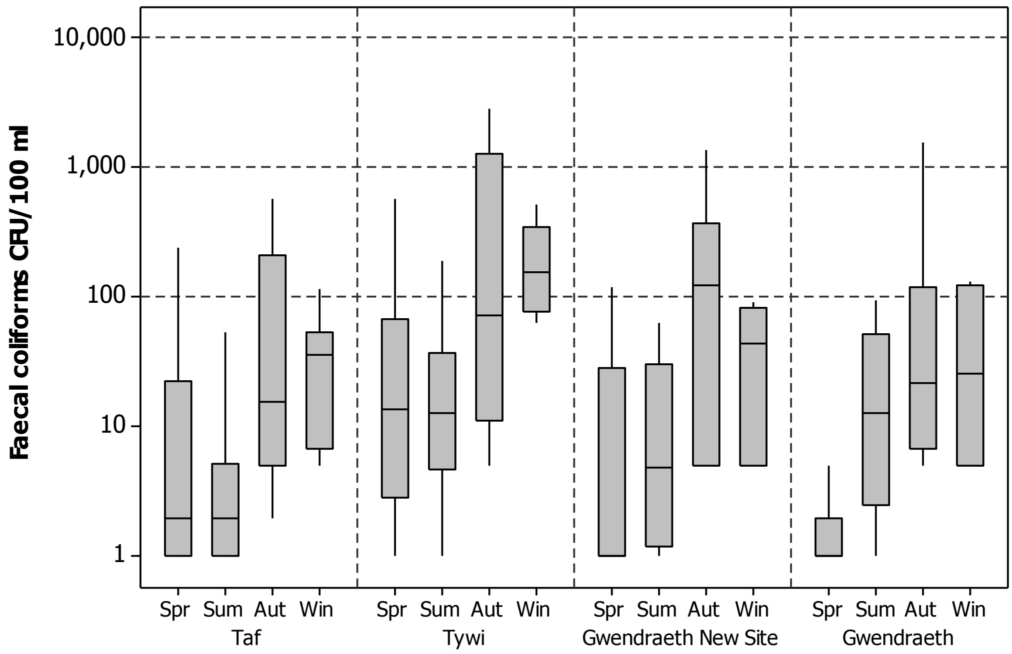


Figure X.7: Boxplot of faecal coliform results by site and season
Data from Natural Resources Wales

The seasonal pattern of results was broadly similar at all sites. One-way ANOVA tests of faecal coliform levels revealed that there were significant differences between seasons at all four sites (p = 0.004, 0.003, 0.009 and 0.002 at Taf, Tywi, Gwendraeth New Site and Gwendraeth respectively). Post ANOVA Tukey tests showed that at Taf, faecal coliform levels were higher in autumn and winter than in summer. At Tywi, faecal coliform levels were higher in autumn and winter than summer and higher in winter than in spring. At Gwendraeth New Site, faecal coliform levels were higher in autumn in spring and summer. At Gwendraeth, faecal coliform levels were higher in autumn and winter than spring.

Influence of tide

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of the shellfish waters sampling points that had been sampled on 30 or more occasions. Correlation coefficients are presented in Table X.5, with statistically significant correlations highlighted in yellow.

Table X.5: Circular linear correlation coefficients (r) and associated p values for faecal coliform results against the high low and spring/neap tidal cycles

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Taf	0.191	0.241	0.191	0.241
Tywi	0.285	0.042	0.088	0.740
Gwendraeth New Site	0.324	0.043	0.100	0.741

Data from Natural Resources Wales

Figure X.8 presents polar plots of log_{10} faecal coliform results against tidal states on the high/low cycle. High water at Ferryside is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

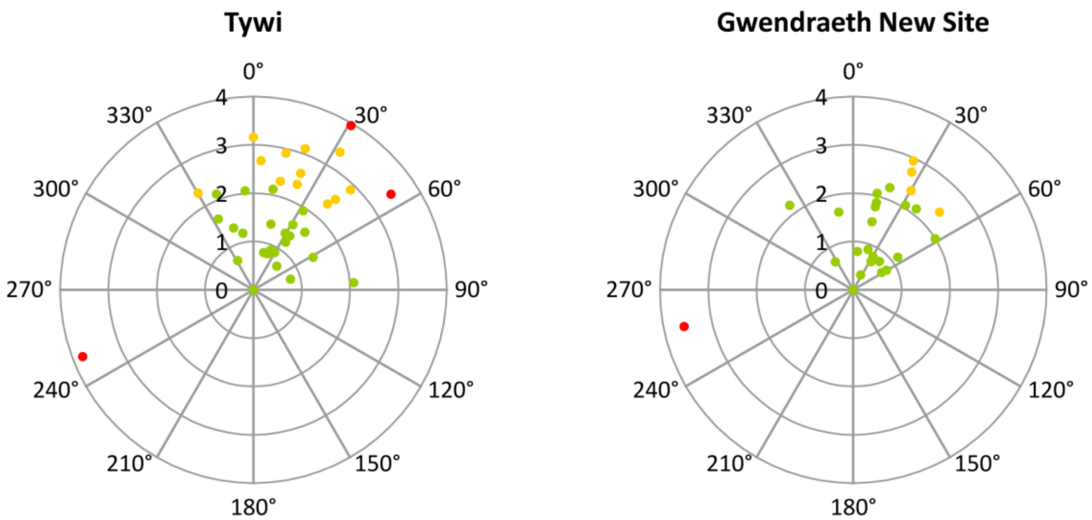


Figure X.8: Polar plots of log_{10} faecal coliforms against tidal state on the high/low tidal cycle for shellfish waters monitoring points with significant correlations
Data from Natural Resources Wales

At both sites, correlations were weak and all samples were taken around high tide. Nevertheless, it is apparent in the plots that higher *E. coli* levels tended to occur once the tide had started to ebb.

Influence of rainfall

To investigate the effects of rainfall on levels of contamination at the water quality monitoring sites Spearman's rank correlations were carried out between rainfall recorded at the Johnstown weather station (Appendix VI for details) over various periods running up to sample collection and faecal coliform results. These are presented in Table X.6 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.6: Spearmans Rank correlation coefficients for faecal coliform results against recent rainfall

	Site	Taf	Tywi	Gwendraeth New Site	Gwendraeth
	n	39	39	30	27
24 hour periods prior to sampling	1 day	0.384	0.311	0.455	-0.024
	2 days	0.445	0.507	0.407	0.403
	3 days	0.347	0.581	0.539	0.231
	4 days	0.470	0.514	0.663	0.360
	5 days	0.429	0.455	0.524	0.268
	6 days	0.274	0.314	0.286	0.350
	7 days	0.367	0.385	0.353	0.298
Total prior to sampling over	2 days	0.487	0.434	0.507	0.202
	3 days	0.436	0.523	0.489	0.101
	4 days	0.502	0.603	0.579	0.264
	5 days	0.516	0.654	0.655	0.294
	6 days	0.556	0.668	0.680	0.365
	7 days	0.595	0.709	0.699	0.440

Data from Natural Resources Wales

The influence of rainfall was weakest at Gwendraeth. At the other three sites, the effect of rainfall was stronger and more consistent.

Influence of salinity

Salinity was recorded on most sampling occasions at Taf Tywi and Gwendraeth New Site, but not Gwendraeth.. Figure X.9 shows scatter-plots between faecal coliforms and salinity. Pearson's correlations were run to determine the effect of salinity on faecal coliforms at shellfish waters sites.

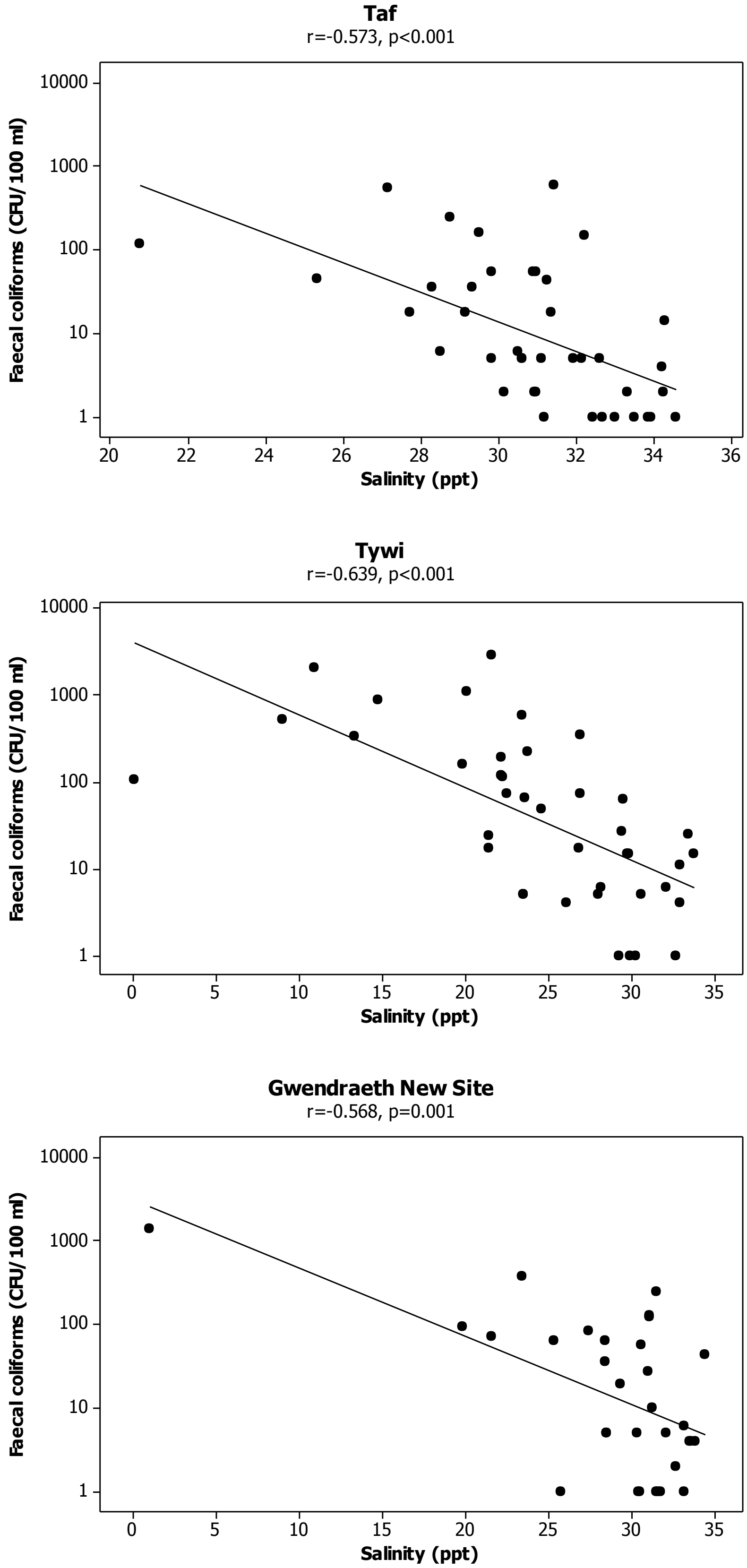


Figure X.9: Scatter-plots of salinity against faecal coliforms.
Data from Natural Resources Wales

There were strong negative correlations between faecal coliform levels and salinity at all three monitoring points tested.

Appendix XI. Microbiological Data: Shellfish Flesh

XI.1. Summary statistics and geographical variation

There are a total of seven RMPs in the Three Rivers production area that have been sampled between 2003 and 2013. Five of these RMPs are for cockles, and two are for mussels. The geometric mean results of shellfish flesh monitoring from all RMPs sampled from 2003 onwards are presented in Figure XI.1. Summary statistics are presented in Table XI.1 and boxplots for sites are show in Figure XI.2 to Figure XI.3. The Tywyn Point cockle RMP and Gwendraeth mussel RMP have been sampled on less than 10 occasions and so will not be considered in the more detailed analyses. It is understood that the Gwendraeth RMP was moved at some time late in 2012 from the location shown to somewhere north of the channel in the vicinity of St Ishmaels point and the Caravan Park. The date of this change and the location of the new RMP could not be confirmed at the time of writing.

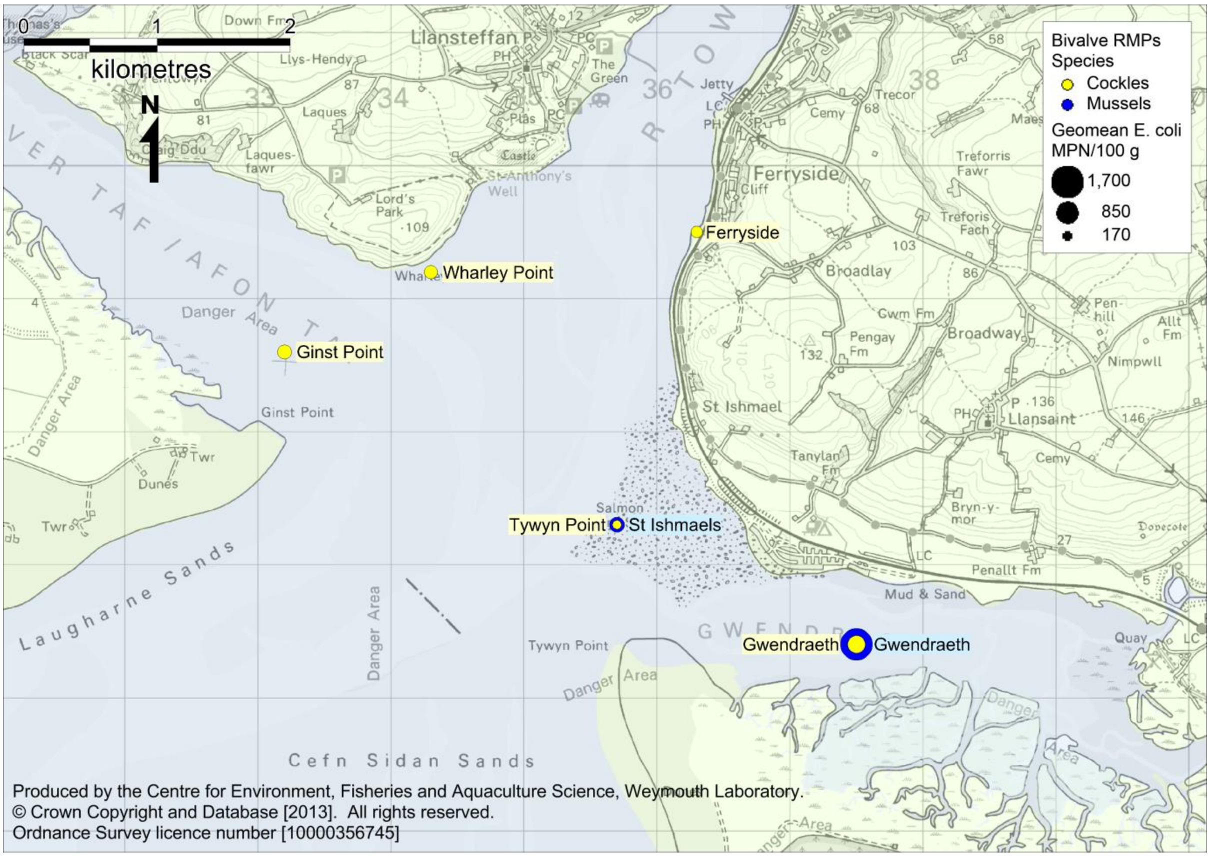


Figure XI.1: Bivalve RMPs active since 2003

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) from RMPs sampled from 2003 onwards

Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600	% over 46,000
Ferryside	Cockle	68	06/01/2003	11/12/2012	290.5	<20	9100	61.8	2.9	0.0
Wharley Point		106	06/01/2003	16/10/2013	386.8	20	>18000	58.5	10.4	0.0
Ginst Point		77	06/01/2003	20/08/2012	431.1	<20	16000	64.9	6.5	0.0
Tywyn Point		6	28/07/2005	09/02/2009	172.2	40	750	50.0	0.0	0.0
Gwendraeth		57	28/07/2005	20/08/2013	619.2	20	54000	73.7	19.3	1.8
St Ishmaels	Mussel	117	06/01/2003	15/10/2013	468.3	<20	16000	69.2	8.5	0.0
Gwendraeth		2	07/11/2005	10/04/2006	1679.6	310	9100	100.0	50.0	0.0

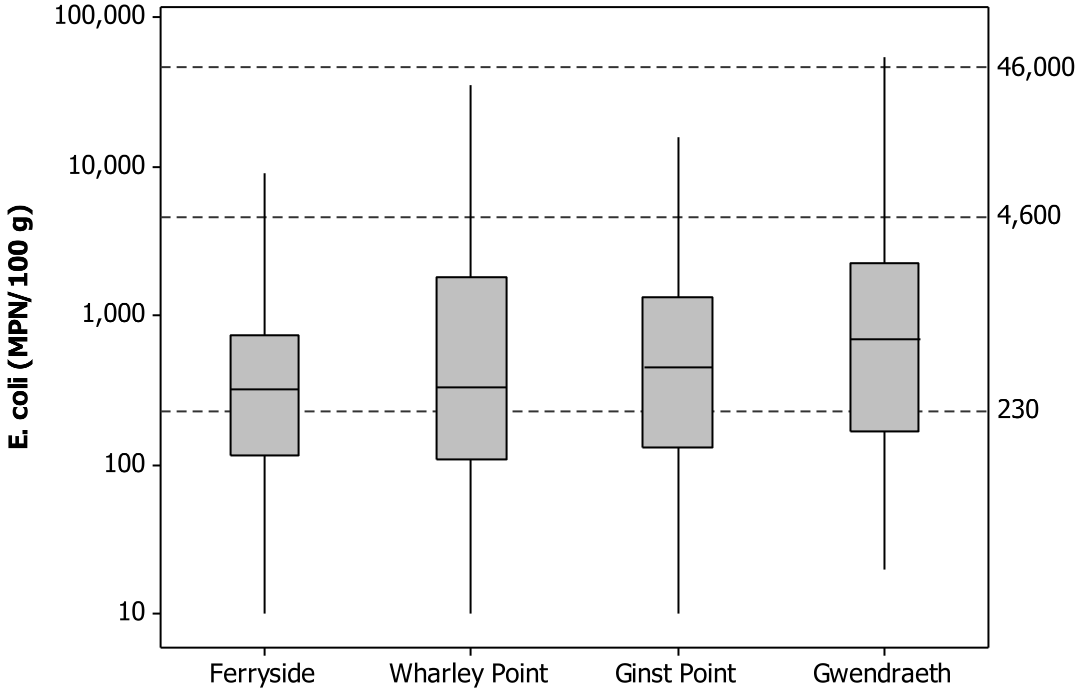


Figure XI.2: Boxplots of *E. coli* results from cockle RMPs from 2003 onwards.

E. coli levels in cockles exceeded 4,600 MPN/100 g at all RMPs sampled on 10 or more occasions, but only exceeded 4,600 MPN/100 g in more than 10% of samples at Wharley Point and Gwendraeth. Only Gwendraeth had a sample that exceeded 46,000 MPN/100 g. Comparisons of the sites (1-way ANOVA) showed that there were no significant differences in the average *E. coli* levels (p = 0.119).

Comparisons of RMPs were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared sampling dates, and therefore environmental conditions, on at least 20 occasions. There were significant correlations ($p < 0.05$) between all cockle RMP pairings, suggesting that they share similar contamination sources.

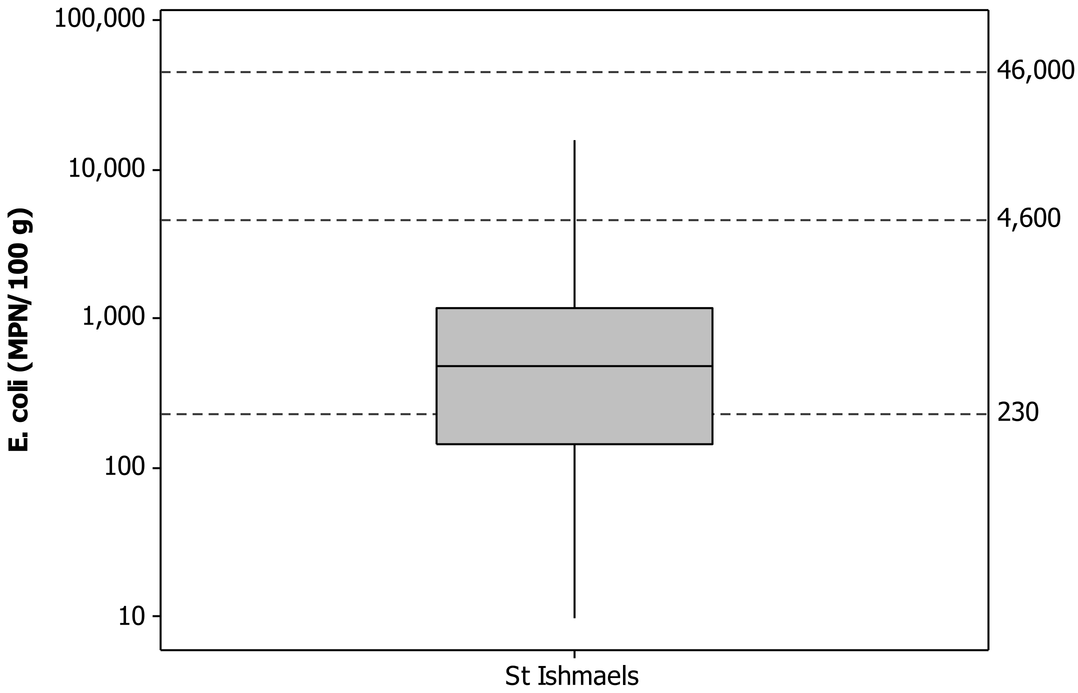


Figure XI.3: Boxplots of *E. coli* results from mussel RMPs from 2003 onwards.

E. coli levels in mussels exceeded 4,600 MPN/100 g in at St Ishmaels, but in less than 10% of samples.

XI.2. Overall temporal pattern in results

The overall variation in *E. coli* levels found in bivalves is shown in Figure XI.4 and Figure XI.5.

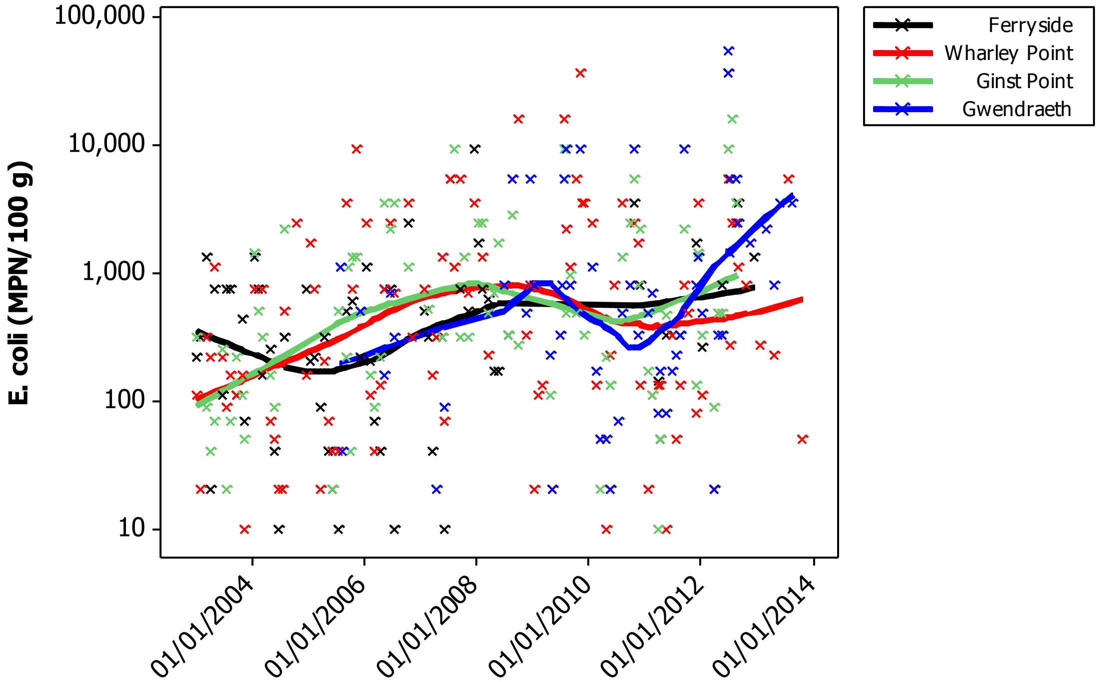


Figure XI.4: Scatterplot of E. coli results for cockles overlaid with loess line.

Since 2003, *E. coli* levels appear to have generally increased at all cockle sites. At Wharley Point and Ginst Point, levels rose until 2008 and have remained fairly stable since. *E. coli* levels at Gwendraeth appear to have increased sharply from 2011 to present.

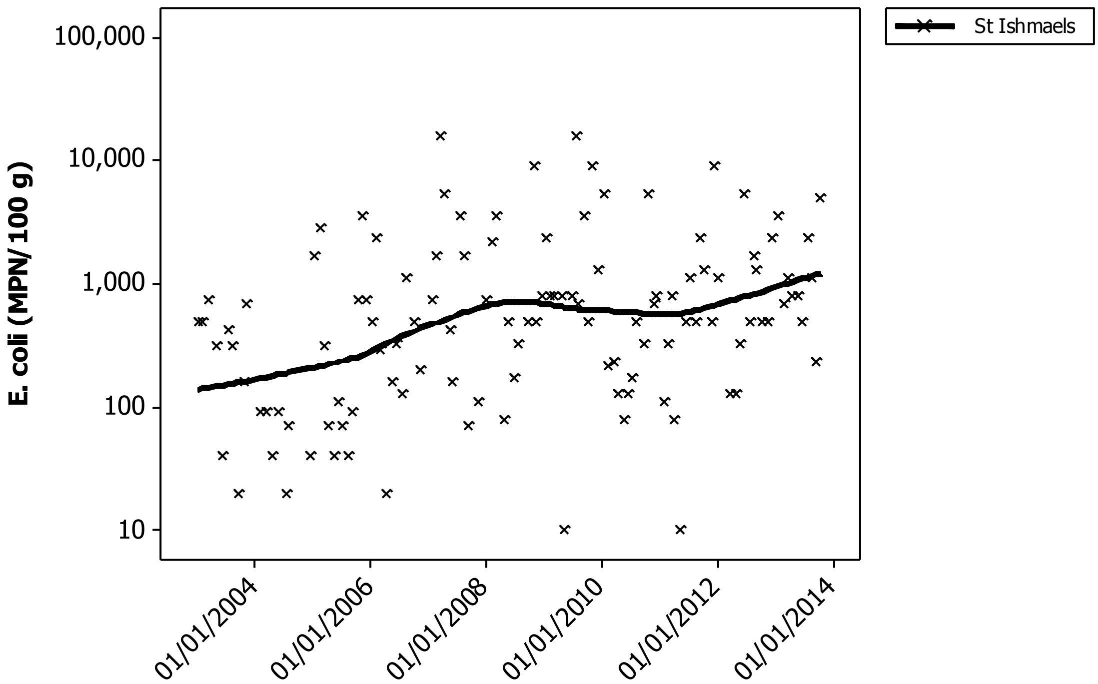


Figure XI.5: Scatterplot of E. coli results for mussels overlaid with loess line.

At the St Ishmaels mussel RMP, *E. coli* levels have risen by around one order of magnitude since 2003.

XI.3. Seasonal patterns of results

Figure XI.6 and Figure XI.7 show the variation in *E. coli* levels between seasons at the different bivalve RMPs.

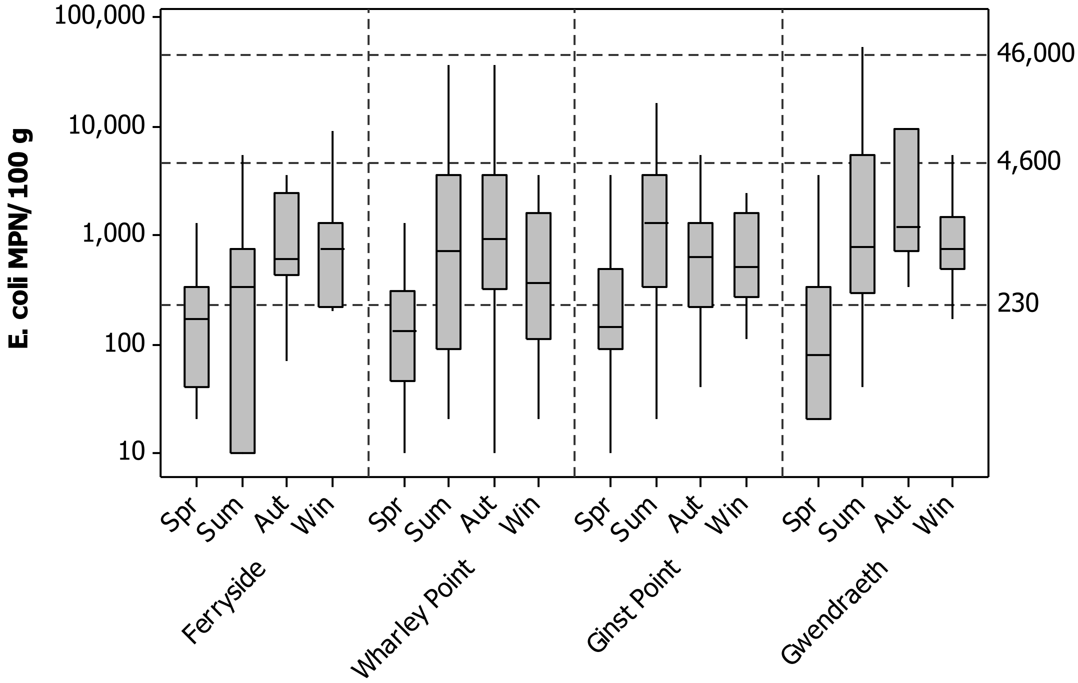


Figure XI.6: Boxplot of *E. coli* results for cockles by RMP and season

One-way ANOVA tests showed that there were significant seasonal variations at all four cockle RMPs tested (p<0.001 to 0.003). Post ANOVA tests showed that at Ferryside, there were significantly higher levels of *E. coli* during the autumn and winter than spring and significantly higher levels of *E. coli* during winter than summer. There were significantly lower levels of *E. coli* during the spring than summer and autumn at Wharley Point. At Ginst Point there were significantly higher levels of *E. coli* during the summer than spring. At Gwendraeth there were significantly lower levels of *E. coli* during the spring than all other seasons.

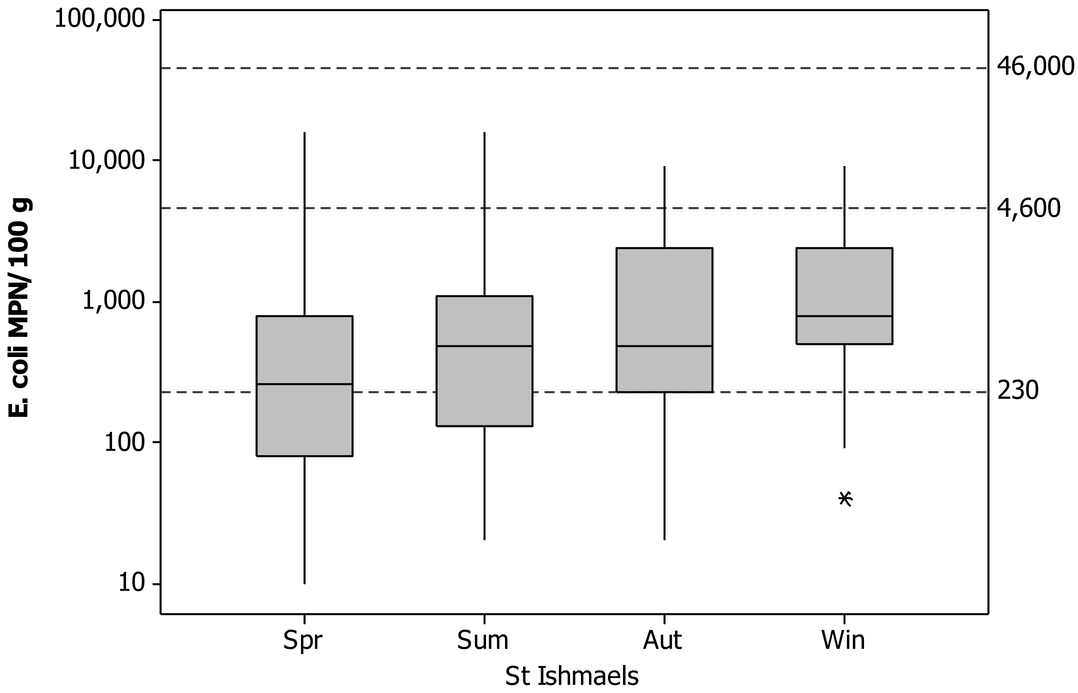


Figure XI.7: Boxplot of *E. coli* results for mussels by RMP and season

One-way ANOVA tests showed that there were significant seasonal variations at the St Ishmaels mussel RMP (p=0.007). Post ANOVA tests showed that at there were significantly higher levels of *E. coli* during the winter than spring.

XI.4. Influence of tide

To investigate the effects of tidal state on *E. coli* results, circular-linear correlations were carried out against the high/low and spring/neap tidal cycles for each RMP where more than 30 samples had been taken. Results of these correlations are summarised in Table XI.2, and significant results are highlighted in yellow.

Table XI.2: Circular linear correlation coefficients (r) and associated p values for *E. coli* results against the high/low and spring/neap tidal cycles

		High/low tides		Spring/neap tides	
Site Name	**Species**	**r**	**p**	**r**	**p**
Ferryside	Cockle	0.252	0.016	0.291	0.004
Wharley Point	Cockle	0.262	0.001	0.200	0.016
Ginst Point	Cockle	0.226	0.023	0.324	<0.001
Gwendraeth	Cockle	0.120	0.461	0.247	0.037
St Ishmaels	Mussel	0.131	0.141	0.262	<0.001

Figure XI.8 presents polar plots of $\log_{10}$ *E. coli* results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Ferryside is at 0° and low water is at 180°. Results of 230 *E. coli* MPN/100g or less are plotted in green, those from 231 to 4600 are plotted in yellow, and those exceeding 4600 are plotted in red.

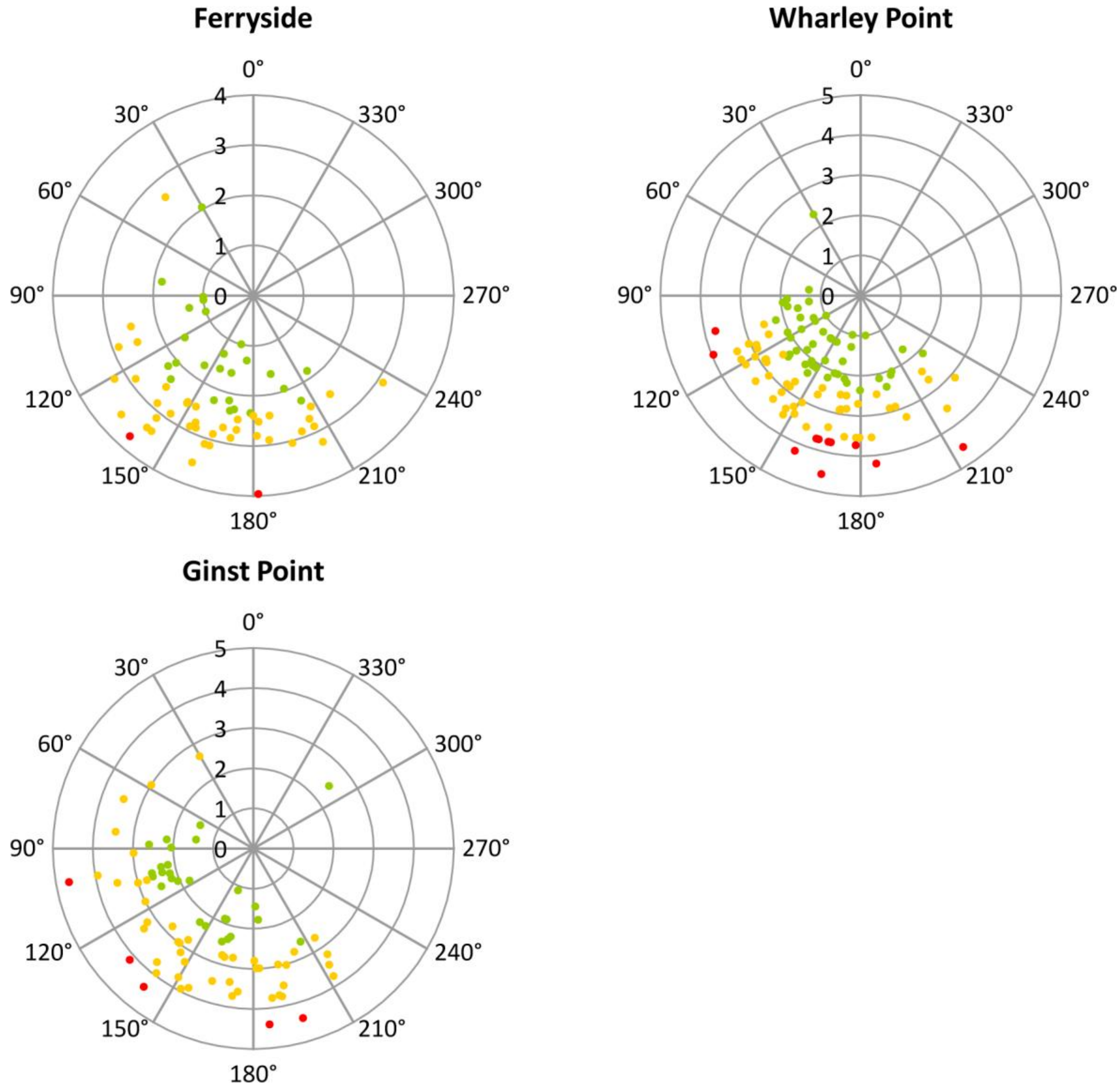


Figure XI.8: Polar plot of $\log_{10}$ E. coli results (MPN/100g) at cockle RMPs against high/low tidal state

Most of the samples were taken around the low tide. The graphs in Figure XI.8 do not appear to show and patterns despite the significant correlations found.

Figure XI.9 presents polar plots of $\log_{10}$ *E. coli* results against the spring neap tidal cycle for each RMP. Full/new moons occur at 0º, and half moons occur at 180º, and 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 230 *E. coli* MPN/100g or less are plotted in green, those from 231 to 4600 are plotted in yellow, and those exceeding 4600 are plotted in red.

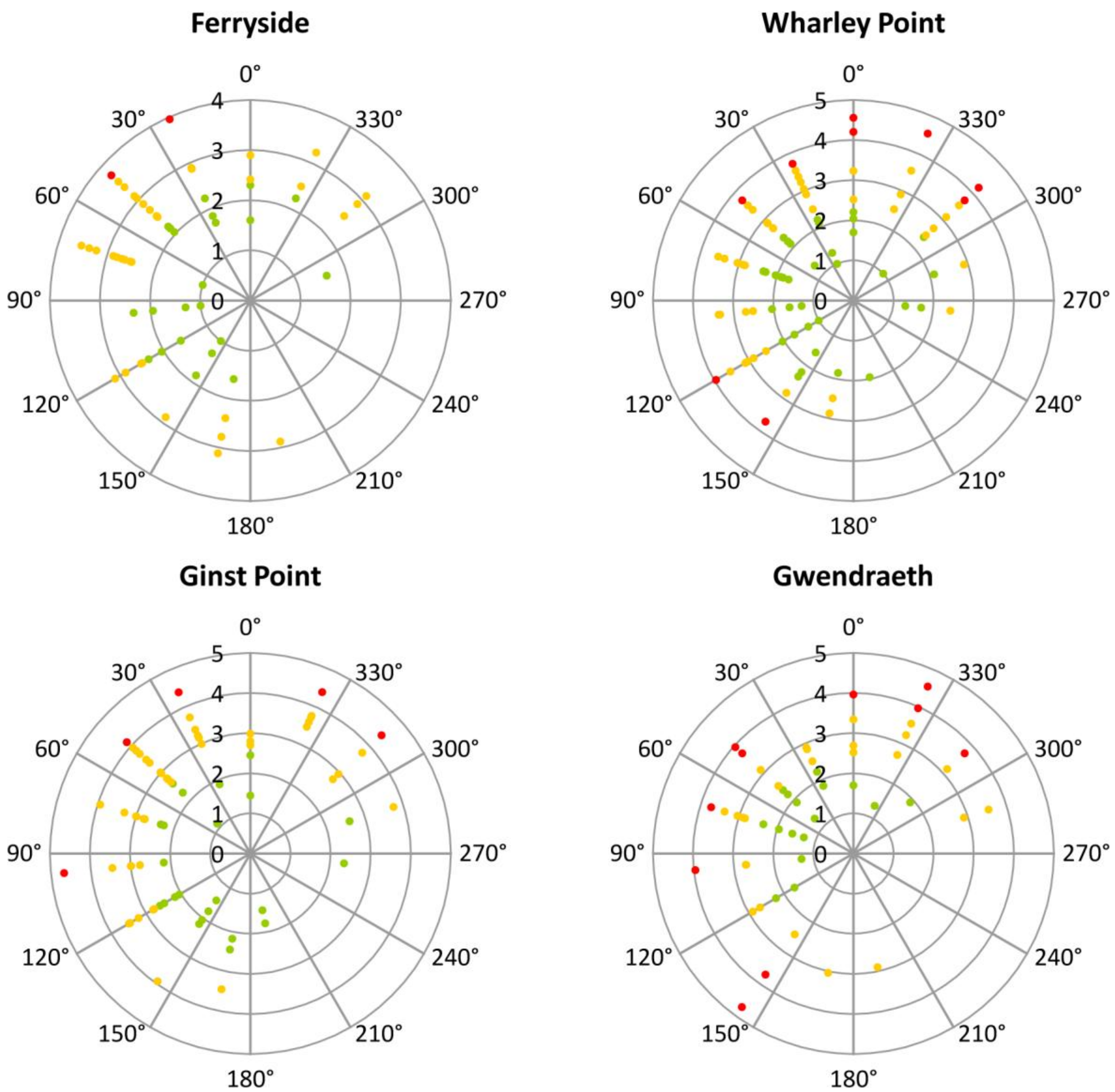


Figure XI.9: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) at cockle RMPs against spring/neap tidal state

The majority of samples were taken as tide sizes increased from neap tides to spring tides. At all sites there appeared to be a tendency for higher results towards spring tides.

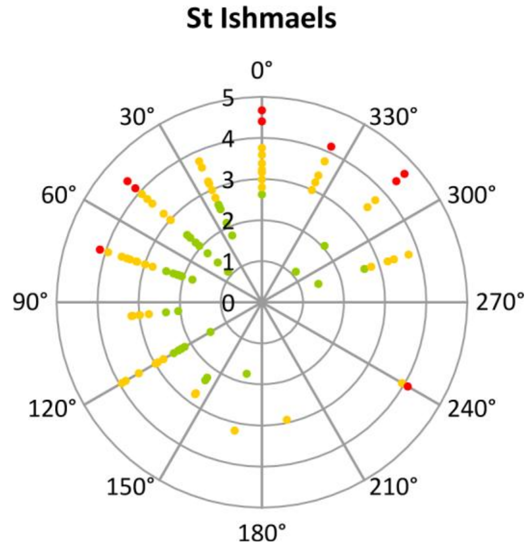


Figure XI.10: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) at mussel RMPs against spring/neap tidal state

As with cockle RMPs, higher results in mussels tended to occur more around spring tides.

XI.5. Influence of rainfall

To investigate the effects of rainfall on levels of contamination within shellfish samples Spearman's rank correlations were carried out between *E. coli* results and rainfall recorded at the Johnstown weather station (Appendix II for details) over various periods running up to sample collection. These are presented in Table XI.3, and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table XI.3: Spearman's Rank correlations between rainfall recorded at Johnstown and shellfish hygiene results

	Species	Cockle				Mussel
	Site	Ferryside	Wharley Point	Ginst Point	Gwendraeth	St Ishmaels
	n	68	102	77	53	107
24 hour periods prior to sampling	1 day	0.227	0.288	0.252	0.521	0.511
	2 days	0.396	0.335	0.230	0.394	0.491
	3 days	0.378	0.323	0.123	0.486	0.474
	4 days	0.414	0.334	0.326	0.421	0.353
	5 days	0.261	0.319	0.170	0.166	0.227
	6 days	0.220	0.242	0.131	0.290	0.132
	7 days	0.141	0.326	0.217	0.425	0.205
Total prior to sampling over	2 days	0.371	0.384	0.261	0.523	0.593
	3 days	0.408	0.413	0.269	0.587	0.618
	4 days	0.505	0.463	0.338	0.699	0.666
	5 days	0.508	0.507	0.380	0.674	0.656
	6 days	0.520	0.504	0.375	0.689	0.656
	7 days	0.521	0.530	0.397	0.701	0.609

Levels of *E. coli* were strongly influenced by rainfall at all sites. This is unsurprising due to the large amount of freshwater in the system from the rivers.

Appendix XII. Shoreline Survey Report

Date (time):
17th December 2013 (10:00-15:30)
18th December 2013 (10:00-14:30)

Cefas Officers:
David Walker
Louise Rae

Survey Partners:
Mark Liley (Carmarthenshire CC)
Lon John (Carmarthenshire CC, 17/12/2013 only)
Victoria King (Carmarthenshire CC, 18/12/2013 only)

Area surveyed:
Afon Taf estuary from Laugharne to Pendine danger area and Wharley Point to Craig Ddu. Afon Tywi estuary from Morfa Bach to Wharley Point and Carmarthen Bay Holiday Centre to Ferryside. Gwendraeth estuary along Pembrey Marsh and from Gwendraeth Fawr to Gwendraeth Fach.

Weather:
17th December 12:00, dry, partially cloudy, 8 °C, wind bearing 140° at 15 km/h
18th December 12:00, overcast & rain, 11 °C, wind bearing 180° at 57 km/h

Tides:
Admiralty TotalTide© predictions for Ferryside (51°46'N 4°22'W). All times in this report are GMT.

17/12/2013			18/12/2013		
High	05:53	6.3 m	High	06:28	6.4 m
High	18:12	6.2 m	High	18:47	6.2 m
Low	01:51	0.4 m	Low	02:39	0.4 m
Low	14:24	0.4 m	Low	15:11	0.4 m

Objectives:

The shoreline survey aims to obtain samples of freshwater inputs to the area for bacteriological testing; confirm the location of previously identified sources of potential contamination; locate other potential sources of contamination that were previously unknown and find out more information about the fishery. A full list of recorded observations is presented in Table XII.1 and the locations of these observations are shown in Figure XII.1.

While every effort was made to survey the entire area, the active firing at the Pendine range on the western side of the estuary meant that it was not possible to gain access all of the way to Ginst point. Additionally, it was not possible to survey between Kidwelly and Carmarthen Bay Holiday Centre on the north shore of Gwendraeth as it was not possible to pass under the railway bridge near Kidwelly Quay.

XII.1. Sampling issues

No samples have been taken from the Ginst Point cockle RMP since August 2012. This is due to difficulty gaining access to the sampling location, as it requires the samplers to travel through the Pendine danger area. The Pendine range is closed to the public during the week and so this makes access problematic. A similar problem exists for the Pembrey range. The main cockle beds in the Gwendraeth estuary are to the south of the main Gwendraeth channel. However the samples taken for classification are collected north of the channel next to the Carmarthen Bay Holiday Centre. The samples are collected north of the channel because the cockle beds are usually inaccessible due to the Pembrey range. The mussel bed at St Ishmael is used intermittently and is not heavily harvested but can be accessed for sampling.

XII.2. Sources of contamination

Sewage discharges

The location of the discharge for the Kidwelly WwTW was confirmed (observation 17), as was the location of the WwTW itself. It was not possible to sample this discharge as it was in the muddy intertidal area behind an embankment. No pipe was visible (possibly submerged), but it was evidently flowing as the water surrounding the discharge was bubbling. The location of the pumping station for the Laugharne sewage overflow was confirmed (observation 64), but no outfall pipe was visible. The location of the pumping station for the Laugharne WwTW was confirmed (observation 66). There was a sewage smell and no pipes were visible even at low tide.

Freshwater inputs

Six of the rivers flowing into the Three Rivers estuary were observed and measured (observations 20, 21, 22, 59, 70 and 71). It was only possible to measure flow and therefore daily *E. coli* loading for two of these rivers (Gwendraeth Fach at observation 20 and Afon Pibwr at observation 22). These rivers had *E. coli* concentrations of 600 and 350 *E. coli* cfu/100 ml and loadings of 3.63×10^{12} and 4.23×10^{11} *E. coli* cfu/day. However, all of the other rivers had *E. coli* concentrations exceeding 1,500 cfu/100 ml. In particular Afon Cynin/Afon Dewi Fawr (observation 70) and Afon Cywyn (observation 71) had high *E. coli* concentrations of 12,000 and 4,700 cfu/100 ml respectively. Both of these samples were taken at the end of 18/12/2013 after heavy rainfall throughout the day, so it is quite likely that the *E. coli* concentrations were elevated as a consequence of this. Additionally in the case of Afon Cynin/Afon Dewi Fawr it is possible that the high *E. coli* concentration was increased by intermittent overflow discharges, of which there are two within 2.5 km (fluvial distance) from the observation point.

In addition to rivers, six smaller streams were observed (observations 25, 32, 39, 51, 57 and 63). Two of these streams (observations 32 and 39) were found to have *E. coli* concentrations of 14,000 and 15,000 cfu/100 ml and loadings of 2.99×10^{12} and 2.59×10^{13} cfu/day. Again, these samples returning higher *E. coli* concentrations were taken at the end of 18/12/2013 following heavy rain.

Livestock

Sheep were observed in fields at observations 26 (30 sheep), 60 (100 sheep) and 68 (100 sheep). At observation 60 the sheep were in an unfenced field with access to the water's edge. A dead sheep was observed at observation 24. It is likely that this sheep had been washed downstream.

Cows were observed at observation 5 (10 cows), 11 (100 cows) and 13 (6 cows). At observation 5 and 11 the cows were on a marsh and had access to the water's edge.

Additionally six horses were observed at observation 14 with access to the water's edge. A horse and rider were observed at observation 58 and horse manure was observed at observation 68.

Wildlife

Flocks of seabirds were seen at observations 34, 25, 37, 50, 56 and 68. Additionally around 300 small passerine birds were seen at observation 9 and around 20 geese at observation 1.

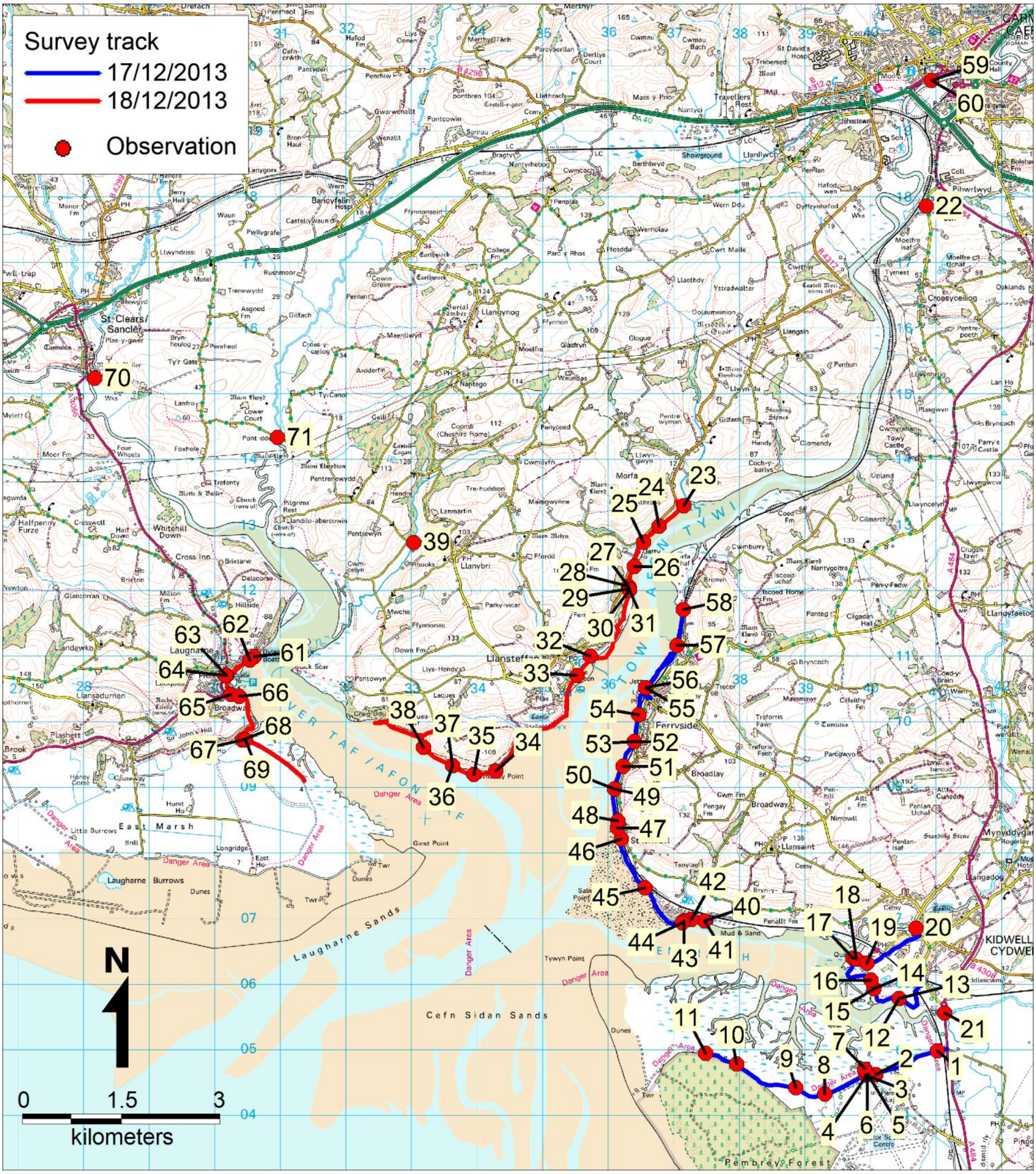


Figure XII.1: Locations of Shoreline Observations (Table XII.1 for details)

Table XII.1: Details of Shoreline Observations

Observation no.	NGR	Date	Time	Description	Photo
1	SN4101304985	17/12/2013	10:47	Around 20 birds (possibly geese) on marsh.	
2	SN4007604620	17/12/2013	11:03	Drainage stream with sluice (3m x 0.75m x 0.244m/s). Sample P01.	Figure XII.4
3	SN3991804615	17/12/2013	11:07	Open half-pipe 50 cm diameter - possibly ground drainage, but not flowing (top blocked).	Figure XII.5
4	SN3994704624	17/12/2013	11:10	Iron pipe going to ground.	Figure XII.6
5	SN3994704624	17/12/2013	11:10	10 cattle in field (landward side of path).	
6	SN3994704624	17/12/2013	11:10	Cow faeces on marsh.	
7	SN3990604699	17/12/2013	11:21	Flapped pipe (end of pipe at observation 4) (1m diameter x 0.2m flow depth x 1.6m/s). Sample P02.	Figure XII.7
8	SN3929704321	17/12/2013	11:36	Small iron inspection cover and blue plastic hose. Not flowing.	Figure XII.8
9	SN3885704417	17/12/2013	11:45	Around 300 small passerine birds.	
10	SN3795504780	17/12/2013	12:02	Three cows on marsh.	Figure XII.9
11	SN3748204944	17/12/2013	12:21	Around 100 cattle scattered across marsh within the aerial range.	
12	SN4043205778	17/12/2013	13:28	30 cm diameter pipe with valve flowing into river (0.5m x 0.05m x 0.5m/s). Sample P03.	Figure XII.10
13	SN4043205778	17/12/2013	13:30	Six cows in field on landward side of seawall.	
14	SN4004405928	17/12/2013	13:37	Six horses on marsh.	
15	SN4004405928	17/12/2013	13:37	Cockle dead-shell on strand line.	
16	SN3999706061	17/12/2013	13:45	Drainage ditch (3.5m x 0.35m x 0.111m/s). Sample P04.	Figure XII.11
17	SN3972506395	17/12/2013	13:58	Discharge in mud (not accessible). No visible pipe, but bubbling water indicates flow. Kidwelly WwTW continuous.	Figure XII.12
18	SN3977606380	17/12/2013	14:00	Outfall for drainage ditch (observation 104).	Figure XII.13
19	SN3994306321	17/12/2013	14:04	Sewage treatment works.	Figure XII.14
20	SN4068606855	17/12/2013	14:25	River - Gwendraeth Fach (14m x 1m x 0.5m/s). Sample P05. Sample P05.	Figure XII.15
21	SN4112305557	17/12/2013	15:00	River - Gwendraeth Fawr (15m wide). Not accessible for depth or flow. Sample P06.	
22	SN4084617865	17/12/2013	15:23	River - Afon Pibwr (7m x 0.5m x 0.4 m/s). Sample P07. Sample P07.	Figure XII.16
23	SN3714813293	18/12/2013	09:59	Entrance to creek. Fenced off so no access. Drainage for tidal pond.	Figure XII.17 & Figure XII.18

Observation no.	NGR	Date	Time	Description	Photo
24	SN3677212982	18/12/2013	10:11	Dead sheep.	Figure XII.19
25	SN3653512738	18/12/2013	10:22	Stream with package treatment plant around 80 m upstream (1.3m x 0.1m x 0.667m/s). Sample LL01.	Figure XII.20
26	SN3638912367	18/12/2013	10:37	30 sheep in field behind treeline.	
27	SN3630312068	18/12/2013	10:38	Quad track in sand.	Figure XII.21
28	SN3630312068	18/12/2013	10:38	Cockle and Tapes clams dead-shell.	
29	SN3631412028	18/12/2013	10:45	Rabbit and dog faeces.	
30	SN3632112005	18/12/2013	10:51	30cm diameter pipe surrounded by a concrete block wall. Mostly buried and fully submerged. Flowing, but stream to shallow to measure (<1cm depth). Sample taken from pool in front of pipe. Sample LL02.	Figure XII.22
31	SN3632112005	18/12/2013	10:59	Valved 60cm diameter iron pipe. Not flowing. Sample taken from pool in front of pipe. Sample LL03.	Figure XII.23
32	SN3571510999	18/12/2013	11:12	Stream with Llanstephan STW continuous 150 m upstream (1.5m x 0.33m x 0.5m/s). Sample LL04.	Figure XII.24
33	SN3551710704	18/12/2013	11:18	Concrete pipe in beach. Approximately 1.5m diameter. End not visible.	Figure XII.25
34	SN3427609245	18/12/2013	11:45	Around 100 oyster catchers.	
35	SN3394209194	18/12/2013	11:45	Around 500 oyster catchers on sand bank on other side of main channel.	
36	SN3362009328	18/12/2013	11:54	Mussel (~3cm average length). On rock all around headland.	Figure XII.26
37	SN3362009328	18/12/2013	12:15	Around 100 oyster catchers on sand bank.	
38	SN3317809610	18/12/2013	12:30	Clam deadshell.	
39	SN3302812734	18/12/2013	14:22	Stream (2 m x 0.5 m x 2 m/s). Sample LL05.	Figure XII.27
40	SN3746306967	17/12/2013	10:13	50cm valved pipe in concrete (not flowing). Possibly related to caravan park swimming pool and leisure centre just behind.	Figure XII.28
41	SN3746306967	17/12/2013	10:14	Buried concrete pipe seaward of observation 40. Sample was taken from pooled water near the end of pipe. Sample CB01.	Figure XII.29
42	SN3726706989	17/12/2013	10:26	Small land drainage pipes approx 5cm diameter in retaining wall (not flowing).	Figure XII.30
43	SN3714706966	17/12/2013	10:29	Small dingy moored on foreshore.	
44	SN3712706935	17/12/2013	10:33	20cm diameter concrete pipe buried under the sand.	Figure XII.31
45	SN3655407471	17/12/2013	10:56	Dead shellfish shells dominating the strandline (razor clams, mussels, cockles, whelks and clams).	Figure XII.32

Observation no.	NGR	Date	Time	Description	Photo
46	SN3618908215	17/12/2013	11:27	Concrete pipe in sea wall (not flowing).	Figure XII.33
47	SN3613208383	17/12/2013	11:35	Pipes in sea wall, all along its length.	Figure XII.34
48	SN3614308485	17/12/2013	11:39	40cm diameter iron pipe in sea wall. Sample taken from pool. Sample CB02.	Figure XII.35
49	SN3608608976	17/12/2013	11:55	10cm diameter grey pipe running down hill above railway. No discharge observed.	Figure XII.36
50	SN3608608976	17/12/2013	11:55	170 seabirds observed on mudflats exposed by tide, generally gathering in small flocks.	
51	SN3622209324	17/12/2013	12:02	Culvert stream through 120cm diameter concrete pipe. Sample CB03.	Figure XII.37
52	SN3639209703	17/12/2013	12:17	120cm diameter concrete pipe. Sample CB04.	Figure XII.38
53	SN3639209703	17/12/2013	12:17	3 dogs being walked on beach.	
54	SN3645510106	17/12/2013	12:30	120cm diameter concrete pipe with rubber valve (not flowing).	Figure XII.39
55	SN3656510524	17/12/2013	13:17	2 large fishing boats moored on sandbank/riverbank.	Figure XII.40
56	SN3656510524	17/12/2013	13:17	200 seabirds on sandbank in middle of river.	
57	SN3704011165	17/12/2013	13:32	Culverted stream with flap. Sample CB05.	Figure XII.41
58	SN3713911713	17/12/2013	13:55	Horse rider observed on beach and horse droppings.	
59	SN4092219780	17/12/2013	15:29	River - Afon Tywi (25m wide). Sample CB06.	Figure XII.42
60	SN4092219780	17/12/2013	15:29	100 sheep grazing in field on opposite bank, unfenced access to water.	
61	SN3059610994	18/12/2013	09:50	10cm diameter green plastic pipe in wall (not flowing). Possibly discharge from Dylan Thomas boathouse.	Figure XII.43
62	SN3052810945	18/12/2013	09:54	Ground water running down cliff. Sample CB07.	Figure XII.44
63	SN3017410703	18/12/2013	10:02	Culverted stream with several drainage pipes in bank (not flowing). Sample taken from stream. Sample CB08.	Figure XII.45
64	SN3016210708	18/12/2013	10:15	Pumping station for Laugharne sewage overflow.	Figure XII.46
65	SN3024010419	18/12/2013	10:23	Culverted stream running alongside footpath. Sample CB09.	Figure XII.47
66	SN3036810385	18/12/2013	10:34	Pumping station for Laugharne WwTW. Sewage smell. No pipes visible at low tide.	Figure XII.48
67	SN3041009719	18/12/2013	11:01	Sluice for marsh drainage. Not accessible to measure depth. Sample CB10.	Figure XII.49
68	SN3041009719	18/12/2013	11:01	Horse manure. Evidence of cattle grazing on marsh. 100 sheep in field landward. 400 birds on marsh.	

Observation no.	NGR	Date	Time	Description	Photo
69	SN3046309722	18/12/2013	11:23	Sluice for marsh drainage. Sample CB11.	Figure XII.50
70	SN2816015239	18/12/2013	13:18	River - Afon Cynin & Afon Dewi Fawr (10m wide). Sample CB12.	
71	SN3094714336	18/12/2013	14:13	River - Afon Cywyn (6m wide). Sample CB13.	Figure XII.51

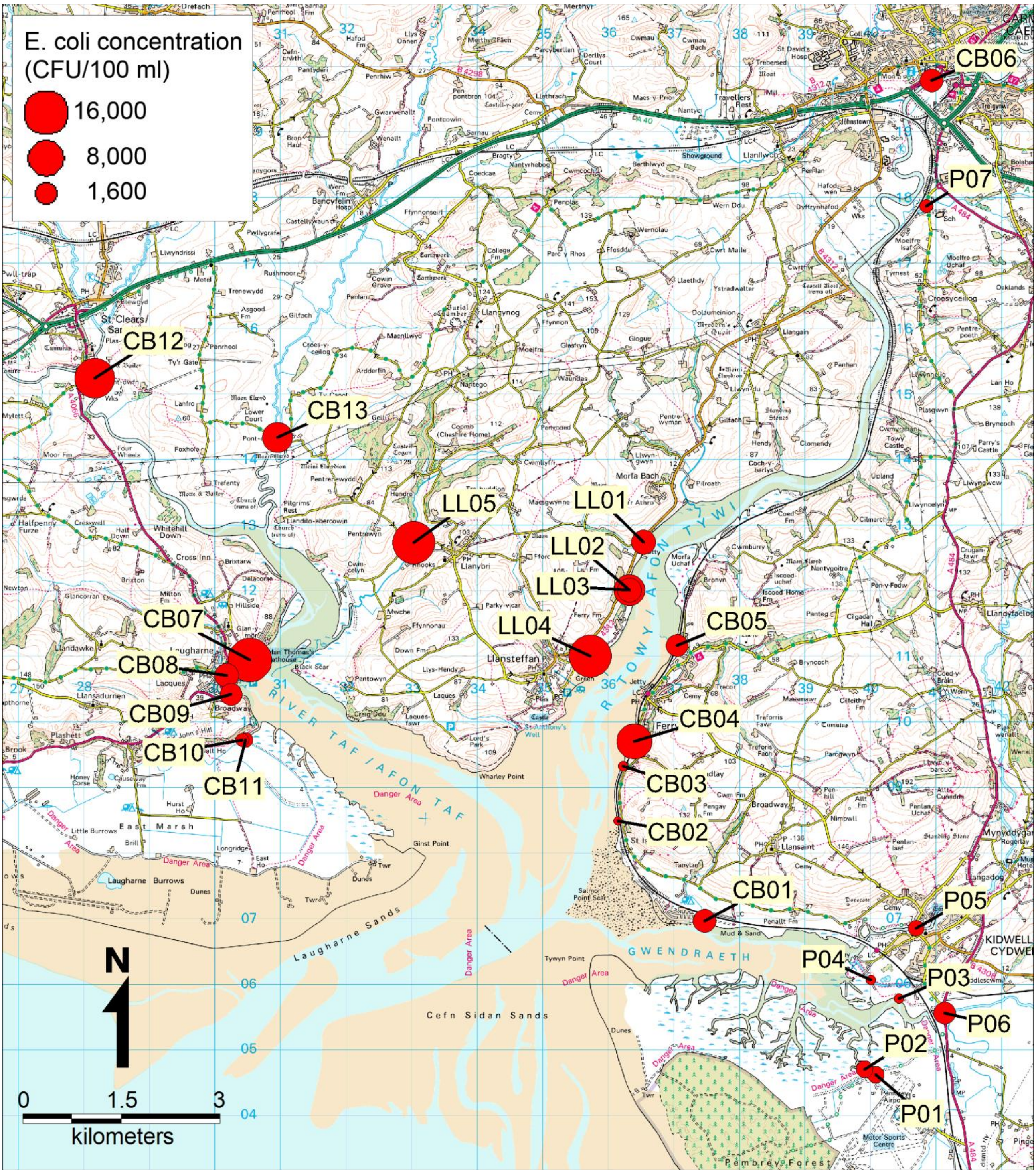


Figure XII.2: Water sample results (Table XII.2 for details)

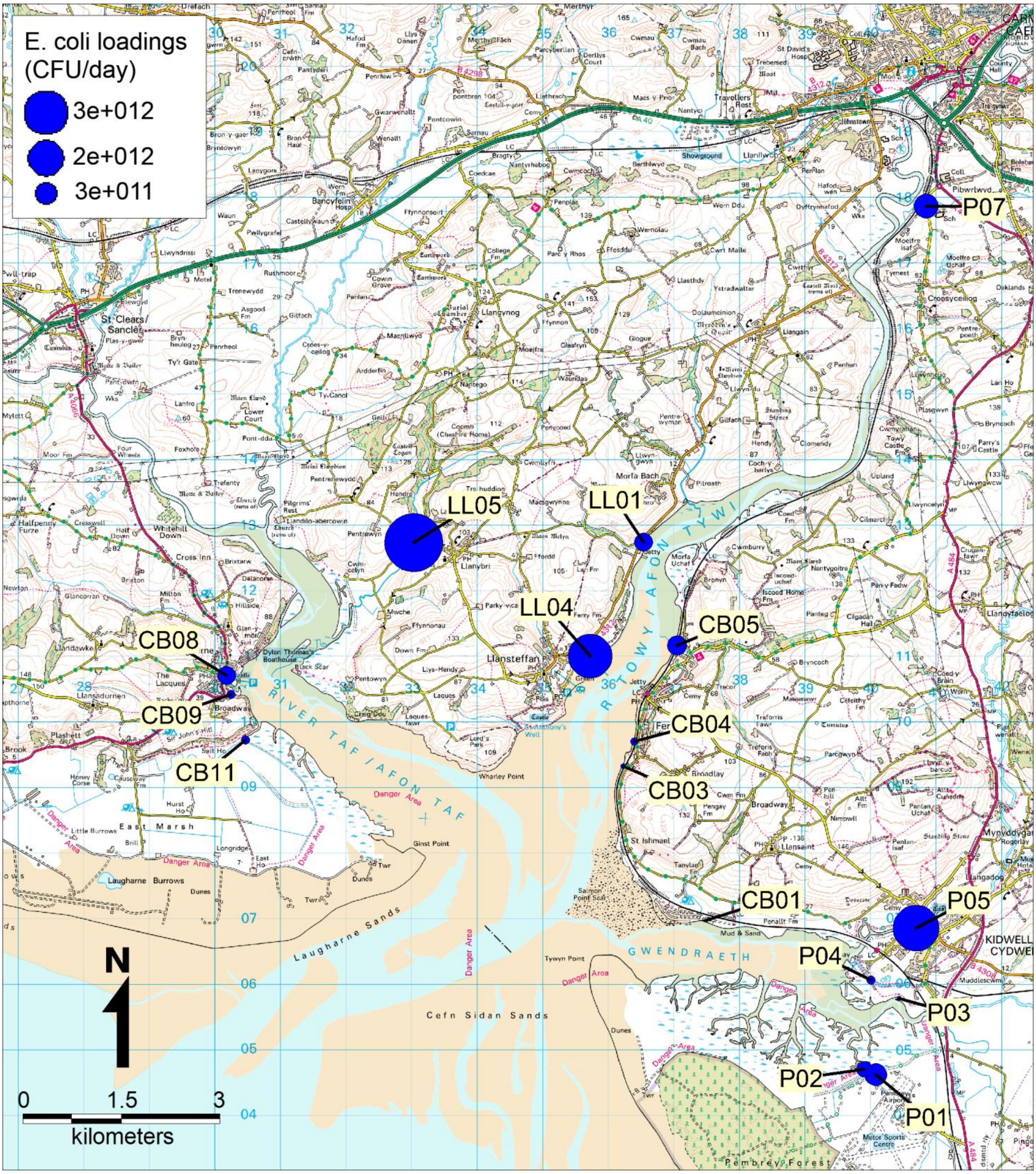


Figure XII.3: ***E. coli*** **loadings (Table XII.2 for details)**

Table XII.2: *E. coli* results, spot flow gauging results and estimated stream loadings (where applicable).

Sample ID	Observation number	Date and time	Water type	Description	Flow (m^3/s)	*E. coli* concentration (CFU/100 ml)	*E. coli* loading (CFU/day)	NGR
P01	2	17/12/2013 11:03	FW	Marsh drainage	0.549	660	3.13×10^{11}	SN4007604620
P02	7	17/12/2013 11:21	FW	Pipe	0.179	620	9.58×10^{10}	SN3990604699
P03	12	17/12/2013 13:28	FW	Pipe	0.013	110	1.19×10^{9}	SN4043205778
P04	16	17/12/2013 13:45	FW	Marsh drainage	0.136	120	1.41×10^{10}	SN3999706061
P05	20	17/12/2013 14:25	FW	River	7.000	600	3.63×10^{12}	SN4068606855
P06	21	17/12/2013 15:00	FW	River		1,700		SN4112305557
P07	22	17/12/2013 15:23	FW	River	1.400	350	4.23×10^{11}	SN4084617865
LL01	25	18/12/2013 10:22	FW	Stream	0.087	2,200	1.65×10^{11}	SN3653512738
LL02	30	18/12/2013 10:51	FW	Pipe		2,100		SN3632112005
LL03	31	18/12/2013 10:59	FW	Pipe		5,300		SN3632112005
LL04	32	18/12/2013 11:12	FW	Stream (STW upstream)	0.248	14,000	2.99×10^{12}	SN3571510999
LL05	39	18/12/2013 14:22	FW	Stream	2.000	15,000	2.59×10^{13}	SN3302812734
CB01	41	17/12/2013 10:14	FW	Pipe	0.000	1,900	3.15×10^{8}	SN3746306967
CB02	48	17/12/2013 11:39	FW	Pipe		80		SN3614308485
CB03	51	17/12/2013 12:02	FW	Stream	0.019	110	1.81×10^{9}	SN3622209324
CB04	52	17/12/2013 12:17	FW	Pipe	0.001	8,100	6.82×10^{9}	SN3639209703
CB05	57	17/12/2013 13:32	FW	Stream	0.140	1,600	1.93×10^{11}	SN3704011165
CB06	59	17/12/2013 15:29	FW	River		2,000		SN4092219780
CB07	62	18/12/2013 09:54	FW	Ground water		16,000		SN3052810945
CB08	63	18/12/2013 10:02	FW	Stream	0.092	2,300	1.82×10^{11}	SN3017410703
CB09	65	18/12/2013 10:23	FW	Stream	0.009	1,500	1.15×10^{10}	SN3024010419
CB10	67	18/12/2013 11:01	FW	Marsh drainage		300		SN3041009719
CB11	69	18/12/2013 11:23	FW	Marsh drainage	0.028	440	1.05×10^{10}	SN3046309722
CB12	70	18/12/2013 13:18	FW	River		12,000		SN2816015239
CB13	71	18/12/2013 14:13	FW	River		4,700		SN3094714336

Figure XII.4

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List of Abbreviations

AONB	Area of Outstanding Natural Beauty
BMPA	Bivalve Mollusc Production Area
CD	Chart Datum
Cefas	Centre for Environment Fisheries & Aquaculture Science
CFU	Colony Forming Units
CSO	Combined Sewer Overflow
CZ	Classification Zone
Defra	Department for Environment, Food and Rural Affairs
DWF	Dry Weather Flow
EA	Environment Agency
E. coli	Escherichia coli
EC	European Community
EEC	European Economic Community
EO	Emergency Overflow
FIL	Fluid and Intravalvular Liquid
FSA	Food Standards Agency
GM	Geometric Mean
IFCA	Inshore Fisheries and Conservation Authority
ISO	International Organization for Standardization
km	Kilometre
LEA (LFA)	Local Enforcement Authority formerly Local Food Authority
M	Million
m	Metres
ml	Millilitres
mm	Millimetres
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MPN	Most Probable Number
NM	Nautical Miles
NRA	National Rivers Authority
NWSFC	North Western Sea Fisheries Committee
OSGB36	Ordnance Survey Great Britain 1936
mtDNA	Mitochondrial DNA
PS	Pumping Station
RMP	Representative Monitoring Point
SAC	Special Area of Conservation
SHS	Cefas Shellfish Hygiene System, integrated database and mapping application
SSSI	Site of Special Scientific Interest
STW	Sewage Treatment Works
UV	Ultraviolet
WGS84	World Geodetic System 1984

Glossary

Bathing Water	Element of surface water used for bathing by a large number of people. Bathing waters may be classed as either EC designated or non-designated OR those waters specified in section 104 of the Water Resources Act, 1991.
Bivalve mollusc	Any marine or freshwater mollusc of the class Pelecypoda (formerly Bivalvia or Lamellibranchia), having a laterally compressed body, a shell consisting of two hinged valves, and gills for respiration. The group includes clams, cockles, oysters and mussels.
Classification of bivalve mollusc production or relaying areas	Official monitoring programme to determine the microbiological contamination in classified production and relaying areas according to the requirements of Annex II, Chapter II of EC Regulation 854/2004.
Coliform	Gram negative, facultatively anaerobic rod-shaped bacteria which ferment lactose to produce acid and gas at 37°C. Members of this group normally inhabit the intestine of warm-blooded animals but may also be found in the environment (e.g. on plant material and soil).
Combined Sewer Overflow	A system for allowing the discharge of sewage (usually dilute crude) from a sewer system following heavy rainfall. This diverts high flows away from the sewers or treatment works further down the sewerage system.
Discharge	Flow of effluent into the environment.
Dry Weather Flow (DWF)	The average daily flow to the treatment works during seven consecutive days without rain following seven days during which rainfall did not exceed 0.25 mm on any one day (excludes public or local holidays). With a significant industrial input the dry weather flow is based on the flows during five working days if production is limited to that period.
Ebb tide	The falling tide, immediately following the period of high water and preceding the flood tide.
EC Directive	Community legislation as set out in Article 189 of the Treaty of Rome. Directives are binding but set out only the results to be achieved leaving the methods of implementation to Member States, although a Directive will specify a date by which formal implementation is required.
EC Regulation	Body of European Union law involved in the regulation of state support to commercial industries, and of certain industry sectors and public services.
Emergency Overflow	A system for allowing the discharge of sewage (usually crude) from a sewer system or sewage treatment works in the case of equipment failure.
Escherichia coli (E. coli)	A species of bacterium that is a member of the faecal coliform group (see below). It is more specifically associated with the intestines of warm-blooded animals and birds than other members of the faecal coliform group.
E. coli O157	*E. coli* O157 is one of hundreds of strains of the bacterium *Escherichia coli*. Although most strains are harmless, this strain produces a powerful toxin that can cause severe illness. The strain O157:H7 has been found in the intestines of healthy cattle, deer, goats and sheep.
Faecal coliforms	A group of bacteria found in faeces and used as a parameter in the Hygiene Regulations, Shellfish and Bathing Water Directives, *E. coli* is the most common example of faecal coliform. Coliforms (see above) which can produce their characteristic reactions (e.g. production of acid from lactose) at 44°C as well as 37°C. Usually, but not exclusively, associated with the intestines of warm-blooded animals and birds.
Flood tide	The rising tide, immediately following the period of low water and preceding the ebb tide.
Flow ratio	Ratio of the volume of freshwater entering into an estuary during the tidal cycle to the volume of water flowing up the estuary through a given cross section during the flood tide.

Geometric mean	The geometric mean of a series of N numbers is the Nth root of the product of those numbers. It is more usually calculated by obtaining the mean of the logarithms of the numbers and then taking the anti-log of that mean. It is often used to describe the typical values of skewed data such as those following a log-normal distribution.
Hydrodynamics	Scientific discipline concerned with the mechanical properties of liquids.
Hydrography	The study, surveying, and mapping of the oceans, seas, and rivers.
Lowess	Locally Weighted Scatterplot Smoothing, more descriptively known as locally weighted polynomial regression. At each point of a given dataset, a low-degree polynomial is fitted to a subset of the data, with explanatory variable values near the point whose response is being estimated. The polynomial is fitted using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. The value of the regression function for the point is then obtained by evaluating the local polynomial using the explanatory variable values for that data point. The LOWESS fit is complete after regression function values have been computed for each of the n data points. LOWESS fit enhances the visual information on a scatterplot.
Telemetry	A means of collecting information by unmanned monitoring stations (often rainfall or river flows) using a computer that is connected to the public telephone system.
Secondary Treatment	Treatment to applied to breakdown and reduce the amount of solids by helping bacteria and other microorganisms consume the organic material in the sewage or further treatment of settled sewage, generally by biological oxidation.
Sewage	Sewage can be defined as liquid, of whatever quality that is or has been in a sewer. It consists of waterborne waste from domestic, trade and industrial sources together with rainfall from subsoil and surface water.
Sewage Treatment Works (STW)	Facility for treating the waste water from predominantly domestic and trade premises.
Sewer	A pipe for the transport of sewage.
Sewerage	A system of connected sewers, often incorporating inter-stage pumping stations and overflows.
Storm Water	Rainfall which runs off roofs, roads, gulleys, etc. In some areas, storm water is collected and discharged to separate sewers, whilst in combined sewers it forms a diluted sewage.
Waste water	Any waste water but see also “sewage”.

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