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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Bigbury and Avon

March 2014

Food Standards Agency

Cover photo: Oyster trestles on the west bank.

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Statement of use

This report provides a sanitary survey relevant to bivalve mollusc beds at Bigbury and Avon, 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
South Hams District Council	25/03/2014	-
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Dissemination

Food Standards Agency, South Hams District Council. The report is available publicly via the Cefas website.

Recommended Bibliographic Reference

Cefas, 2014. Sanitary survey of Bigbury and Avon. 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 Pacific oysters (*Crassostrea gigas*) within the Avon estuary, in south Devon. 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 Avon estuary is situated on the south coast of Devon and discharges to the English Channel. It lies between Salcombe estuary, to the east and the Erme estuary to the west, and its location is illustrated in Figure 1.1.

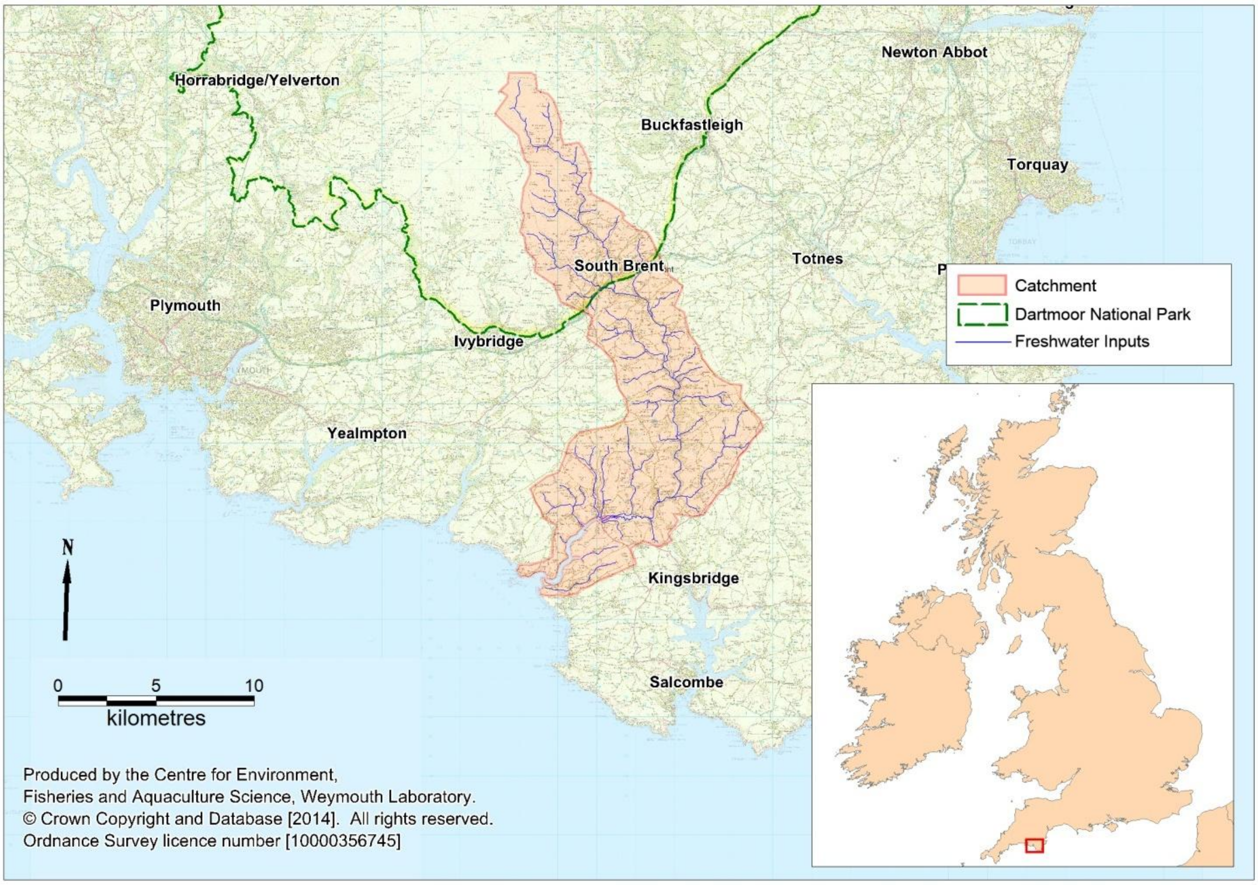


Figure 1.1: Location of the Bigbury and Avon survey area

The estuary is a narrow and meandering drowned river valley of about 6 km in length, which lies within a steep sided valley. It is characterised by a subtidal river channel bisecting the intertidal areas, which are sandy in the outer reaches, and more muddy in the inner reaches. It is largely unmodified from its natural state, and the majority of the shoreline is undeveloped. Its main freshwater input, the Devon Avon, drains to its head. The estuary supports a large Pacific oyster culture fishery in its lower reaches.

1.3. Catchment

The hydrological catchment covers an area of 145 km², and extends up into Dartmoor, where the maximum elevation is just over 500 m. Figure 1.2 illustrates landcover within this area. Its catchment is predominantly rural with moorland and grassland in the north and a mixture of pasture and arable farmland in the south, with the proportion of the latter increasing towards the coast. A very small percentage is urbanised, and the largest urban area is at South Brent, in the middle reaches of the catchment.

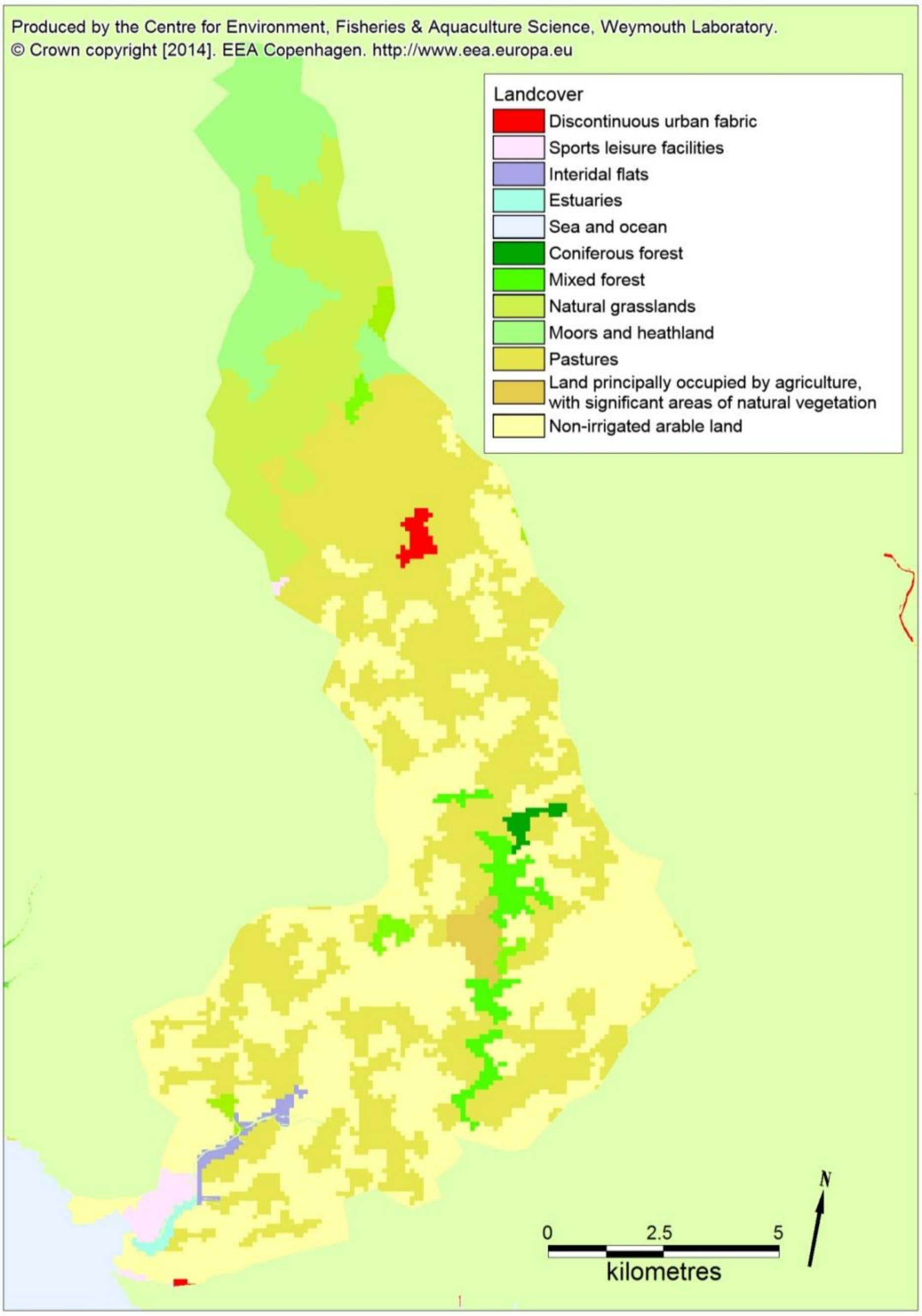


Figure 1.2: Landcover in the Bigbury and Avon survey area

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 increases contribution by up to 100 fold.

The underlying geology is comprised of granite in the north of the catchment, with carboniferous deposits underlying the majority of the rest of the catchment. The hydrogeology is categorised as of very low permeability throughout (NERC, 2012) so a large proportion of rainfall will run off, and discharge rates from watercourses will be highly variable, responding rapidly to rainfall.

2. Recommendations

Three zones and RMPs are proposed, covering the three discrete blocks of oyster trestles:

West Bank. This zone contains a block of trestles of about 250 m in length. There are no identified sources of contamination discharging directly to it. The primary influence is likely to be land runoff, the vast majority of which arrives in the estuary upstream of this zone. The majority of sewage effluent entering the estuary also arrives upstream of this zone. This results in a gradient of decreasing contamination towards the head of the estuary. There is a small stream to the west bank about 100 m south of the trestles which receives sewage effluent from a small private discharge. On balance it is recommended that the RMP is located at the northern end of the trestles to best capture contamination from upstream sources.

South Hexdown. This zone contains a block of trestles about 200 m in length. There are no identified sources of contamination discharging directly to it. The primary influence is likely to be land runoff, the vast majority of which arrives in the estuary upstream of this zone. The majority of sewage effluent entering the estuary also arrives upstream of this zone. This results in a gradient of decreasing contamination towards the head of the estuary. There is a small stream to the west bank about 75 m north of the trestles which receives sewage effluent from a small private discharge. There are no significant identified sources to the west bank of the estuary further downstream. It is therefore recommended that the RMP is located at the northern end of the trestles to best capture contamination from upstream sources.

East Bank. This zone contains a block of trestles about 150 m in length. There are no sources of contamination discharging directly to it. The primary influence is likely to be land runoff, the vast majority of which arrives in the estuary upstream of this zone. The majority of sewage effluent entering the estuary also arrives upstream of this zone. This results in a gradient of decreasing contamination towards the head of the estuary. Locally, there is a small stream discharging to the east bank about 500 m to the south, and a slightly larger one a similar distance to the north. It is therefore recommended that the RMP is located at the northern end of the trestles to best capture contamination from upstream sources.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Bigbury and Avon
Cefas Main Site Reference	M030
Ordnance survey 1:25,000 map	Explorer 20
Admiralty Chart	1613

Shellfishery

Species/culture	Pacific oyster	Trestle culture
Seasonality of harvest	Year round	

Local Enforcement Authority

Name	Environmental Health South Hams District Council Follaton House Plymouth Road Totnes Devon TQ9 5NE
Principal Environmental Health Officer	Mr Peter Wearden
Telephone number ☎	01803 861234
Fax number	01803 861294
E-mail	pete.wearden@southhams.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 Avon

Classification zone	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency
West Bank	B030I	West Bank North	SX 6739 4497	50° 17.385’ N 03° 51.776’ W	Pacific oyster	Trestle culture	Hand	Hand	10 m	Monthly
South Hexdown	B030J	South Hexdown North	SX 6711 4467	50° 17.219’ N 03° 52.005’ W	Pacific oyster	Trestle culture	Hand	Hand	10 m	Monthly
East Bank	B030K	East Bank North	SX 6748 4484	50° 17.316’ N 03° 51.697’ W	Pacific oyster	Trestle culture	Hand	Hand	10 m	Monthly

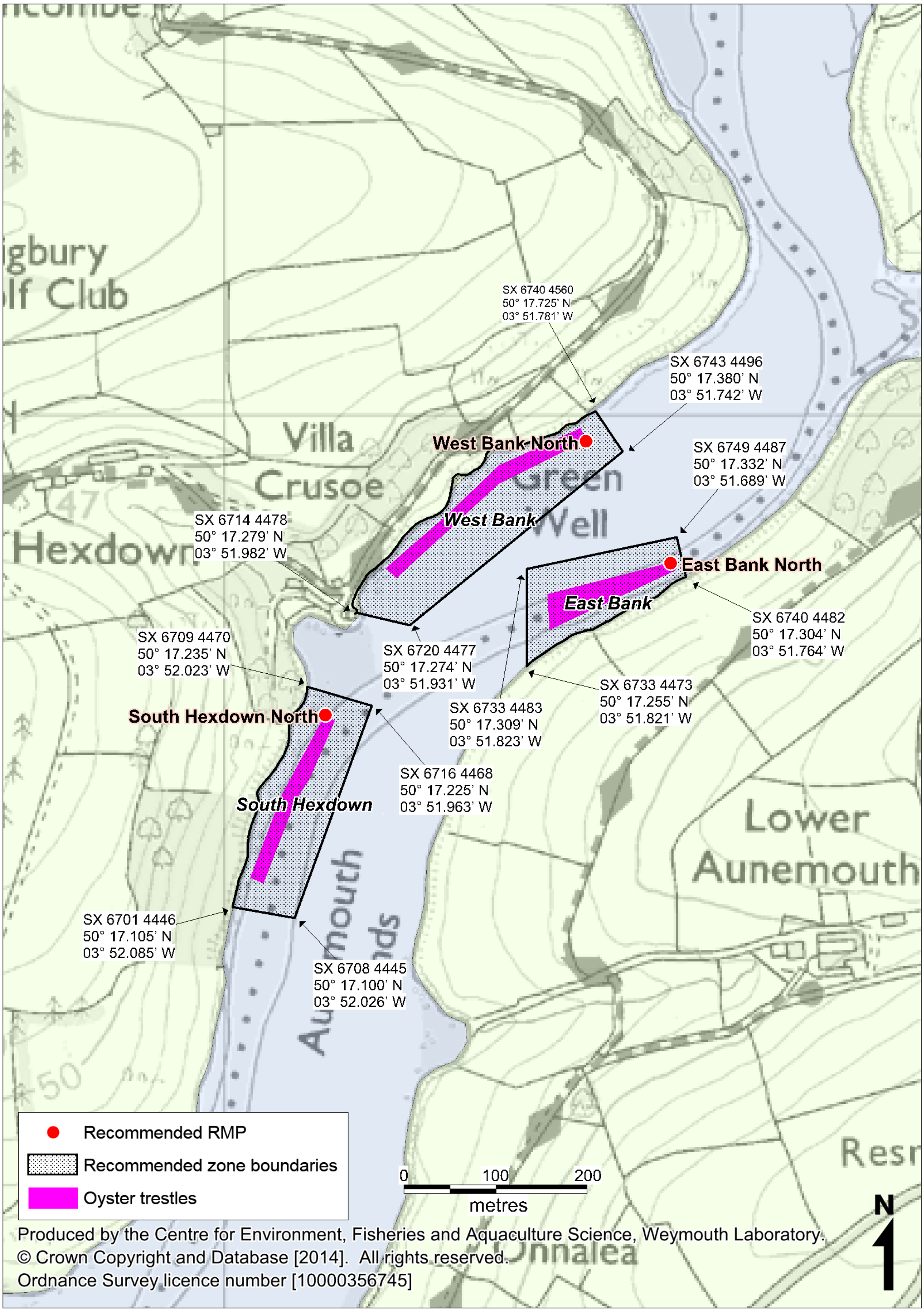


Figure 3.1: Recommended zoning and monitoring arrangements

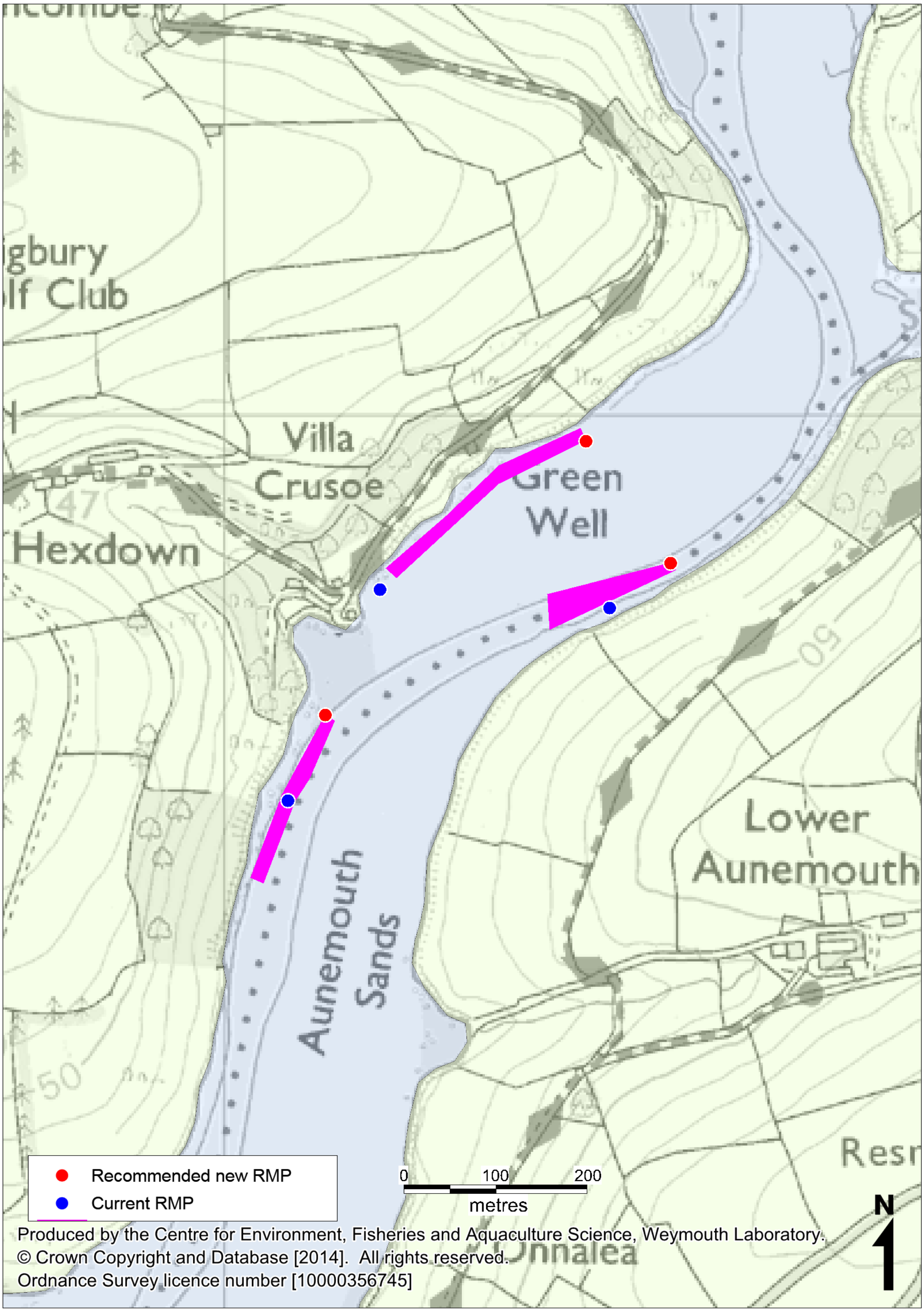


Figure 3.2: Comparison of current and recommended RMP locations

4. Shellfisheries

4.1. Species, location and extent

The estuary supports a Pacific oyster trestle farm, the extent of which is shown in Figure 4.1. The estuary bed is leased from the landowner (the Duchy of Cornwall) to Evans Estates, which in turn leases the area in which the trestles are located to the harvester.

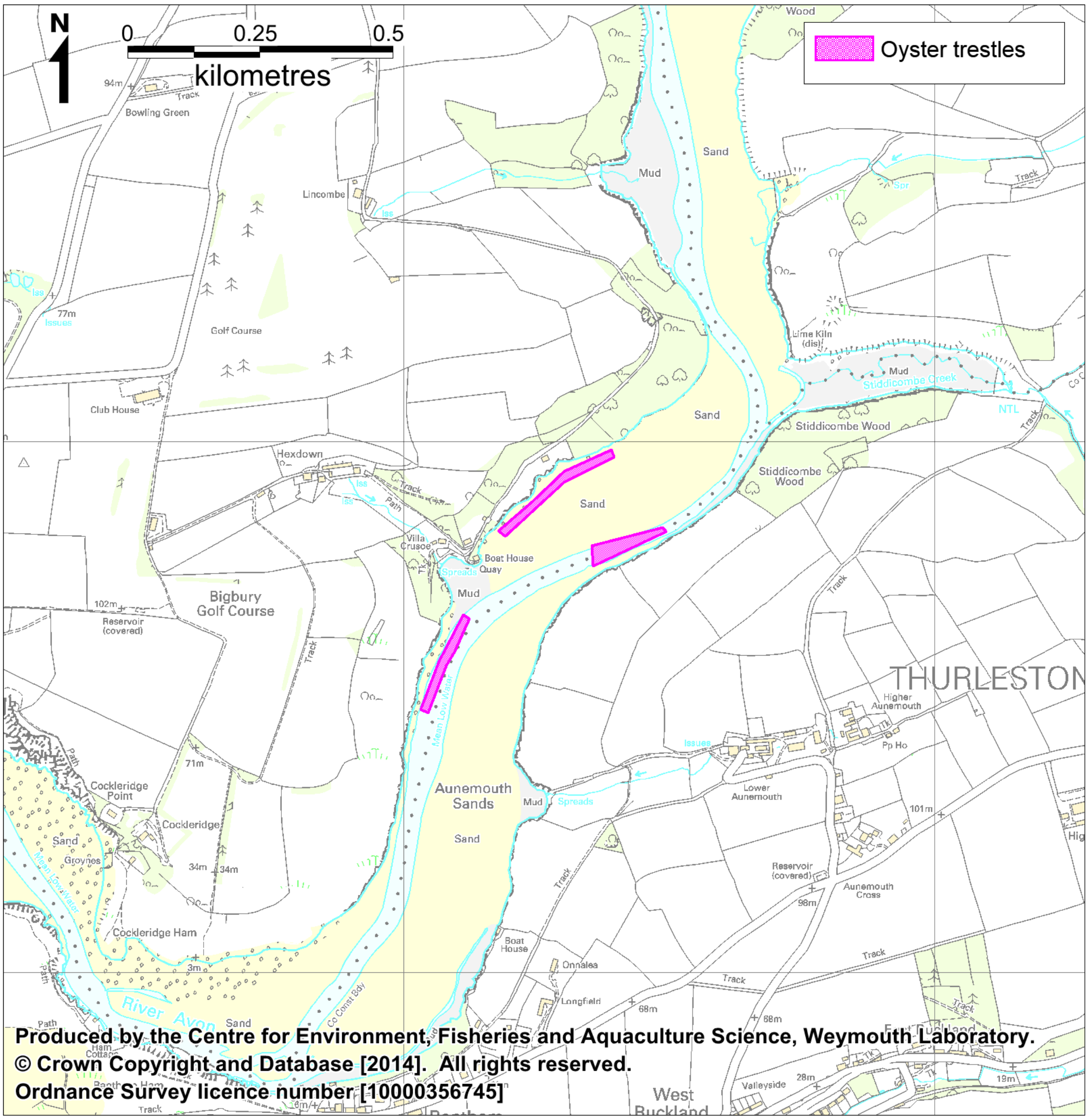


Figure 4.1: Extent of trestle farm

4.2. Growing Methods and Harvesting Techniques

Pacific oysters are grown from seed on trestles, and take three to four years to reach maturity. The relatively slow growth is probably a consequence of the highly variable salinity at the farm. Harvesting and husbandry is undertaken by hand, and the growers have their own depuration tanks.

4.3. Seasonality of Harvest, Conservation Controls and Development Potential

No conservation controls apply to cultured Pacific oysters. Harvest may be at any time of the year. Whilst there may be potential for increasing production, the variable microbiological quality of the water in the estuary is likely to constrain further investment. Class B compliance has been borderline at this site, and a downgrade to a C is a real possibility at any time[1]. Also, the Evans Estate is currently for sale, adding further uncertainty to future prospects.

4.4. Hygiene Classification

Table 4.1 lists all classifications within the survey area from 2004 onwards.

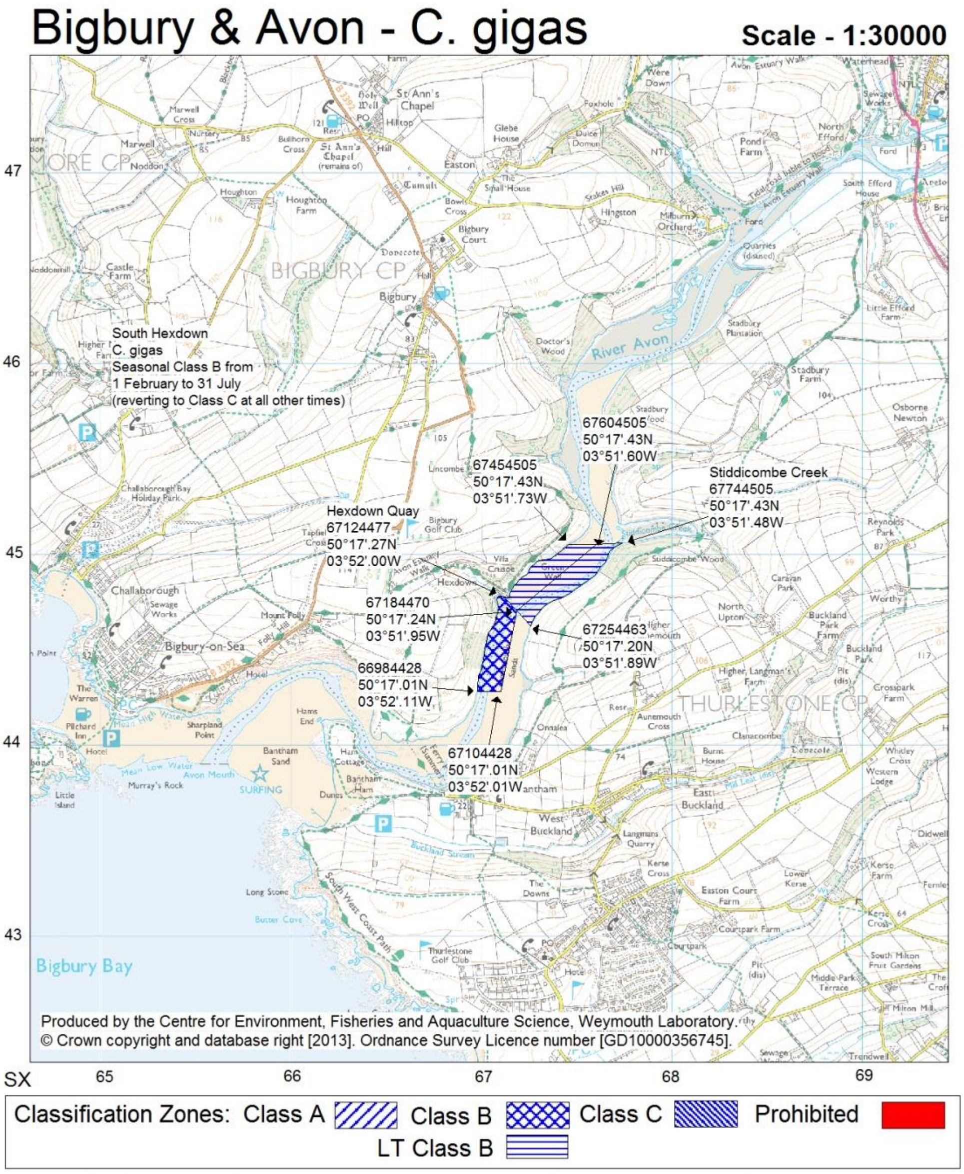
Table 4.1: Classification history for Bigbury and Avon, 2004 onwards

Area	Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
West Bank	P. oyster	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
South Hexdown	P. oyster	-	B	B	C	C	B	B	B	B	B
East Bank	P. oyster	-	-	-	-	B	B	B-LT	B-LT	B-LT	B-LT
West Bank	Mussels	B	C	C	-	-	-	-	-	-	-
South Hexdown	Mussels	-	C	C	-	-	-	-	-	-	-

LT denotes long term classification

The block of trestles at South Hexdown was downgraded to C in 2007, then the B classification was reinstated in 2009. All three trestle blocks currently hold B classifications for Pacific oysters[1], although more than 10 % of sample results have exceeded the class B threshold since 2003 at each (Table XI.1). Mussels were classified from 2004 to 2006, but when it became apparent any classification other than a C was unlikely for this species, plans for mussel culture were abandoned.

[1] In April 2014 East Bank and West Bank were downgraded to C, but South Hexdown remains B.



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

Food Authority: South Hams District Council

Figure 4.2: Current Pacific oyster classification map

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 Devon Avon supports a Pacific oyster farm, which is spread over three discrete blocks of trestles within a 600 m stretch of the lower to middle reaches of the estuary. The oysters are grown from seed to a market size, a process that takes 3-4 years. Harvesting and husbandry is undertaken by hand, and the growers have their own depuration facilities. Harvesting may occur at any time of the year, so continued year round classification is required. The fishery is not subject to any conservation controls such as minimum sizes. Compliance with the B classification requirements have been borderline in recent years, which causes some uncertainty around the future of the operation[2]. Further uncertainty arises as the estate which leases the seabed to the harvester is on the market.

The fishery is currently classified on the basis of three RMPs, one in each block of trestles. It may be prudent to maintain RMPs at all three blocks of trestles even if the assessment identifies that they are subject to similar sources and levels of microbiological contamination. Such a strategy may offer a better chance of maintaining a B classification for at least a part of the fishery. If a part of the fishery is downgraded, the remaining B area(s) would require designation as a relay area so stock from any downgraded areas could be relayed there for two months running up to harvest. A relay designation could be made as required by administrative action alone, without any need for further sampling.

[2] In April 2014 East Bank and West Bank were downgraded to C, but South Hexdown remains B.

5.3. Pollution Sources

Freshwater Inputs

The Avon estuary has a catchment area of 145 km^{2}, the majority of which (~85%) drains to the head of the estuary. It is rural in character, with a mixture of moorland, pasture, and arable farming. The underlying geology is of low permeability throughout so a high proportion of rainfall will run off into watercourses. The main freshwater input is the River Avon, which is a high gradient spate river that extends up into Dartmoor. There are also several other smaller watercourses that drain to the estuary at various locations. The mean daily flow at Loddiswell gauging station on the lower reaches of the Avon was 3.7 m^3/sec over the past decade. There was considerable day to day variation in discharge, with high flows exceeding base flows by more than a factor of 10. Flows were higher on average from October through to March, with a much smaller secondary peak in August. High flow events (exceeding 10 m^3/sec) were recorded in all months of the year, but they were more frequent and of a higher magnitude from October to February and in July. As the majority of the catchment drains to the head of the estuary, highest concentrations of faecal indicator bacteria deriving from land runoff are anticipated in the upper reaches of the estuary. The smaller watercourses entering the estuary in the vicinity of the fisheries will be of more localised significance and may cause hotspots of contamination where they enter the estuary. Of likely significance to the fishery is the Hexdown Stream, which is a small watercourse discharging in between the two blocks of trestles on the west bank. On the east bank, there are small watercourses draining to the shore about 500 m to the north and south of the block of trestles there (Stiddicombe Stream and Lower Aunemouth Stream). The bacterial loadings delivered by land runoff will be very variable on a day to day basis, depending largely on antecedent rainfall. Whether the seasonal variation in average flows results in a corresponding seasonal fluctuation in bacterial loadings the estuary receives is uncertain.

During the shoreline survey, watercourses which could be safely accessed were sampled for *E. coli* and spot flow measurements were taken, from which estimates of the bacterial loading that each was delivering at the time were made. Most watercourses were measured in this manner, although several were not, including two significant tributaries draining to the very upper reaches of the estuary. The survey was undertaken on a dry day during the winter, following a prolonged spell of wet weather. The results confirmed the Avon as the main source of runoff borne faecal indicator bacteria, with a measured bacterial loading of about 1.7×10^{14} *E. coli*/day, representing about 95 % of the measured bacterial loadings. There were several further significant inputs to the upper reaches of the estuary generating bacterial loadings in the 10^{11} to 10^{13} *E. coli*/day range. None of the smaller measured watercourses discharging to the middle and lower reaches of the estuary were delivering bacterial loadings exceeding 10^{11} *E. coli*/day, so will only be of more localised significance. Two minor freshwater inputs discharging between the two blocks of trestles on the west bank (one of which was the Hexdown Stream) were delivering a loading of only $5.3x10^9$ *E. coli*/day between them.

Human Population

Total resident population within the census areas contained within or partially within the catchment was approximately 22,000 at the time of last census (2011). The largest settlement in the catchment is South Brent, which lies on the banks of the Avon some distance inland, and had a population of approximately 2,600. The population in the far north of the catchment is relatively sparse due to the Dartmoor National Park which makes up around 30 % of the catchment's area. The shores of the estuary are largely undeveloped, although there are a few small settlements including Aveton Gifford at its head, and Bigbury just to the west of its mouth.

The South Hams district is a popular tourist destination and receives significant numbers of visitors. Population increases are therefore anticipated during the summer months. Increased population numbers will result in increased volumes of sewage treated by the sewage works so there may be some seasonality in the bacteriological loadings generated by these.

Sewage Discharges

There are 13 water company owned sewage treatment works of potential relevance to the survey area. Of these, two discharge to tidal waters. The Aveton Gifford STW discharges to the very upper reaches of the estuary, and is consented to discharge a dry weather flow of 306 m^3/day of UV disinfected effluent. Bacteriological testing results indicate that the UV treatment is reasonably effective, and an estimate of the average bacterial loading this works generates is about $2.4x10^9$ faecal coliforms/day. However, the bacteriological quality of the effluent does vary, and the highest recorded concentration of faecal coliforms in the effluent was about three orders of magnitude higher than the average used to estimate the loading it generates. The Bigbury & Challaborough STW discharges around the low water mark at the western end of the Bigbury seafront, and is consented to discharge 470 m^3/day of secondary treated effluent. An approximate estimate of the bacterial loading it generates is $1.6x10^{12}$ faecal coliforms/day. Its plume is unlikely to be carried far into the estuary given the bathymetry and water circulation patterns in the area.

Of the remaining 11 sewage works, two discharge to soakaway inland so should be of no impact to the shellfishery. The other nine all discharge to watercourses draining to the estuary upstream of the fishery. The treatment they provide (where specified on the database) is secondary. The consented dry weather flows were only stated for six of them, and these totalled 804 m^3/day. The vast majority of this was from Loddiswell STW (197 m^3/day) and South Brent STW (509 m^3/day) both of which discharge to the main River Avon. These works will make a contribution to the bacterial loadings delivered to the estuary by the watercourses they discharge to. Some bacterial die-off is likely to occur during transit, particularly for the more inland works.

As well as the sewage works, there are 15 consented intermittent overflow discharges associated with the sewerage networks within the survey area. All but four discharge to the very upper reaches of the estuary or watercourses draining to the estuary upstream of the fishery. There are three discharging to the seafront at Bigbury, and another discharging to a short watercourse that drains to Bantham Beach. Only three of these discharges are monitored, and all of these are at Aveton Gifford. An examination of spill records (2007-2012) indicated that two of these hardly ever spilled, and one did spill from time to time but was active for less than 1% of the period considered. As such these three discharges are unlikely to be of much significance to the fishery. For the unmonitored discharges, it is difficult to assess their significance to the shellfishery, apart from noting their location and potential to spill storm sewage. The intermittent discharges closest to the fishery are at Aveton Gifford (~3.5 km) and these will contribute to upstream sources of contamination.

Although most of the survey area is served by water company sewerage infrastructure, there are also a number of private discharges in the catchment. These typically serve one or a small number of properties and provide treatment by septic tanks or package plants. Of these, 116 discharge to soakaway so should be of no impact assuming they are functioning correctly. The remaining 55 discharge to water, all but eight of which are to watercourses draining to the estuary upstream of the fishery. These will make minor contributions to the loading these watercourses deliver to the estuary. Of most significance to the fishery is a package plant at Hexdown Barns which is consented to discharge up to 4.2 m^3/day to a short watercourse that drains to the estuary between the two blocks of trestles on the west bank. Whilst it is a small discharge it may cause a slight elevation in *E. coli* levels towards the ends of the trestle blocks closest to this stream. As it provides treatment to effluent from holiday lets, there may be some seasonality to the volumes it discharges. There are also four small private discharges direct to the outer estuary at Bantham consented to discharge a combined maximum flow of 4.4 m^3/day of septic tank effluent, but it is unlikely that these are of much influence outside of their immediate vicinity.

Agriculture

The majority of land within the Avon catchment is used for agriculture. The upper reaches are moorland and rough grassland which are grazed extensively, and the middle and lower reaches are a mixture of pasture and arable land, with a higher proportion of the latter in the more coastal areas. A total of 10,507 cattle and 25,172 sheep were recorded within the catchment area in the 2010 agricultural census, so significant impacts from grazing animals are anticipated. There were also small numbers of pigs and some poultry farms in the area.

Faecal matter from grazing livestock is either deposited directly on pastures, or collected from livestock sheds if animals are housed indoors during the colder months and then applied to agricultural lands as a fertilizer. Manure from pigs and poultry is typically stored and applied tactically to nearby farmland. Contamination deposited on farmland is then washed into watercourses via land runoff, so fluxes of agricultural contamination into the estuary will be highly rainfall dependent. Watercourses which animals can access will be more vulnerable than those that are fenced off. Some of the streams local to the shellfishery were identified as subject to livestock poaching, including those at Hexdown and Lower Aunemouth, and have been fenced off to prevent excessive contamination by cattle and sheep.

A large proportion of the agricultural land lies within parts of the catchment drained by watercourses discharging to the estuary upstream of the fishery so higher impacts towards the up-estuary ends of the shellfisheries are generally anticipated on this basis. Given the ubiquity of farmland throughout the survey area, all watercourses are likely to be affected to some extent. Therefore, in general RMPs should be situated at the up-estuary ends of shellfish beds, or in the immediate vicinity of smaller watercourses draining to the estuary.

There is likely to be some seasonality in fluxes of faecal indicator bacteria of agricultural origin into the estuary. Rainfall and river flows are generally higher during the winter months, although high rainfall events may occur at any time of the year. Numbers of cattle will increase significantly in the spring, with the birth of calves, and decrease in the autumn when animals are sent to market. During the warmer months, livestock are likely to access watercourses more frequently to drink and cool off. 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. Other manures and sewage sludge may be spread at any time of the year depending on its availability and crop cycles. Therefore peak levels of contamination from agriculture 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. An investigation into microbiological contamination of agricultural origin concluded that the bulk of faecal matter deposited on agricultural land in the Avon catchment was via direct defecation on pastures, but there were also significant amounts of slurry/manure spread on arable land and pasture. There was strong seasonality in the amount of faecal matter applied to or deposited on agricultural land, which was lowest from November to March, and peaked in August and September.

Microbial source tracking assays have identified ruminants as the origin of the majority of faecal indicator bacteria at the shellfishery. Agricultural sources should therefore be given a high priority relative to other inputs in the sampling plan.

Boats

Boat traffic in the area is limited to smaller recreational craft such as yachts, sailing dinghies and kayaks. There are no marinas in the estuary, but there are areas of anchorages and moorings. These are mainly located in the Bantham area, just downstream of the shellfishery, and in the upper reaches of the estuary around Aveton Gifford. There is no fishing fleet based in the estuary, and the ownership of fishing rights and various other fishing restrictions mean that very few fishing vessels are likely to work the estuary.

Smaller pleasure craft such as kayaks and windsurfers will not have onboard toilets and so are unlikely to make overboard discharges. Private vessels such as yachts and motor cruisers of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the area. Therefore, whilst overboard discharges may be made anywhere within the survey area, it is likely that the moorings and the main navigation routes through the estuary are most at risk of contamination from this source. 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.

Wildlife

The Avon estuary encompasses a variety of habitats including intertidal mudflats, saltmarsh, grassland and sandy beaches at Bantham and Bigbury-on-Sea. These features attract significant populations of birds and other wildlife. The most significant wildlife aggregation in terms of shellfish hygiene is most likely to be overwintering waterbirds (waders, wildfowl etc). The 5 year average in peak waterbird counts is only 2,155 birds, so it is concluded that the Avon estuary is not as attractive to birds as other similar nearby estuaries where counts are typically much higher. Nevertheless, such numbers of birds may be a significant contaminating influence at times. On the (winter) shoreline survey small aggregations of birds such as gulls were observed throughout the estuary in particular roosting on uncovered sand banks. Around 20 swans were also recorded on the marsh in the north east of the Avon estuary.

Geese and ducks will mainly frequent the saltmarsh and coastal grasslands, where their faeces will be carried into coastal waters via runoff into tidal creeks or through tidal inundation. RMPs within or near to the drainage channels from saltmarsh areas and watercourses draining pasture will be best located to capture contamination from such birds. Other species forage on intertidal invertebrates and so will defecate directly on intertidal areas. They may tend to aggregate in certain areas holding the highest densities of prey of their preferred size and species, but this will probably vary from year to year. At high tide waders are likely to frequent more undisturbed and isolated areas. 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.

Some birds will remain in the area to breed in the summer, but most are likely to migrate elsewhere outside of the winter months. Bird numbers and potential impacts on the hygiene status of the fisheries are therefore lower during the summer. There are resident and breeding seabird populations in the area (gulls, terns, etc.). There is a small breeding colony around the mouth of the estuary, where 72 breeding pairs of gulls, cormorants, shags and fulmar were recorded in 2000. These seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. As this is not in the immediate vicinity of the fishery, their presence will have no influence on the sampling plan.

There are no major seal colonies in the vicinity of the survey area, so whilst seals may enter the estuary from time to time they are unlikely to be a significant source of contamination to the shellfishery. Otters have been sighted in the area very occasionally but given their very low numbers they are of no influence on the sampling plan. No other wildlife species which may have a bearing on the sampling plan have been identified.

Domestic animals

Dog walking takes place on beaches and paths adjacent to the estuary 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 Bantham and Bigbury. The shore adjacent to the fishery is relatively inaccessible for the most part, and some distance from any major settlement so can be considered less vulnerable. 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					+	+	+	+	+	+		
Urban runoff												
Continuous sewage discharges												
Intermittent sewage discharges	?	?	?	?	?	?	?	?	?	?	?	?
Birds												
Boats												

Red - high risk; orange - moderate risk; yellow - lower risk; white – little or no risk.

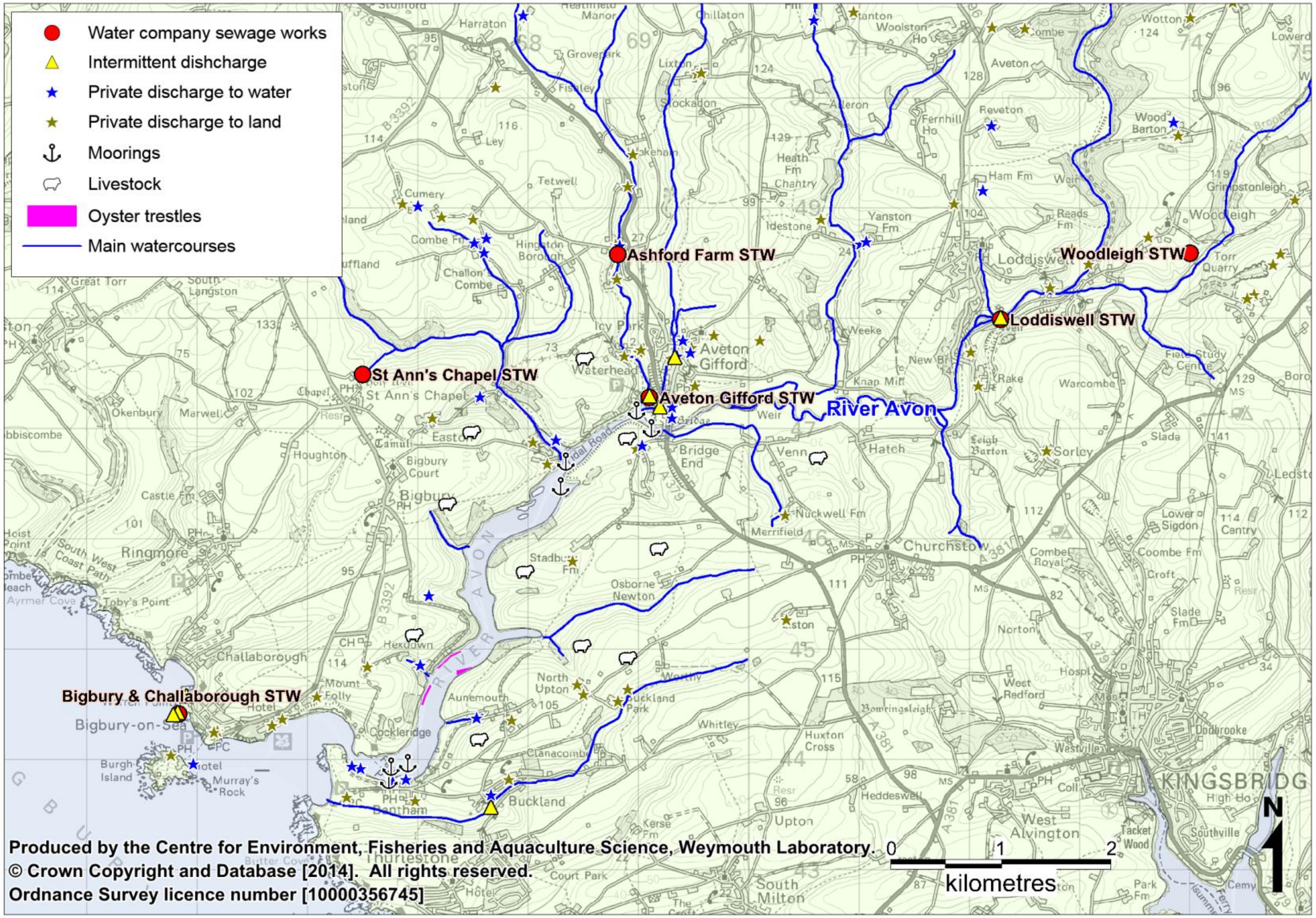


Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The Avon estuary is a ria of about 7.8 km in length and a relatively uniform 2-300 m in width throughout, although it opens out at the mouth, and narrows towards its tidal limit. There is also a constriction and pronounced meander just inside the estuary mouth where it narrows to about 60 m where there may be increased potential for turbulent mixing of the water column. It follows a steep sided, meandering valley and consists of a shallow subtidal river channel which is generally less than 2 m in depth, flanked by intertidal areas. Given its shallow nature, a large proportion of water will therefore be exchanged each tidal cycle, but dilution potential will be low. Its principle freshwater input is to its head. There are also several minor watercourses which drain to small creeks and embayments off the main channel, and then follow drainage channels though the intertidal to the main river channel. Intertidal sediments are sandy throughout the lower and middle reaches, but become muddier in the upper reaches suggesting a reduction in current speeds here. Throughout the estuary sediments within the river channel are generally coarser than those found on the intertidal area, which is indicative of higher flow rates in this channel. Burgh Island lies just to the west of the estuary mouth, about 250 m off Bigbury, and is separated from the mainland by an intertidal area. Tidal streams will therefore only pass inshore of the island at higher states of the tide.

Tidal ranges in the Avon estuary decrease from 3.7 m on spring tides at Bantham beach (estuary mouth) to 3.0 m at Bantham (lower estuary) and then to 1.5 m at North Efford in the upper estuary. Within the English Channel, offshore tidal streams move eastwards on the flood, and ebb in a westerly direction. Contamination from sources discharging to the shore to the west of the estuary may be carried in on the flood tide, but sources to the east will be carried past the estuary mouth rather than into the estuary as the tide ebbs. However, it is possible that eddies may form within Bigbury Bay and around the mouth of the estuary on various scales and at certain states of the tide which will complicate circulation patterns. Also, tidal streams will only be able to pass inshore of Burgh Island at higher states of the tide. This will limit the impacts from Bigbury STW, as it will only be carried directly towards the estuary during the latter parts of the flood tide, meaning its plume will not penetrate far into the estuary, if at all.

Within the estuary itself, tidal streams will move up on the flood, and out on the ebb, and the main stream will follow the main estuary channel. As the channel fills, water will spread over the intertidal areas and move up any side channels and creeks. The opposite will occur on the ebb. 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.

Current measurements within the estuary show peak velocities at Bantham of 1 m/s on the ebb tide and 0.8 m/s on the flood tide. They were slightly slower in the upper estuary at North Efford, peaking at 0.7 m/s on the flood and 0.5 m/s on the ebb. A particle tracking model indicated that particles released in the very upper reaches reached the shellfishery from 2h 25m to 14h 40m after release time depending on river flow and tidal conditions. This indicates that the plume from the Avon may or may not reach the shellfishery during the course of an ebb tide. River discharge was responsible for most of the variation in transit times, with higher discharge associated with faster transit. Transit times decreased slightly with higher tidal amplitudes. On average, the upstream end of the shellfishery will be exposed to the river plume for longer before the tide reverses and carries it back up the estuary, so RMPs located at the up-estuary ends of the trestle sites would best capture contamination from sources in the wider catchment.

Superimposed on tidally driven currents, are the effects of freshwater inputs and wind. The ratio of river flow to tidal exchange is sufficiently high to suggest that stratification may occur, particularly at times of elevated river flow. This results in a net seaward movement of less dense fresher water on the surface, with a corresponding return of more saline water at depth. Vertical salinity profiling under low river discharge conditions showed no stratification at Bantham, but strong stratification was recorded at North Efford during the ebb tide, when surface currents were much faster than bed currents.

As land runoff typically contains higher levels of faecal indicator bacteria than seawater, decreased salinity is generally associated with higher levels of faecal indicator bacteria in the water column. Multiple salinity measurements indicate that the average salinity was approaching that of full strength seawater on the beaches just outside the estuary mouth. It then decreased to 22.6 ppt just inside the estuary mouth, then to 19.0 ppt in the vicinity of the trestles, then down to less than 5 ppt in the narrower uppermost reaches. This suggests that there is a strong underlying gradient of runoff related contamination throughout the estuary. Salinity in the vicinity of the trestle site was very variable, with conditions varying from fully marine to freshwater. Much variation occurred across the tidal cycle, with high salinities at high water and low salinities at low water. Salinities also tended to be lower here during neap tides presumably relating to the reduced flushing of the estuary at such times.

Strong winds may affect circulation by driving surface currents, which in turn create return currents at depth or along sheltered margins. The estuary is afforded some protection from the prevailing south westerly winds, but the steep valley it lies in will tend to funnel winds from this direction up it, and so push surface water in an upstream direction. 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 re-suspended. Given the shape of the estuary mouth, swells from the English Channel are unlikely to penetrate past the meander at Cockleridge.

5.5. Summary of Existing Microbiological Data

The Devon Avon has been subject to considerable microbiological monitoring over recent years, deriving from the Bathing Waters and Shellfish Waters monitoring programmes as well as *ad hoc* investigative work and shellfish flesh monitoring for hygiene classification purposes. Figure 5.2 shows the locations of the monitoring points referred to in this assessment.

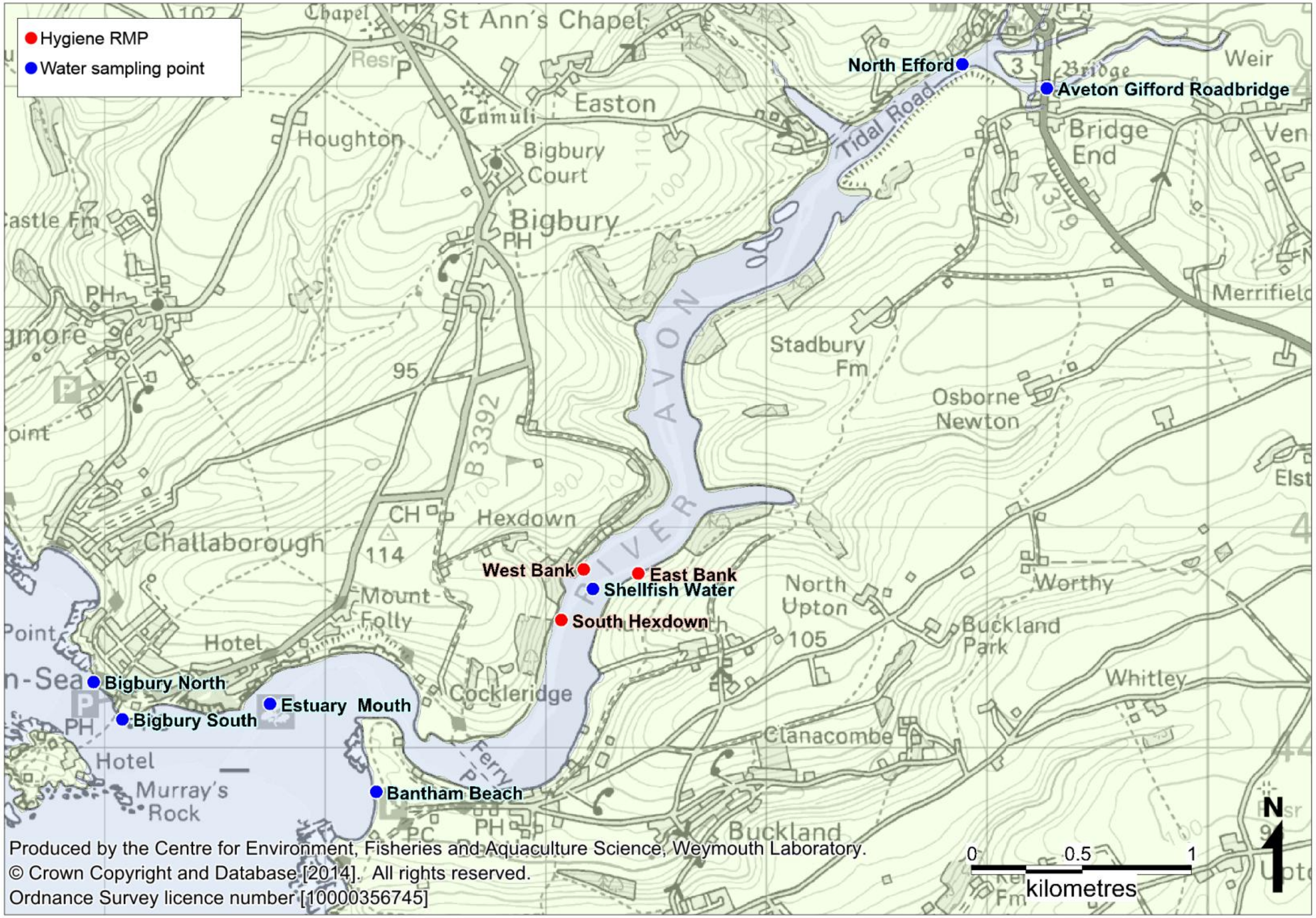


Figure 5.2: Microbiological sampling locations

Bathing waters

There are three designated bathing waters around the mouth of the Avon estuary (Bigbury North, Bigbury South, and Bantham Beach) where around twenty water samples are taken during the bathing season (May to September) and enumerated for faecal coliforms. Some additional sampling to assess the quality of recreational water was carried out during the bathing water season at a three further points within the estuary (Estuary Mouth, North Efford and Aveton Gifford Road bridge). Due to changes in analysis methods in 2012, only samples taken from 2003 to 2011 were considered in the following analyses.

Levels of faecal coliforms at the three bathing water beaches around the estuary mouth were generally low, although results were significantly higher at Bigbury South and Bantham Beach (geometric mean of 11.5 faecal coliforms/100ml at both) than at Bigbury North (geometric mean of 5.8 faecal coliforms/100ml). This suggests that Bigbury & Challaborough STW is not a major contaminating influence. Results then increased significantly at Estuary Mouth, where the geometric mean was 169 faecal coliforms/100ml. A further statistically significant increase in faecal coliforms occurred at the two upper estuary sites (North Efford and Aveton Gifford Road bridge), where geometric mean faecal coliform results were 2183 and 1697 faecal coliforms/100ml respectively. Peak concentrations of faecal coliforms at these upper estuary sites were very high, at 81,000 and 60,000 faecal coliforms/100ml. These results show a clear pattern of increasing levels of faecal indicator bacteria in the water column into and up the estuary, which can reach very high levels towards the tidal limit. Comparisons of paired (same day) samples showed significant correlations between all site pairings indicating the entire system is influenced by similar sources of contamination.

Faecal coliform levels have remained reasonably stable at all bathing waters sites since 2003, with the exception of Avon Estuary Mouth. There appeared to be a reduction in faecal coliform concentrations here between 2009 and 2010, after which monitoring ceased. A statistically significant influence of tidal state across both the high/low and spring/neap tidal cycles was detected at all monitoring points with the exception of Aveton Gifford Road bridge, which is close to the tidal limit and so conditions here are more riverine than estuarine. In relation to the high/low tidal cycle, lower results tended to occur around high water at Bigbury South, Bantham Beach, and possibly Bigbury North and North Efford. No pattern was apparent when results for Estuary Mouth were plotted, and sampling here was targeted towards low water. The pattern observed suggests that up-estuary sources are a major influence, and that this influence extends out to Bigbury and Bantham beaches. Plots of results across the spring/neap tidal cycle show a general tendency for higher results as tide sizes increase from neaps to springs, although this is more obvious at some locations than others.

A statistically significant influence of antecedent rainfall was found at all six monitoring points. This persisted for longer after a rainfall event at Bigbury South, Bantham Beach and Estuary Mouth compared to Bigbury North and the two sites in the upper reaches.

There were significant negative correlations between salinity and faecal coliform concentrations at all sites apart from Bigbury North and Aveton Gifford Road bridge. There was little variation in salinity at these two locations, with the former being largely fully saline, and little saline influence at the latter. The correlations were very strong at all other sites indicating that land runoff is a highly significant contaminating influence.

Shellfish waters

There is one designated shellfish water monitoring point in the Avon estuary, which lies in the vicinity of the oyster trestle site. Water samples are taken here on a quarterly basis and enumerated for faecal coliforms. The geometric mean result was 370 faecal coliforms/100ml, indicating quite high average levels of microbial contamination. The highest recorded result was 39,000 faecal coliforms/100ml. Faecal coliform concentrations have remained reasonably stable here since 2003. No statistically significant seasonal variation was found, although results were slightly higher on average during the autumn. A strong influence of tide across both the high/low and spring/neap tidal cycles was detected at this monitoring point. There was a tendency for highest results around low water and the early part of the flood tide, and for lowest results on the latter part of the flood tide suggesting up-estuary sources may be an influence. Across the spring/neap tidal cycle highest results occurred on neap tides and the first few days of increasing tide sizes just after neap tides, possibly relating to lower levels of flushing at such times. Antecedent rainfall over various periods was a significant and consistent influence at the shellfish water monitoring point. A strong negative correlation was found between faecal coliforms and salinity indicating the levels of faecal coliforms increase with the amount of freshwater in the system. A strong tendency for lower salinities here around low water was noted in the hydrographic assessment, which is consistent with the observed correlations between faecal coliform concentrations and the high/low tidal cycle. Similarly, the variation in salinity in relation to the spring/neap tidal cycle is also consistent with the variation in faecal coliform concentrations.

Shellfish Hygiene classification monitoring

Since 2003, shellfish samples have been taken from three locations, one on each of the blocks of trestles. Both Pacific oysters and mussels were sampled from all these points. Pacific oysters were sampled on a more or less monthly basis from 2003 to present, whilst mussel sampling only continued until July 2006.

The geometric mean *E. coli* result was consistently high across all three mussel RMPs, ranging from 3288 to 3800 MPN/100g, with no significant difference between them. The proportion of results exceeding 4,600 *E. coli* MPN/100g was also similar, ranging from 32.6 % to 53.8 %. Prohibited level results were recorded once at South Hexdown and twice at West Bank, but not at East Bank. A comparison of paired (same day) samples from West Bank and South Hexdown found a very strong correlation between results on a sample by sample basis, indicating that they are subject to similar sources of contamination. There were insufficient paired samples to make similar comparisons between East Bank and either South Hexdown or West Bank.

Across the three Pacific oyster RMPs, the geometric mean results were all very similar (1138 to 1291 *E. coli* MPN/100g) with no significant difference between them. Although no prohibited levels results were recorded in Pacific oysters the proportion of results exceeding 4600 MPN was more than 10 % at all three RMPs, ranging from 14.1 % to 21.2 %. This indicates that the compliance with the requirements for the current B classification is borderline. Comparisons of paired (same day) samples could be undertaken between all Pacific oyster RMP pairings, and very strong correlations were found for each. This indicates that all three RMPs share similar sources of contamination. Together with the lack of spatial variation in average results, this suggests that separate monitoring of all three trestle blocks may not be necessary for public health protection purposes.

Between 2003 and 2006 there was a slight increase in average results for both mussels and oysters. After 2006, mussel sampling was discontinued, but there was a slight decrease in levels of contamination within Pacific oysters. Statistically significant seasonal variation was found at all RMPs. At all three mussel RMPs results were significantly higher in the summer compared to the winter and spring. All three Pacific oyster RMPs showed significantly higher results in the summer and autumn compared to the winter. This very marked seasonality was not observed in water sampling at the nearby shellfish water monitoring point, so is probably largely driven by seasonal variations in parameters such as salinity and temperature influencing the ability of shellfish to accumulate bacterial indicators.

The only RMP where a statistically significant influence of tide was detected was West Bank (both species) where there were correlations between *E. coli* results and the high/low tidal cycle. However, sampling was strongly targeted towards low water and no patterns were obvious when this data was plotted. No influence of antecedent rainfall was found for any of the RMPs, although there was one statistically significant (negative) correlation found which was likely to be a consequence of chance rather than a real effect. This is somewhat surprising given that the fishery is within the estuary of a significant river that drains an agricultural catchment, and levels of faecal indicator bacterial in the water column are strongly influenced by rainfall. It is therefore likely that the fluctuations in salinity here following significant rainfall events are sufficiently acute and abrupt to cause the shellfish to cease feeding.

Microbial source tracking

A microbial source tracking assay was applied to 25 water samples taken from various locations on the Avon estuary from 2007 to 2009. These allowed the relative contribution of human and ruminant sources to be estimated. No other animal types were tested for. The results consistently found a high contribution from ruminants (75-99%) relative to humans (1-25%). Whilst the accuracy of quantification is uncertain, the results do strongly suggest that agricultural runoff from sheep and cattle farming is the dominant source of microbiological contamination to the estuary.

Bacteriological survey

The Devon Avon has an extensive microbiological monitoring history as described above, so there was little to be gained from taking additional shellfish samples. Six additional sediment samples were taken during the shoreline survey and enumerated for *E. coli*, and 24 water samples (freshwater and estuarine water) were also taken. Four estuarine water samples taken by the north block of trestles on the west bank showed very high levels of *E. coli* (3200-4900 cfu/100ml). A sample taken from the main river channel by the block of trestles on the east bank the following day contained lower levels of *E. coli* (360 cfu/100ml). The results of freshwater samples and spot flow measurements are discussed under the freshwater inputs assessment above. The sediment samples showed higher levels of *E. coli* towards the up-estuary ends of the trestle sites.

Appendices

Appendix I. Human Population

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

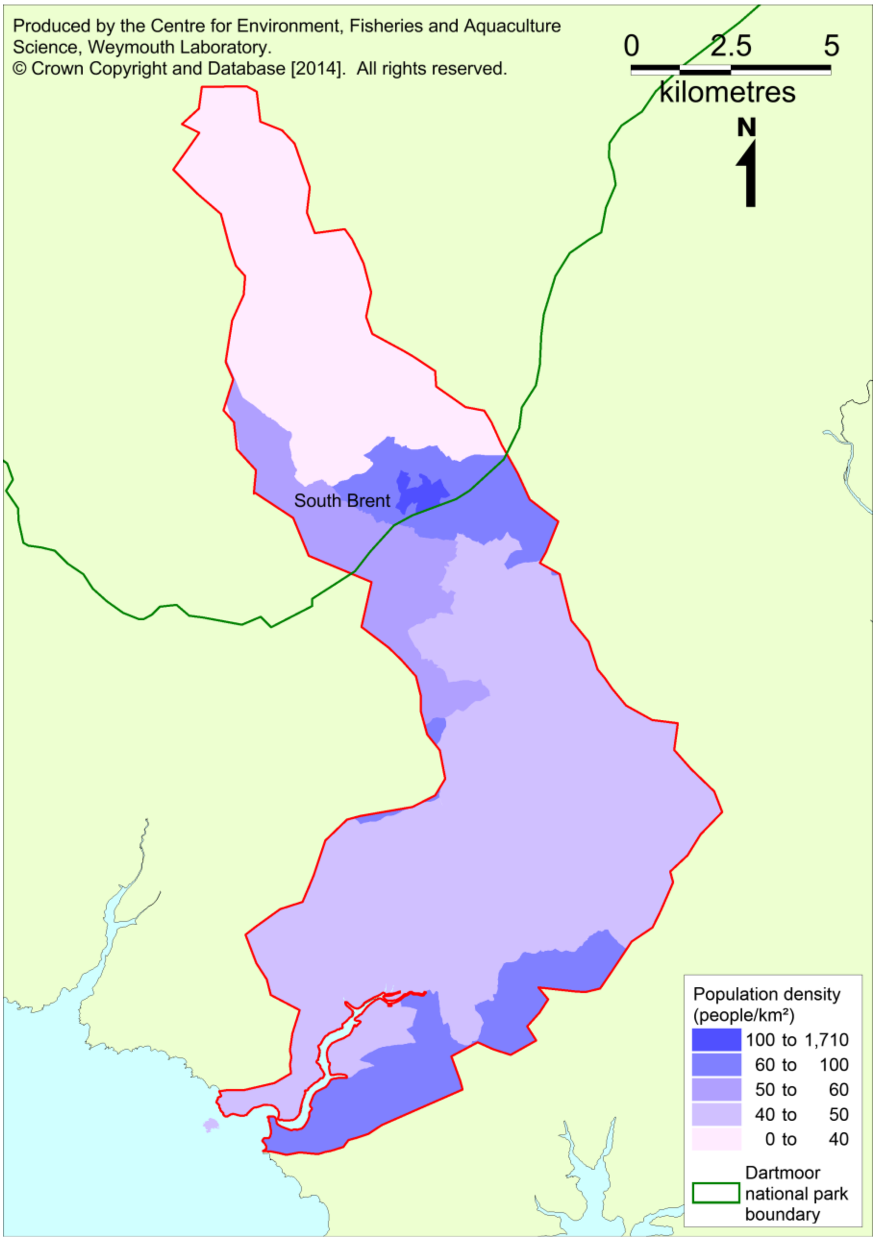


Figure I.1: Human population density in census areas in the Avon catchment.

Total resident population within the census areas contained within or partially within the catchment area was approximately 22,000 at the time of the 2011 census. The largest settlement in the catchment is South Brent, which had a population of approximately 2,600. The population in the far north of the catchment is relatively sparse due to the Dartmoor National Park which makes up around 30 % of the catchment's area. The population on the southern shore of the Avon estuary is marginally higher than the northern shore (60 people/km² compared to 47 people/km²).

The majority of the Avon catchment is within the South Hams district. In 2011, there were a total of 2,454,000 tourist nights in South Hams (Visit South Devon, 2012). Much of the area is within the South Devon area of outstanding natural beauty and 78 % of visitors in 2003 said that the quality of the environment was one of the key reasons for their visit (South West Tourism, 2004). Due to the outdoor nature of much of the attraction of the area, it is likely that the majority of visitors arrive during the summer months. It is therefore likely that there will be a significant seasonal fluctuation in population.

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

Details of all consented sewage discharges in the River Avon hydrological catchment were taken from the most recent update of the Environment Agency national permit database (October 2013). All sewage discharges are mapped in Figure II.1 and Figure II.2.

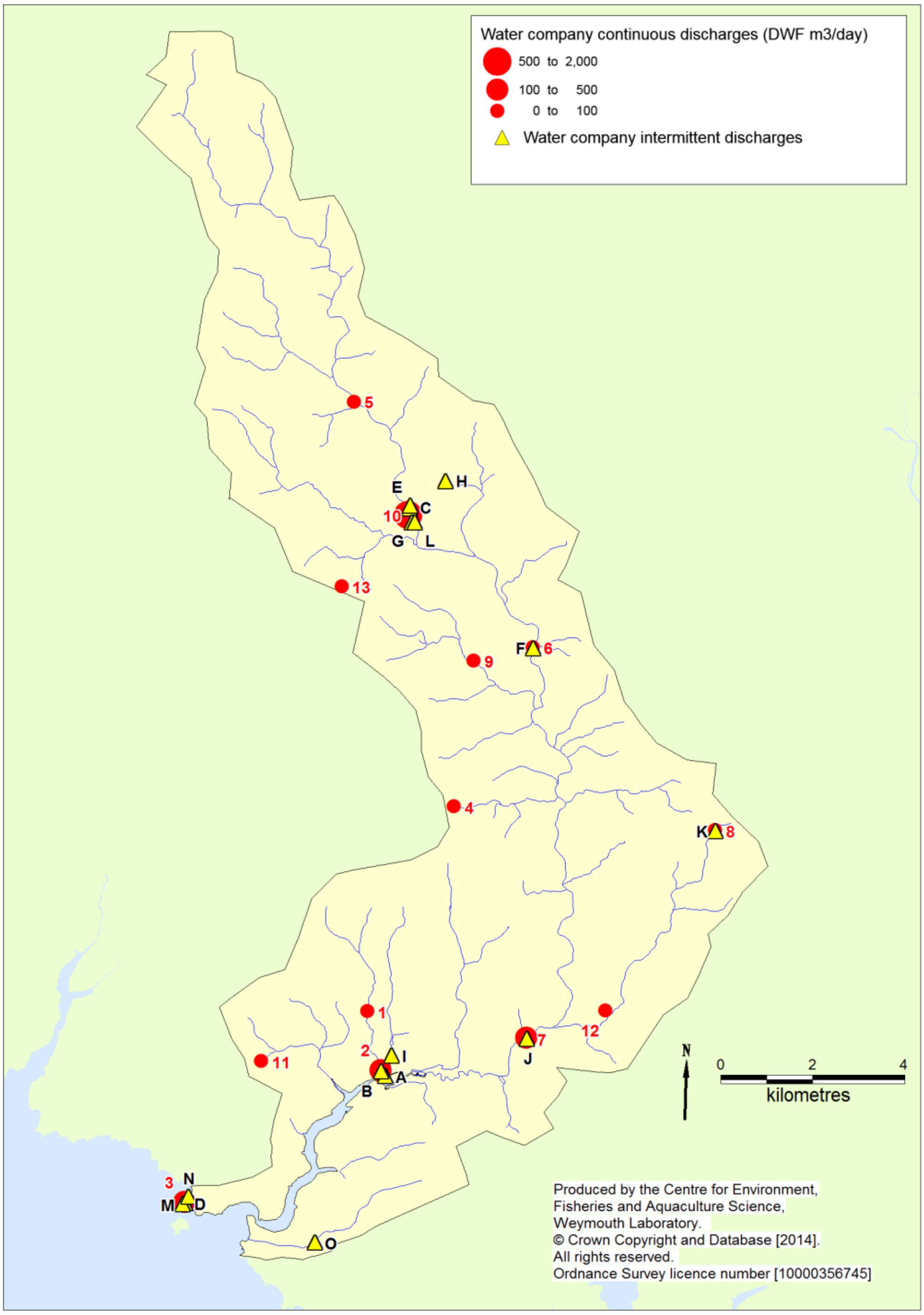


Figure II.1: All water company continuous and intermittent discharges in the River Avon catchment
Data from the Environment Agency

There are 13 water company sewage treatment works of potential relevance to the survey area, details of which are presented in Table II.1.

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	Ashford Farm STW	SX 68810 48590	Biological Filtration	4.9	1.62×10^{10}	Tributary of River Avon
2	Aveton Gifford STW	SX 69100 47290	UV Disinfection	306	2.35×10^{9}**	River Avon
3	Bigbury & Challaborough STW	SX 64830 44420	Biological Filtration	470	1.55×10^{12}	Bigbury Bay
4	California Cross STW	SX 70700 53050	Not specified	Not specified	-	Unnamed Watercourse
5	Didworthy STW	SX 68520 61870	Biological Filtration	13	4.29×10^{10}	River Avon
6	Diptford STW	SX 7242 056520	Biological Filtration	44	1.45×10^{11}	River Avon
7	Loddiswell STW	SX 72280 48000	Biological Filtration	197	3.50×10^{11}	River Avon
8	Moreleigh STW	SX 76380 52530	Land Irrigation	36	1.19×10^{11}	Tributary of Torr Brook
9	North Huish STW	SX711305 6230	Septic Tank	4	1.32×10^{10}	To land-Soakaway
10	South Brent STW	SX 69700 59400	Biological Filtration	509	1.68×10^{12}	River Avon
11	St Ann's Chapel STW	SX 66500 47500	Septic Tank	Not specified	-	Trib Of St Anns Chapel Stream
12	Woodleigh STW	SX 74000 48600	Biological Filtration	Not specified	-	Soakaway
13	Wrangaton STW	SX 68250 57850	Not specified	Not specified	-	Not Specified

*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)
Data from the Environment Agency

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	7.2×10^6
Primary (12)	127	1.0×10^7	14	4.6×10^6
Secondary (67)	864	3.3×10^5	184	5.0×10^5
Tertiary (UV) (8)	108	2.8×10^2	6	3.6×10^2

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

One continuous water company discharge, Aveton Gifford STW receives UV disinfection. Table II.3 and Figure II.2 summarise the results of bacteriological testing of the final effluent for Aveton Gifford STW.

Table II.3: Summary statistics for final effluent testing data from Aveton Gifford STW, January 2008 to December 2012

Sewage works	No.	Geometric mean result (faecal coliforms cfu/100ml)	Minimum	Maximum
Aveton Gifford STW	87	665	0	2.4×10^5

Data from the Environment Agency

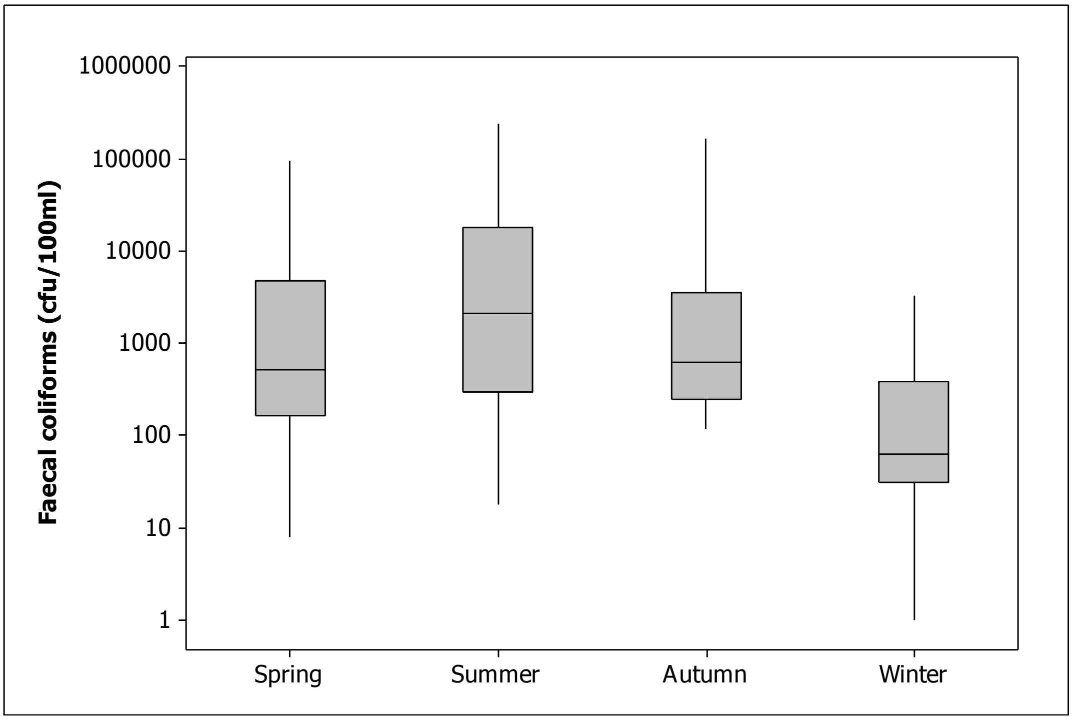


Figure II.2: Boxplot of faecal coliform concentrations in final effluent by season at Aveton Gifford STW

Data from the Environment Agency

Bacteriological testing results for the final effluent at Aveton Gifford STW indicate that disinfection is reasonably effective. The measured geometric mean for faecal coliform concentration it generates is 665 cfu/100ml, which is about twice the reference geometric mean for UV disinfected works (Table II.2). The maximum faecal coliform concentration recorded at Aveton Gifford over the period was 2.4×10^5 cfu/100ml, which is over three orders of magnitude higher than the average. Some seasonality in faecal coliform concentrations was observed at Aveton Gifford STW, with significantly lower concentrations in the winter than during the rest of the year. However, although this may mean overall concentrations are lower in winter, flows may increase during the colder months as more surface water typically enters sewers at this time of year. It must be noted that UV disinfection is less effective at eliminating viruses than bacteria (e.g. Tree *et al*, 1997).

Altogether there are 12 continuous water company sewage treatment works in the hydrological catchment, and a further one (Bigbury & Challaborough STW) to the foreshore at Bigbury, just outside the estuary mouth. Most are small, and only three have a consented dry weather flow exceeding 50 m^3/day, although consented flows are unspecified for five of these works. Aveton Gifford STW is the only one which discharges to estuarine waters, just below the tidal limit at the head of the estuary, about 3 km upstream of the fishery. Whether the effluent from Bigbury & Challaborough STW is carried into the estuary is dependent on patterns of water circulation in the area. The two discharging to soakaway (North Huish and Woodleigh STWs) should be of no influence. The others discharge to watercourses which feed into the estuary upstream of the fisheries, so RMPs set at the up-estuary end of the shellfishery are likely to be most effective at capturing contamination from them. The closer the discharges are located to the classification zone and the larger they are, the greater the microbiological impact will be. Depending on river transit times, some natural die-off of micro-organisms is likely to occur between the point of discharge and the shellfisheries.

In addition to the continuous sewage discharges, there are various intermittent discharges associated with the water company sewerage networks. Details of these are shown in Table II.4 and illustrated in Figure II.1. Those discharges highlighted in yellow have spill event duration monitoring, the results from which are summarised in Table II.5.

Table II.4: Intermittent discharges in the River Avon hydrological catchment

Label	Name	Grid reference	Receiving water	Type
A	Aveton Gifford PSCSO/EO	SX6919047190	River Avon Estuary (E)	Storm Overflow/ Storm Tank
B	Aveton Gifford STW	SX6910047290	River Avon Estuary(E)	Storm Overflow/ Storm Tank
C	Avondale House PSEO	SX6972059570	River Avon (S)	Pumping Station
D	Bigbury & Challaborough STW	SX6482044420	Bigbury Bay(C)	Storm Overflow/ Storm Tank
E	Brent Mill Slumberland CSO	SX6973059622	River Avon (S)	Storm Overflow
F	Diptford STW	SX7242056520	River Avon	Storm Overflow/ Storm Tank
G	Football Field CSO	SX6977059262	River Avon (S)	Storm Overflow
H	Heather Park PCSO	SX7051060160	Unspecified	Pumping Station
I	Jubilee Street CSO	SX6933047640	River Avon (S)	Storm Overflow
J	Loddiswell STW	SX7228048000	River Avon(S)	Storm Overflow/ Storm Tank
K	Moreleigh STW	SX7638052530	(S) Trib Of Torr Brook	Storm Overflow/ Storm Tank
L	South Brent STW	SX6984059260	River Avon (Devon)	Storm Overflow/ Storm Tank
M	The Warren PS	SX6478044400	Bigbury Bay (C)	Pumping Station
N	Warren Point PS	SX6490044570	Bigbury Bay (C)	Pumping Station
O	West Buckland PS	SX6766043560	Buckland Stream	Pumping Station

Data from the Environment Agency

Of the 15 intermittent sewage discharges listed on the database, all but four discharge to the very upper reaches of the estuary or watercourses draining to the estuary upstream of the fishery. There are three intermittent discharges to the shore at Bigbury, just to the west of the mouth of the estuary, and West Buckland PS discharges to a short watercourse that drains to the east shore of the estuary mouth. Only three of these intermittent discharges have spill monitoring (Table II.5).

Table II.5: Summary of spill events, 2007-2012

Discharge	Permit	2007		2008		2009		2010		2011		2012	
		Number of spills	**% time active**	**Number of spills**	**% time active**	**Number of spills**	**% time active**	**Number of spills**	**% time active**	**Number of spills**	**% time active**	**Number of spills**	**% time active**
Aveton Gifford STW CSO	202403	9	0.3%	14	0.68%	1	0.03%	8	0.52%	No spills		18	3.1%
Aveton Gifford PS CSO/EO	202383	No spills		No spills		No spills		No spills		No spills		6	0.8%
Jubilee Street CSO	202384	2	0.01%	No spills		No spills		No spills		No spills		9	0.48%

Data available from the Environment Agency at the time of writing

For those discharges with no spill monitoring, it is difficult to assess their significance to the shellfishery, apart from noting their location and potential to spill storm sewage. Aveton Gifford STW storm overflow, at the head of the estuary, was the most active of the monitored discharges, and spilled for 3.1 % of the year in 2012, although it did not spill at all in 2011. This asset has some potential to contribute to microbiological contamination at the shellfishery, although the low frequency of events suggest that this would not usually be captured during the course of a year's worth of monthly monitoring. The other two monitored intermittent discharges hardly spilled at all during the period considered.

Whilst the majority of the survey area is served by water company sewerage infrastructure, there are also a number of private discharges in the catchment. Where specified, these are generally treated by small treatment works such as package plants. Table II.6 details private discharges >4 m^3/day (max daily flow) and the locations of all consented private discharges are mapped in Figure II.3.

Table II.6: Details of private discharges over 4 m^3/day in the River Avon hydrological catchment

Label	Property served	Grid reference	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	5 Dwell. At Land Adjac.	SX6935047660	Unspecified	4.9	Unnamed trib of River Avon
B	9 Barn Conversions At Stanton Farm	SX7059050710	Biological Filtration	9	Tributary Of River Avon
C	Colmer Estate	SX7085753036	Tertiary Biological	10	Colner Brook
D	Combe Farm (10 Barn Convs. At)	SX6760048600	Unspecified	7	Tributary Of River Avon
E	Hexdown Barns STW	SX6702044860	Unspecified	4.2	Tributary Of River Avon
F	Ham Farm	SX7212049160	Package Treatment Plant	4.5	River Avon
G	Land Betw. Court Barton Fm & County	SX6940047800	Unspecified	4.68	Aveton Gifford Stream
H	Lower Yanston Farm	SX7106348698	Package Treatment Plant	4.6	Tributary Of River Avon
I	South Efford House	SX6903046850	Package Treatment Plant	9.6	Avon Estuary
J	The Mill Restaurant & Public House	SX6976058870	Package Treatment Plant	9.3	The River Avon
K	8 Dwellings At Former Monastery	SX7389049660	Package Treatment Plant	7.0	Soakaway
L	Avon Court	SX6608044570	Unspecified	5.25	Soakaway
M	Bonwitco Boat Builders	SX7475048490	Unspecified	4.5	Soakaway
N	Burgh Island	SX6476044040	Septic Tank	29	Soakaway
O	Capton Farm	SX7510051810	Septic Tank	4.5	Soakaway
P	Court Barton Farm (Barns)	SX6968047850	Unspecified	9	Soakaway

Label	Property served	Grid reference	Treatment type	Max. daily flow (m^3/day)	Receiving environment
Q	Elston Park	SX7034045270	Septic Tank	4.86	Soakaway
R	Farmhse & 4 Props. At North Upton	SX6844044680	Unspecified	4.6	Soakaway
S	Flats 1 - 9	SX6577044370	UV Disinfection	5	Soakaway
T	Higher Torr Farm & 4 Holiday Units	SX7482048590	Package Treatment Plant	5	Soakaway
U	House & Chalets Buckland Park	SX6890044640	Unspecified	5	Soakaway
V	Leigh Grange & 3 Barns Adjacent To	SX7079061120	Septic Tank	5	Soakaway
W	Nine Barn Conversions	SX7095050780	Biological Filtration	9	Soakaway
X	Seven Barn Conversions At Chilley	SX7616050830	Septic Tank	4.95	Soakaway
Y	Twelve Dwellings	SX7439050870	Unspecified	5	Soakaway
Z	Webland Farm & Caravan Site	SX7142059080	Package Treatment Plant	9.7	Soakaway

Data from the Environment Agency

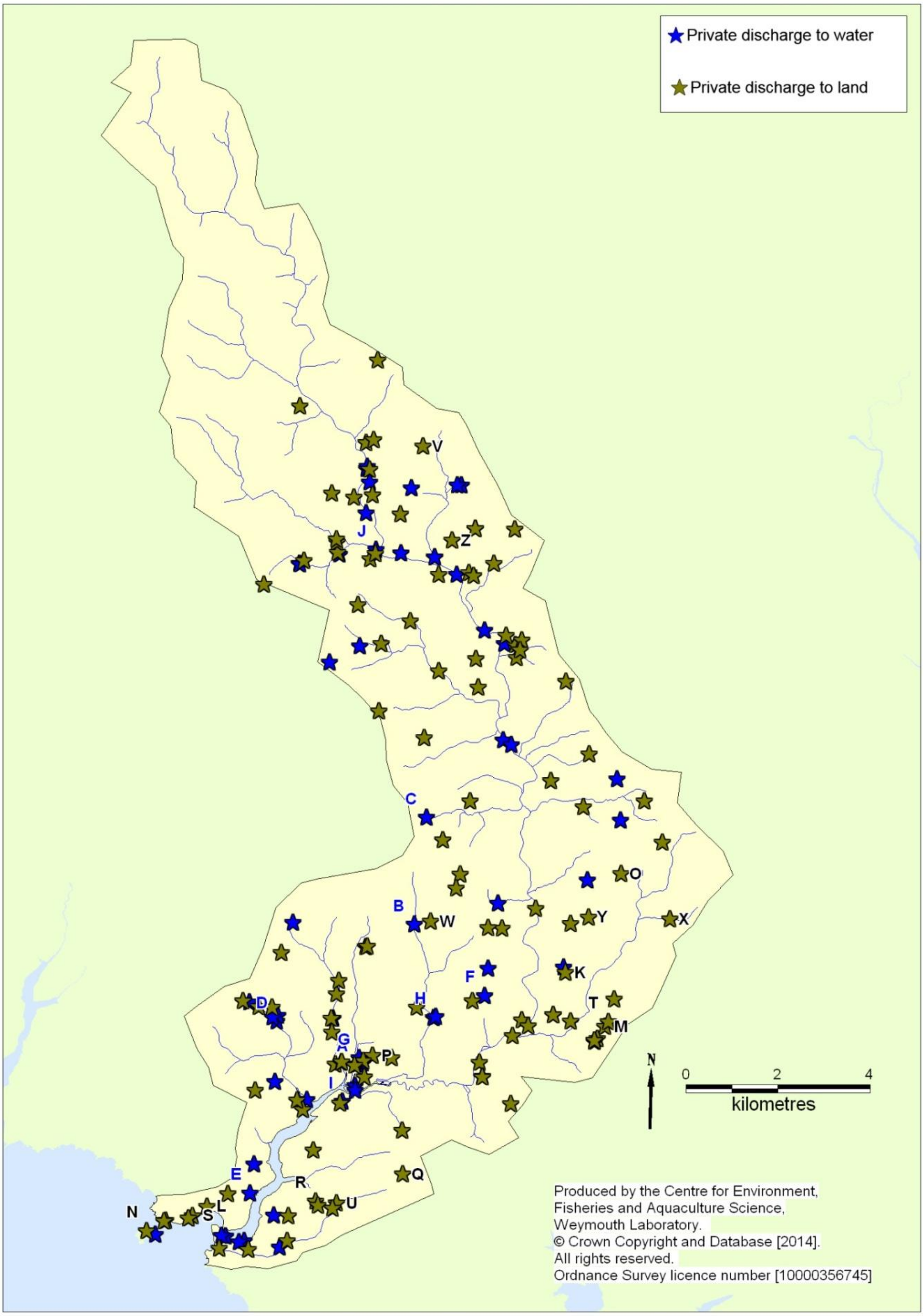


Figure II.3: Private discharges within the River Avon hydrological catchment
Data from the Environment Agency

There are 116 consented private discharges to soakaway and 55 discharging to water within the survey area. The vast majority are consented for maximum flows of less than 4 m^3/day. Those discharging to soakaway should be of negligible influence assuming they are functioning correctly. Those discharging to watercourse will make minor contributions to the bacterial loadings the watercourses deliver to coastal waters. Of those discharging to water, all but eight are to watercourses which drain to the estuary upstream of the fishery. Their spatial pattern of impacts will therefore be similar to that of the water company discharges, although the volumes involved are much smaller. Again, some die-off in transit is anticipated, particularly for those further inland. Of potential significance to the fishery, there is a package plant (Hexdown Barns) which is consented for a maximum flow of 4.2 m^3/day and discharges to a short watercourse that in turn drains to the west shore of the estuary between the two blocks of trestles there. This may have some influence at the shellfishery on the west bank. The barns provide holiday accommodation so are more likely to be fully occupied during holiday periods. There are also four small private discharges direct to the outer estuary at Bantham consented to discharge a combined maximum flow of 4.4 m^3/day of septic tank effluent. It is unlikely that these are of much influence outside of their immediate vicinity.

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

The majority of land within the Avon catchment is devoted to agriculture (Figure 1.2). It is a mix of pasture and arable land in the lower reaches, with the proportion of pasture increasing further inland. The upper reaches of the catchment are grassland and moorland, which will also be grazed to some extent. Table III.1 presents livestock numbers and densities for the catchment. These data were provided by Defra and are derived from the June 2010 census as this provides more details than censuses undertaken in 2011 and 2012. Geographic assignment of animal counts in this dataset is based on the allocation of a single point to each farm, whereas in reality an individual farm may span the catchment boundary. Nevertheless, Table III.1 should give a reasonable indication of the numbers and types of livestock within the catchment.

Table III.1: Summary statistics from 2010 livestock census for the Avon catchment

Cattle		Sheep		Pigs		Poultry	
No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)
10,507	73	25,172	174	343	2.4	55,028	381

Data from Defra

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.

Animal	Faecal coliforms (No./g wet weight)	Excretion rate (g/day wet weight)	Faecal coliform load (No./day)
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).

Table III.1 indicates that there are large numbers of both cattle and sheep within the catchment, as well as some poultry farms and a few pigs. Hardly any livestock were observed during the shoreline survey, but the vegetation and topography would likely have obscured most of the adjacent fields from view.

Contamination of livestock origin will either be deposited directly on pastures by grazing animals, or collected from operations such as cattle sheds and poultry houses and spread on both arable land and pasture. This in turn will enter watercourses which will carry it to coastal waters. Watercourses which animals can access will be more vulnerable than those that are fenced off. Given the ubiquity of farmland throughout the survey area, all watercourses are likely to be affected to some extent. Some of the streams local to the shellfishery had been identified as subject to livestock poaching including those at Hexdown and Lower Aunemouth, and have been fenced off under the Catchment Sensitive Farming initiative (Environment Agency, pers comm.).

The geographical pattern of agricultural impacts are likely to closely mirror those of land runoff, with increasing influence towards the head of the estuary, and potential hotspots where smaller watercourses join the lower estuary. As the primary mechanism for mobilisation of faecal matter deposited on pastures into watercourses is via land runoff, fluxes of agricultural contamination into coastal waters will be highly rainfall dependent. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the 'first flush').

There is likely to be seasonality in levels of contamination originating from livestock. Numbers of cattle will increase significantly in the spring, with the birth of calves, and decrease in the autumn when animals are sent to market. During the warmer months, livestock are likely to access watercourses m ore frequently to drink and cool off. 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. Other manures and sewage sludge may be spread at any time of the year. Therefore peak levels of contamination from 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 may be more likely in winter or spring.

A report produced by ADAS (2003) examined agricultural practices within the catchment as part of an investigation of fluxes of faecal indicator bacteria into the estuary. This study concluded that the bulk of faecal matter deposited on agricultural land was via direct defecation on pastures, but there were also significant amounts of slurry/manure spread on arable land and pasture. There was strong seasonality in the amount of faecal matter applied to or deposited on agricultural land, which was lowest from November to March, and peaked in August and September.

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 Bigbury and Avon survey area. Boat traffic in the area is limited to smaller recreational craft such as yachts, sailing dinghies and kayaks. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources.

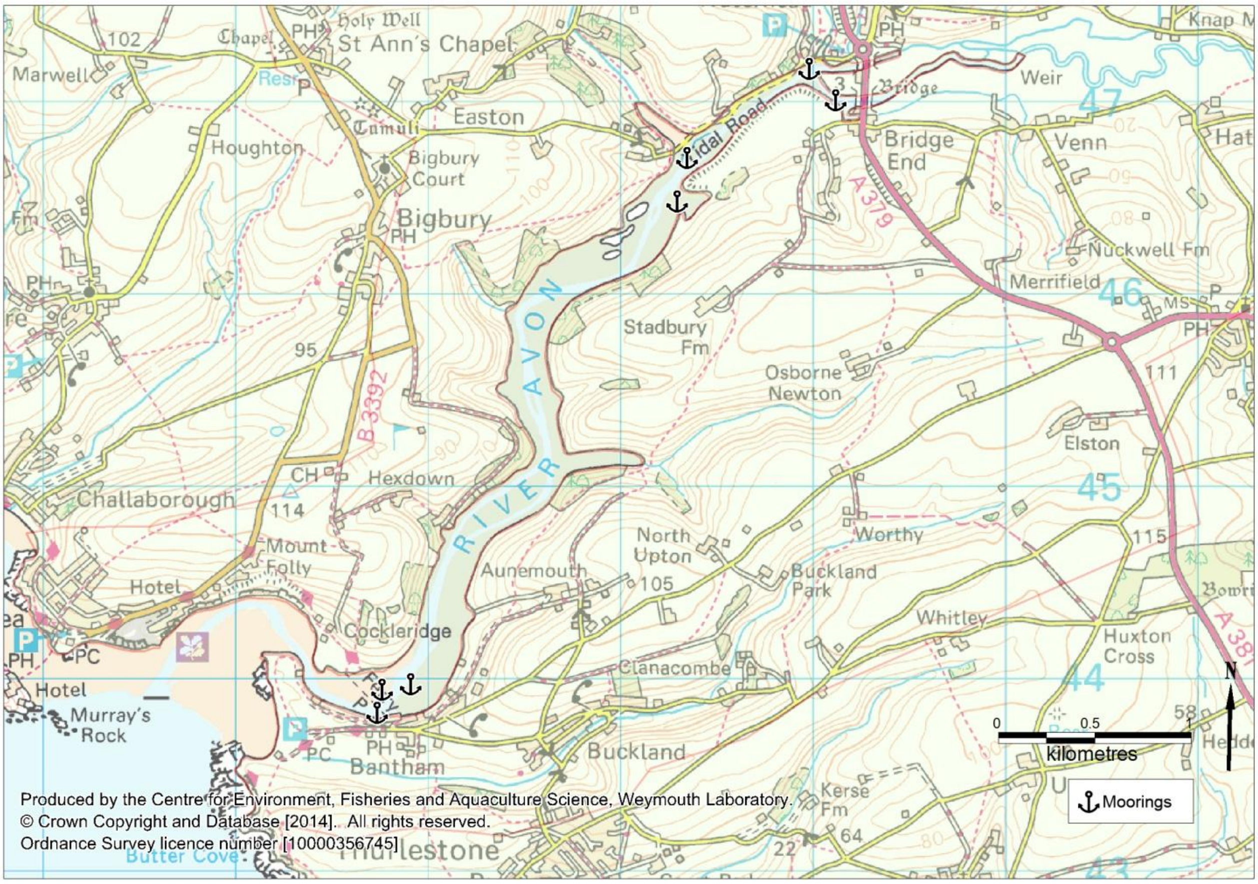


Figure IV.1: Boating Activity in the Bigbury and Avon

There are no commercial ports, harbours or marinas within the survey area and consequently there are no sewage pump-out facilities; the closest are located in the Yealm estuary (The Green Blue, 2010). There are however numerous moorings and anchorages located throughout the Avon for recreational craft, the locations of which are shown in Figure IV.1. Watersports such as windsurfing, kitesurfing and surfing takes place at Bigbury-on-Sea and Bantham beaches and kayaking takes place on the tidal River Avon. A small passenger ferry also runs between Bantham and Cockleridge Ham.

Commercial fishing is limited within the survey area as a result of it being both a several fishery and a bass nursery area. Netting is prohibited all year round and permissions to fish via a boat between 30th April and 1st January must be granted by the Duchy of Cornwall (ACA, 2009). Consequently very few vessels are likely to engage in fishing within the estuary.

Smaller pleasure craft will not have onboard toilets and so are unlikely to make overboard discharges. Private vessels such as yachts and motor cruisers of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the area. Therefore, whilst overboard discharges may be made anywhere within the survey area, it is likely that the moorings and the main navigation routes through the area are most at risk of contamination from this source.

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 Avon estuary encompasses a variety of habitats including intertidal mudflats, saltmarsh, grassland and sandy beaches at Bantham and Bigbury-On-Sea. These features attract significant populations of birds and other wildlife. Parts of the Avon and its surrounding areas have been designated as a cSAC, SSSIs, Nature Reserves, and form part of the South Devon Area of Outstanding Natural Beauty (AONB). The Devon Avon estuary has also been recommended as a Marine Conservation Zone (MCZ).

The most significant wildlife aggregation in terms of shellfish hygiene is most likely to be overwintering waterbirds (waders and wildfowl). 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). The British Trust for Ornithology online Wetland Bird survey results (BTO, 2014) indicate that the 5 year average in peak bird counts is only 2155 birds, so it is concluded that the Avon estuary is not as attractive to birds as other similar estuaries where counts are typically much higher. On the shoreline survey small aggregations of birds (predominantly gulls) were observed throughout the Avon estuary in particular roosting on uncovered sand banks. In addition to this around 20 swans were observed on the marsh in the north east of the Avon estuary.

Geese and ducks will mainly frequent the saltmarsh and coastal grasslands, 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 and watercourses draining pasture will be best located to capture contamination from such birds. Waders, such as dunlin and oystercatchers forage upon shellfish and so will forage directly on invertebrates in intertidal areas. They may tend to aggregate in certain areas holding the highest densities of prey 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 more undisturbed and isolated areas. 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.

Some waterbirds will remain in the area to breed in the summer, but most are likely to migrate elsewhere outside of the winter months. Bird numbers and potential impacts on the hygiene status of the fisheries are therefore lower during the summer. There are resident and breeding seabird populations in the area (gulls, terns, etc.).

The JNCC Seabird 2000 census recorded 72 breeding pairs of gulls, cormorants, shags and fulmar around the mouth of the estuary (Mitchell et al, 2004). These seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. As this is not in the immediate vicinity of the fishery, their presence will have no influence on the sampling plan.

There are no major seal colonies in the vicinity of the survey area (SCOS, 2012), so whilst seals may enter the estuary from time to time they are unlikely to be a significant source of contamination to the shellfishery. Otters have been sighted in the area very occasionally (Devon Mammal Group, 2014) but given their very low numbers they are of no influence on the sampling plan. No other wildlife species which may have a bearing on the sampling plan have been identified.

Appendix VI. Meteorological Data: Rainfall

The Hope Cove weather station, received an average of 836 mm of rain per year between 2003 and 2012. Figure VI.1 presents a boxplot of daily rainfall records by month at Hope Cove.

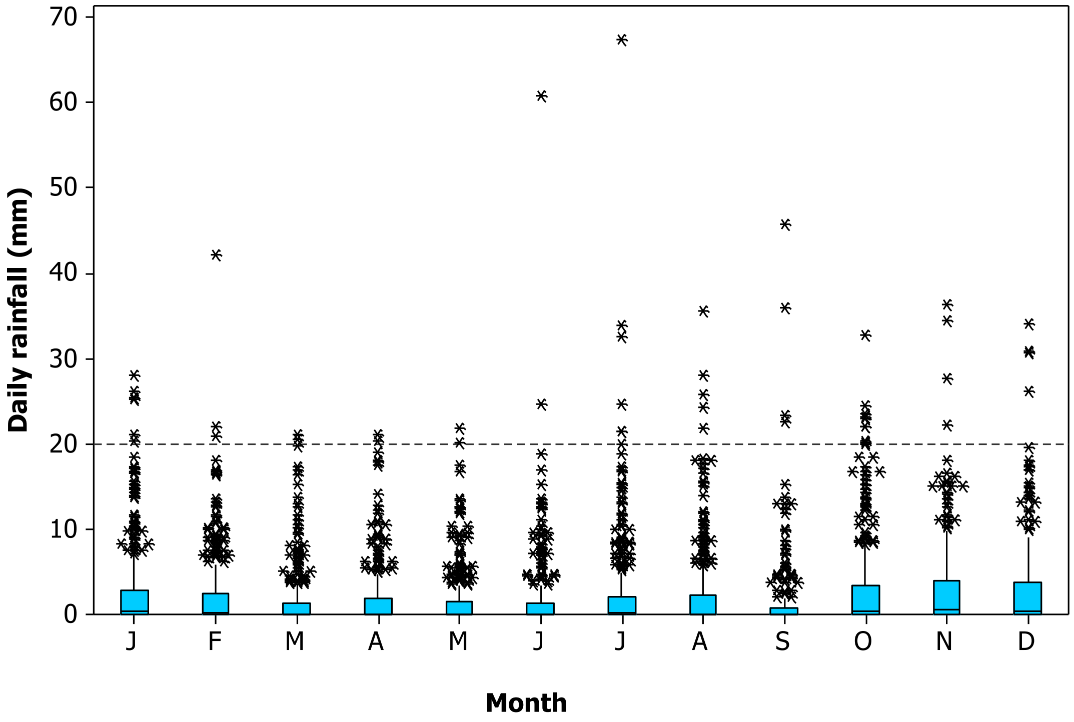


Figure VI.1: Boxplot of daily rainfall totals at Hope Cove, January 2003 to December 2012.
Data from the Environment Agency

Rainfall records from Hope Cove, which is representative of conditions in the vicinity of the shellfish beds indicate some seasonal variation in average rainfall with less rainfall from March to June and low rainfall in September. Rainfall was lowest on average in September and highest on average in October and November. Daily totals of over 20 mm were recorded on 1.4 % of days and 50 % of days were dry. High rainfall events occurred in all months, but were more frequent in the second half of the year. The hydrological catchment extends some distance inland into an area of high relief (Dartmoor). Moist air that is forced up the hills may be cooled to the dew point, which produces cloud and rain. Annual rainfall on Dartmoor is about 2000 mm (NERC, 2012).

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

South-west England is one of the more exposed areas of the UK, with wind speeds on average only greater in western Scotland (Met Office, 2012). The strongest winds are associated with the passage of deep depressions across or close to the UK. The frequency of depressions is greatest during the winter months so this is when the strongest winds normally occur.

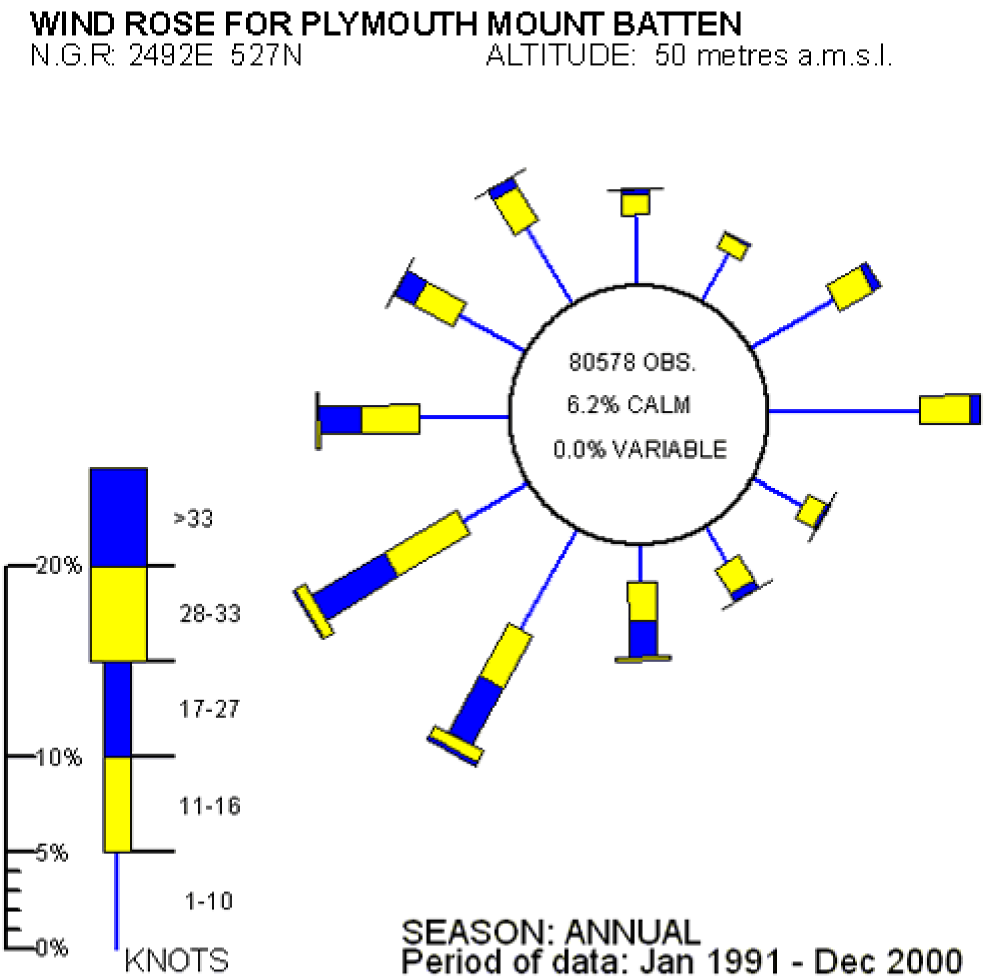


Figure VII.1: Wind Rose for Plymouth Mount Batten
Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The wind rose for Plymouth is typical for coastal locations in the south west of England, and confirms a prevailing south westerly wind throughout the year. During spring there is also a high frequency of north-easterly winds due to a build up of high pressure over Scandinavia (Met Office, 2012). Periods of very light or calm winds are more prevalent inland, with coastal areas having similar wind directions to inland locations but higher wind speeds. The Avon estuary faces south west into the English Channel and is therefore exposed to the prevailing winds which will be funnelled up the estuary, however the shape of the estuary mouth will prevent south westerly swells from penetrating as far as the fishery.

Appendix VIII. Hydrometric Data: Freshwater Inputs

The survey area has a catchment area of 145 km^{2,} the majority of which (~85%) drains to the head of the estuary. As the majority of the catchment drains to the head of the estuary, highest concentrations of faecal indicator bacteria deriving from land runoff are anticipated in the upper reaches of the estuary. The smaller watercourses entering the estuary in the vicinity of the fisheries will be of more localised significance and may cause hotspots of contamination where they enter the estuary.

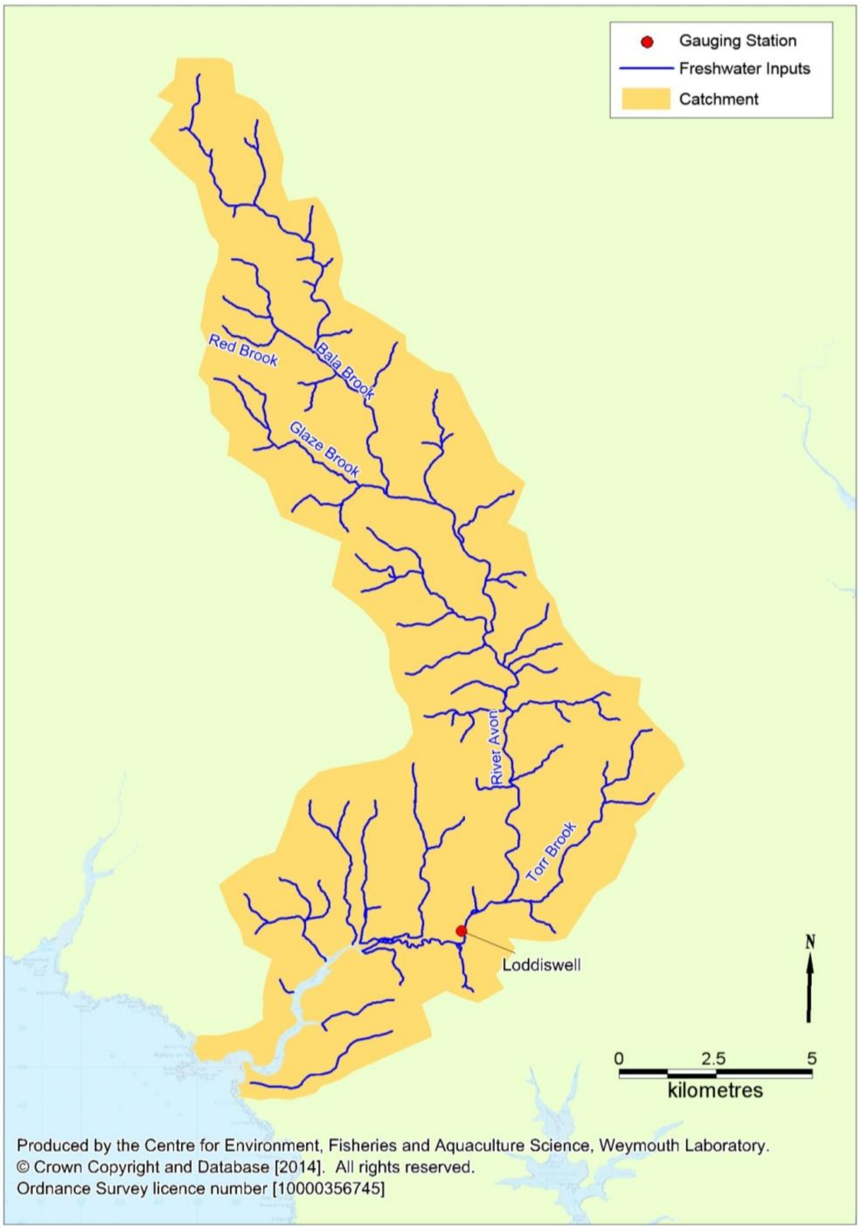


Figure VIII.1: Freshwater inputs into the Avon estuary

The main freshwater input is the Avon, which is about 37 km in length, and originates on Dartmoor at an altitude of around 460 m. It initially flows through steep sloping valleys of impermeable granite then through more gently sloping valleys comprising of Devonian and carboniferous deposits in the lower catchment. The hydrogeology is categorised as of very low permeability throughout (NERC, 2012). The River Avon discharges to the head of the estuary at Aveton Gifford. Land within the catchment area is mainly in agricultural use. The lower catchment is a mixture of arable and pasture, the middle reaches are mainly pasture with some arable land, and the upper reaches are grassland and moorland where extensive grazing takes place. A very small percentage of the catchment is urbanised, although most of the larger watercourses receive some sewage inputs. As such, the watercourses draining to the estuary are all likely to carry contamination of mainly agricultural origin. The relatively high gradients and impermeable geology suggests that a large proportion of rainfall will run off, and the watercourses will respond rapidly to rainfall. There is one river gauging station, on the lower Avon at Loddiswell. Summary statistics for this gauging station are presented in Table VIII.1. Data for mean flow, Q95 and Q10 cover the period from 2003 - 2013.

Table VIII.1: Summary flow statistics for the Loddiswell gauging station draining into the Avon survey area

Watercourse	Station Name	Catchment Area (km²)	Mean Annual Rainfall 1961 - 1990 (mm)	Mean Flow (m^3s^{-1})	Q95[1] (m^3s^{-1})	Q10[2] (m^3s^{-1})
Avon	Loddiswell	102.3	1560	3.709	0.583	8.344

Data from NERC (2012) and Environment Agency

Spate flows (Q10) are quite high relative to base flows (Q95) indicating the river responds rapidly to rainfall, which is characteristic of watercourses fed largely by surface run off. Figure VIII.2 presents boxplots of mean daily flows by month.

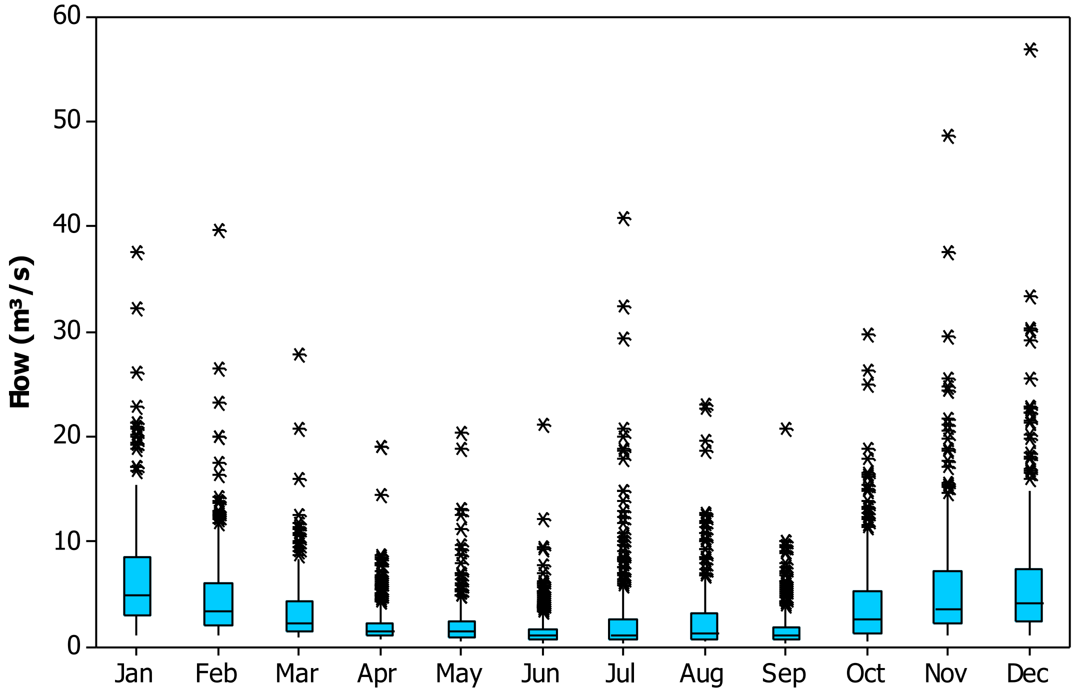


Figure VIII.2. Boxplots of mean daily flow records from the Loddiswell gauging station on the Avon watercourse (2003 – 2013)
Data from the Environment Agency

Flows were higher on average from October through to March, with a much smaller secondary peak in August. High flow events (exceeding 10 m^3/sec) were recorded in all months of the year, but they were more frequent and of a higher magnitude from October to February and in July. 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, watercourses which could be safely accessed were sampled for *E. coli* and spot flow measurements were taken, from which estimates of the bacterial loading that each was delivering at the time were made. The survey was conducted under dry conditions but previous to this there had been a prolonged period of heavy rain. Table VIII.2 and Figure VIII.3 present the results of these measurements.

Table VIII.2: *E. coli* sample results, measured discharges and calculated *E. coli* loadings for flowing freshwater inputs

Reference	Description	*E. coli* concentration (CFU/100 ml)	Flow (m^3s^{-1})	*E. coli* loading (CFU/day)
A	River Avon	4,600	29.000	1.15×10^{14}
B	River Avon	11,000	17.430	1.66×10^{14}
C	Stream	70	0.462	2.79×10^{10}
D	Stream	3,300	0.216	6.17×10^{11}
E	Stream	2,800	0.822	1.99×10^{12}
F	Stream	5,600	1.376	6.66×10^{12}
G	Stream	70	0.032	1.95×10^{9}
H	Stream	1,000	0.051	4.45×10^{10}
I	Culvert	130	0.030	3.34×10^{9}
J	Spring	<10	2.0×10^{-4}	8.64×10^{5}
K	Stream	8,000	0.006	4.13×10^{10}
L	Stream	100	0.266	2.30×10^{10}
M	Stream	20	0.042	7.26×10^{8}
N	Stream	50	0.003	1.29×10^{8}
O	Drainage sluice from marsh	130	1.227	1.38×10^{11}

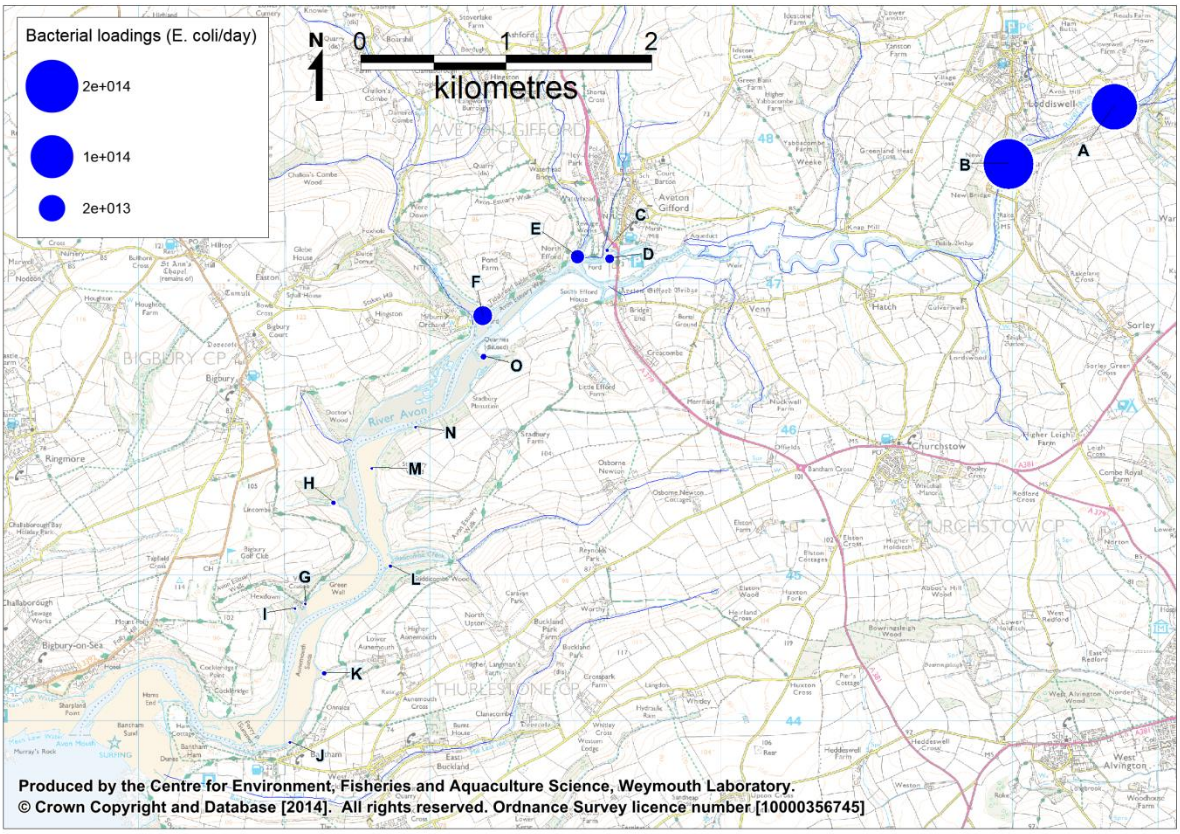


Figure VIII.3: Measured bacterial loadings of freshwater inputs to the estuary

These observations indicate that the Avon is a major source of contamination to the estuary, delivering a bacterial loading of about 1.7×10^{14} *E. coli*/day at the time of survey, representing about 95 % of the measured bacterial loadings. There were several further significant inputs to the upper reaches of the estuary. None of the smaller measured watercourses discharging to the middle and lower reaches of the estuary were delivering bacterial loadings exceeding 10^{11} *E. coli*/day, so will only be of localised significance. The two minor freshwater inputs discharging between the two blocks of trestles on the west bank were delivering a loading of 5.3×10^{9} *E. coli*/day between them. These results should however be treated with some caution as they are single measurements which only reflect the conditions at the time of survey.

Appendix IX. Hydrography

IX.1. Bathymetry

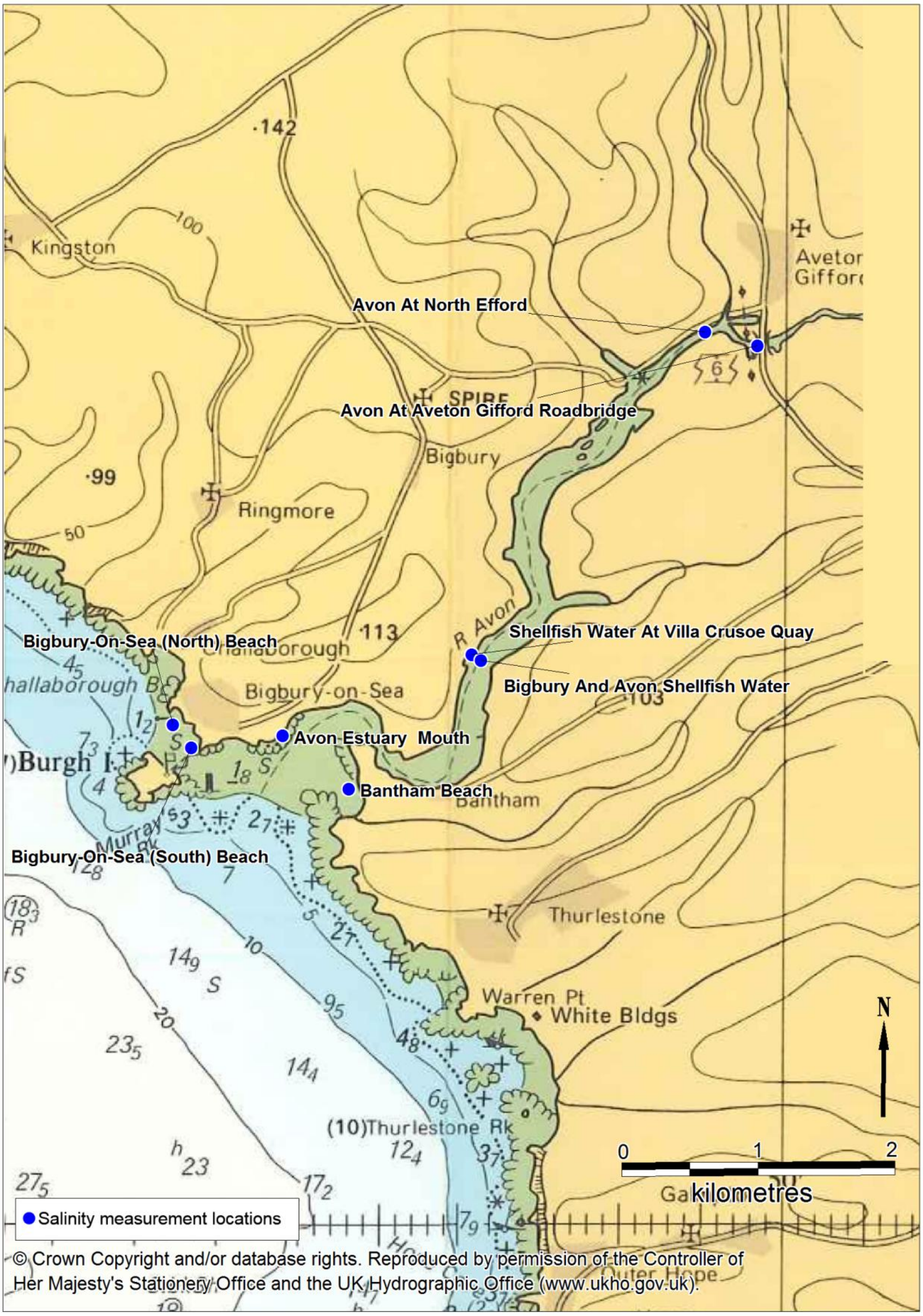


Figure IX.1: Bathymetry of the River Avon and Bigbury Bay

The Avon estuary is a meandering drowned river valley which covers an area of 2.14 km², of which 68 % is intertidal (Futurecoast, 2002). It is about 7.8 km in length, and relatively uniform in width (around 200-300 m), although the upper reaches narrow towards the tidal limit, the mouth opens out at Bantham and Bigbury beaches and there is a marked constriction at Cockleridge. It consists of a shallow subtidal river channel which is generally less than 2 m in depth, flanked by intertidal areas. There are several minor watercourses which drain to small creeks and embayments off the main channel, and then follow drainage channels though the intertidal to the main river channel. It lies in a steep sided valley and is a largely natural water body, apart from an area of reclaimed land in its upper reaches (South Efford Marsh), which is now being allowed to revert to saltmarsh through controlled tidal inundation. Intertidal sediments are sandy through the lower and middle reaches, but become muddier in the upper reaches suggesting a reduction in current speeds in the upper estuary. Throughout the estuary sediment within the deep water channel are generally coarser than those found on the intertidal area, which is indicative of higher flow rates in the main channel (Uncles *et. al*, 2007).

Given its shallow nature, a large proportion of water will therefore be exchanged each tidal cycle, but dilution potential will be low. There is a constriction at Cockleridge, just inside the estuary mouth where it narrows to about 60 m where there may be increased potential for turbulent mixing of the water column. There is also a very pronounced meander here that will afford the estuary protection from the prevailing south westerly winds and swells. Burgh Island lies just to the west of the estuary mouth, about 250 m off Bigbury, and is separated from the mainland by an intertidal area. Tidal streams will therefore only pass inshore of the island at higher states of the tide.

IX.2. Tides and Currents

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. Both the River Yealm and Salcombe situated to the west and east of Bigbury are macrotidal, with tidal ranges exceeding 4 m on spring tides. Tidal ranges are slightly smaller in the vicinity of the Avon estuary, and decrease from 3.7 m on spring tides at Bantham beach (estuary mouth) to 3.0 m at Bantham (lower estuary) and then to 1.5 m at North Efford in the upper estuary (Uncles *et. al*, 2007).

Table IX.1 Tidal levels and ranges either side of the Avon estuary

	Height above chart datum (m)				Range (m)	
Port	MHWS	MHWN	MLWN	MLWS	Spring	Neap
River Yealm Entrance	5.4	4.3	2.1	0.7	4.7	2.2
Salcombe	5.3	4.1	2.1	0.7	4.6	2.0

Data from Admiralty Totaltide

Advection of pollutants by tidal currents is the main mode of contaminant transport in the area. Within the English Channel, offshore tidal streams move eastwards on the flood, and ebb in a westerly direction. Contamination from sources discharging to the shore to the west of the estuary may be carried in on the flood tide, but sources to the east will be carried past the estuary mouth rather than into the estuary as the tide ebbs. However, it is possible that eddies may form within Bigbury Bay and around the mouth of the estuary on various scales and at certain states of the tide which will complicate circulation patterns. Also, tidal streams will only be able to pass inshore of Burgh Island at higher states of the tide.

Within the estuary itself, tidal streams will move up on the flood, and out on the ebb, and the main stream will follow the main estuary channel. As the channel fills, water will spread over the intertidal areas and move up any side channels and creeks. The opposite will occur on the ebb. 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.

There are no tidal diamonds either around the mouth or within the estuary to confirm the directions and strengths of tidal streams, or to allow estimations of tidal excursions to be made. A series of current measurements were made as part of a study into sediment movements within the estuary (Uncles *et. al*, 2007). Peak current velocities at Bantham in the lower estuary were 1 m/s on the ebb tide and 0.8 m/s on the flood tide. They were slightly slower in the upper estuary at North Efford, peaking at 0.7 m/s on the flood and 0.5 m/s on the ebb. A particle tracking model simulated the movements of bacteria released to the upper estuary under various tidal and river discharge conditions (ADAS, 2003). Results indicated that the time taken for a particle to reach the shellfishery varied from 2h 25m to 14h 40m depending on the conditions, and that river discharge was responsible for most of the variation in transit times. The duration of exposure to the plume of bacteria will decrease with distance downstream as transit times increase so the up-estuary ends of the shellfishery will generally be more heavily impacted. At times the plume front will only reach the up-estuary end of the shellfishery before the tide reverses and it is carried back up. Under such conditions there may be a marked increase in *E. coli* in the water column towards the upstream end of the fishery, although it is difficult to predict how frequently this may occur.

Superimposed on tidally driven currents, are the effects of freshwater inputs and wind. The average and maximum flow ratios (volume of freshwater input:tidal exchange) are 0.018 and 0.301 suggesting stratification may occur at times of higher river discharge. Stratification results in a net seaward movement of less dense fresher water on the surface, with a corresponding return of more saline water at depth. Vertical salinity profiling under low river discharge conditions showed no stratification at Bantham. Strong stratification was recorded at North Efford during the ebb tide, when surface currents were much stronger than bed currents. Salinity through the water column here was almost homogeneous on the flood with no vertical shear in current speeds (Uncles *et al*, 2007).

As land runoff typically contains higher levels of faecal indicator bacteria than seawater, salinity may be a useful indicator of levels of freshwater borne contamination. An overall gradient of decreasing salinity towards the head is typical within estuaries such as the Avon, and the associated geographic variation in levels of *E. coli* are often key considerations when developing shellfish hygiene sampling plans. Box plots of near surface salinity measurements are presented in Figure IX.2 (sampling locations in Figure IX.1).

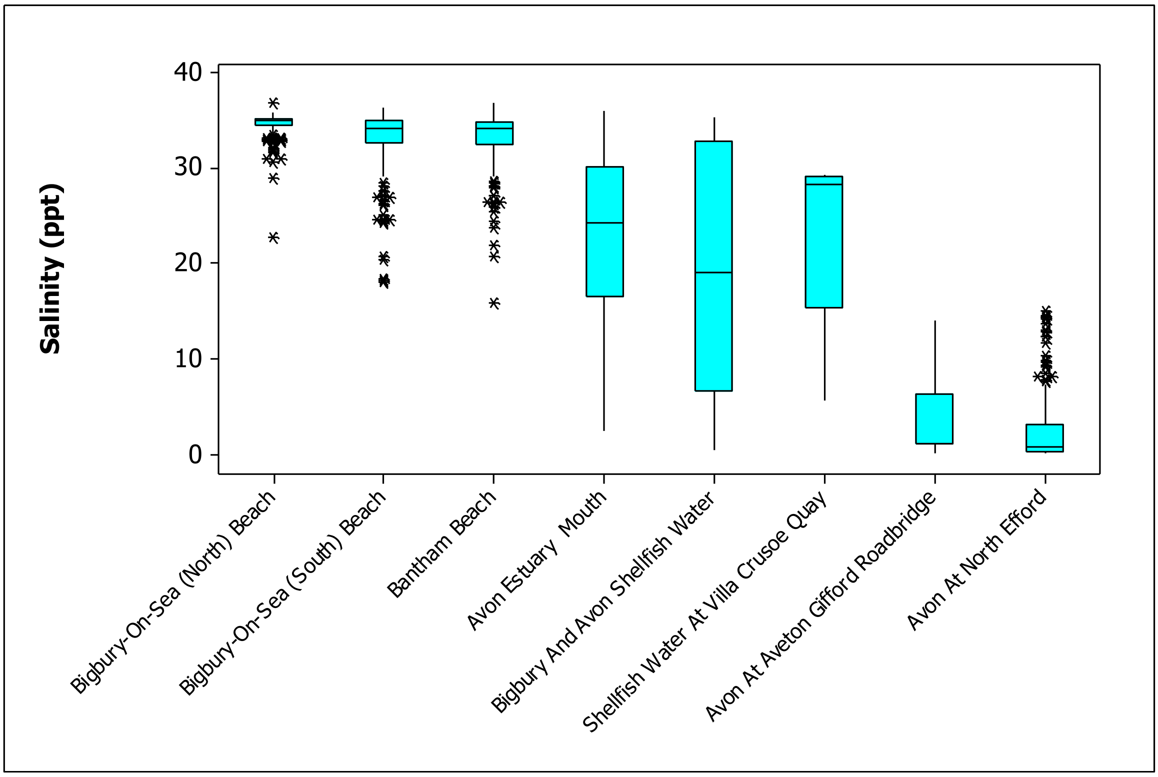


Figure IX.2: Boxplot of salinity readings from various locations within the estuary
Data from the Environment Agency

The average salinity was approaching that of full strength seawater on the beaches just outside the estuary mouth, then decreased to 22.6 ppt at Estuary Mouth, then to 19.0 ppt at the shellfish water, then down to less than 5 ppt at the two upper estuary sites. Salinity was most variable at the shellfish water site, and this variation was largely related to tidal state across the high/low tidal cycle (Figure IX.3) and to a lesser extent the spring/neap tidal cycle (Figure IX.4).

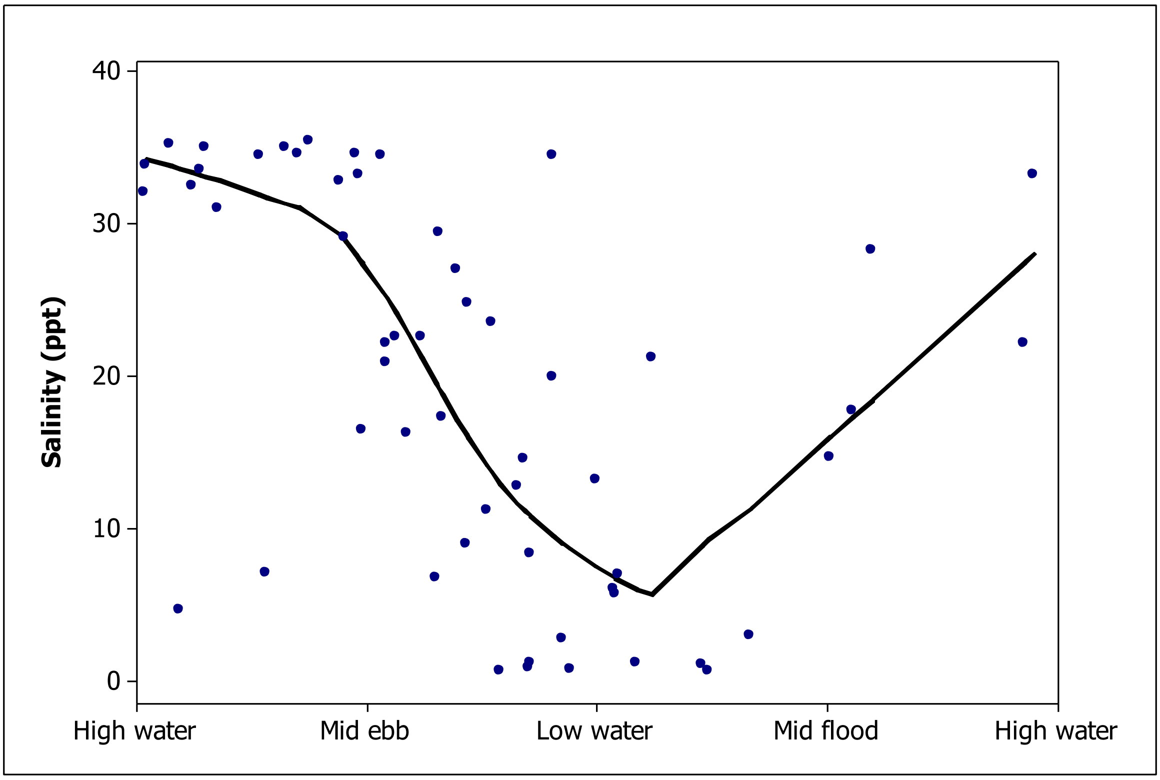


Figure IX.3: Scatterplot of salinity against tidal state (high/low cycle) at the shellfish water, overlaid by loess line
Data from the Environment Agency

Occasionally, low salinities were recorded at the shellfishery at higher states of the tide, presumably when river discharge was highest. Also, some high salinities were recorded around low water, suggesting that the plume of fresher water is not always carried as far down as the shellfishery by the ebbing tide.

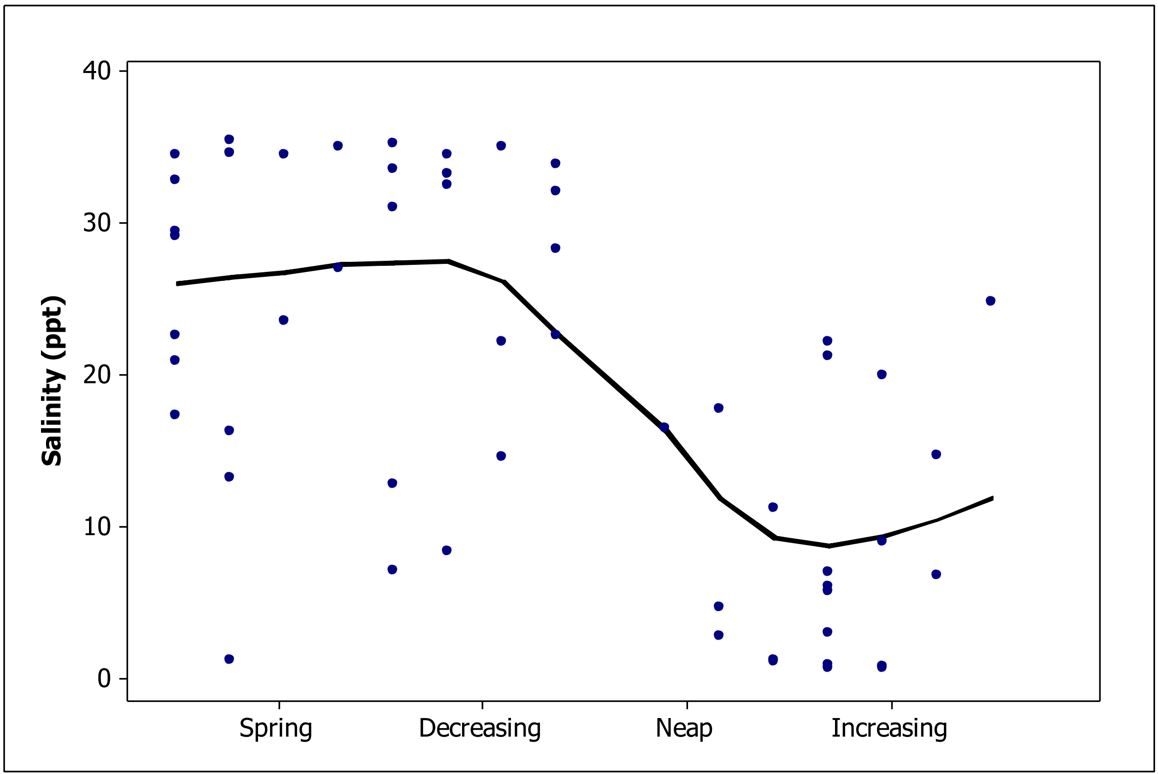


Figure IX.4: Scatterplot of salinity against tidal state (spring/neap cycle) at the shellfish water, overlaid by loess line
Data from the Environment Agency

Salinity was higher on average but more variable on the spring tides. This is likely to be a consequence of the increased flushing the estuary is subject to on the larger tides.

Strong winds will modify surface currents. Winds typically drive surface water at about 3 % of the wind speed (Brown, 1991) so a gale force wind (34 knots or 17.2 m/s) would drive surface water currents of about 0.5 m/s. These create return currents which may travel lower in the water column or along sheltered margins. The estuary is afforded some protection from the prevailing south westerly winds, but the steep valley it lies in will tend to funnel winds from this direction up it, and so push surface water in an upstream direction. 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 re-suspended. Given the shape of the estuary mouth, swells from the English Channel will not penetrate past Cockleridge.

Appendix X. Microbiological Data: Seawater

X.1. Bathing Waters

There are three bathing waters in the Avon estuary designated under the Directive 76/160/EEC (Council of the European Communities, 1975). Some additional sampling to assess the quality of recreational water was carried out at a three further points (Estuary Mouth, North Efford and Aveton Gifford Road bridge). Due to changes in the analyses of bathing water quality by the Environment Agency from 2012, only data produced up to the end of 2011 were used in these analyses.

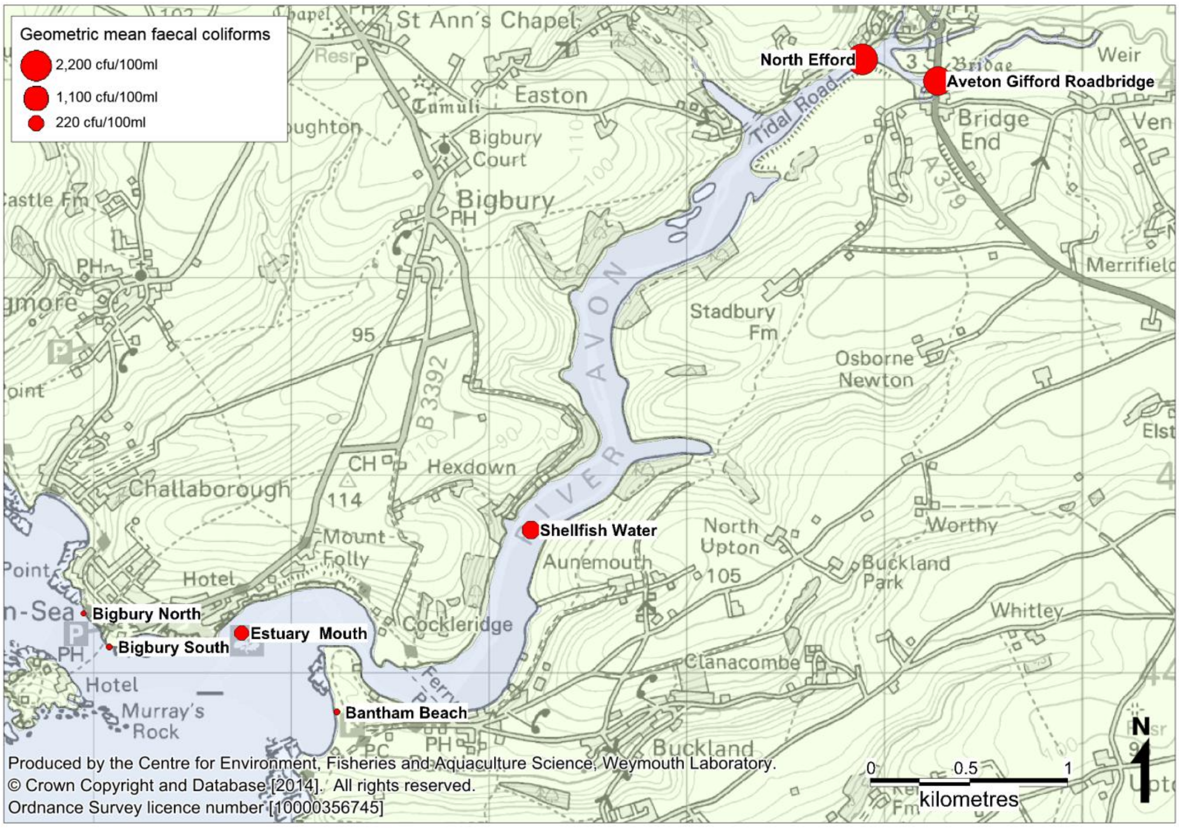


Figure X.1: Location of bathing waters and shellfish waters monitoring points.
Data from the Environment Agency

Around twenty water samples were taken from each of these sites during each bathing season, which runs from the 15th May to the 30th September. Faecal coliforms (presumptive) were enumerated in all these samples. Summary statistics of all results by site 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 (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
Bigbury North	182	01/05/2003	23/09/2011	5.8	<2	1120	6.6%	0.5%	0.0%
Bigbury South	185	01/05/2003	23/09/2011	11.5	<2	1760	17.3%	1.6%	0.0%
Bantham Beach	195	07/04/2003	15/11/2011	11.5	<2	14000	14.9%	1.5%	0.5%
Estuary Mouth	61	01/05/2003	26/07/2010	168.7	2	10000	68.9%	14.8%	0.0%
North Efford	120	06/05/2006	15/11/2011	2182.7	136	81000	100.0%	74.2%	11.7%
Aveton Gifford Road bridge	75	01/05/2003	15/11/2011	1696.7	192	60000	100.0%	57.3%	12.0%

Data from the Environment Agency

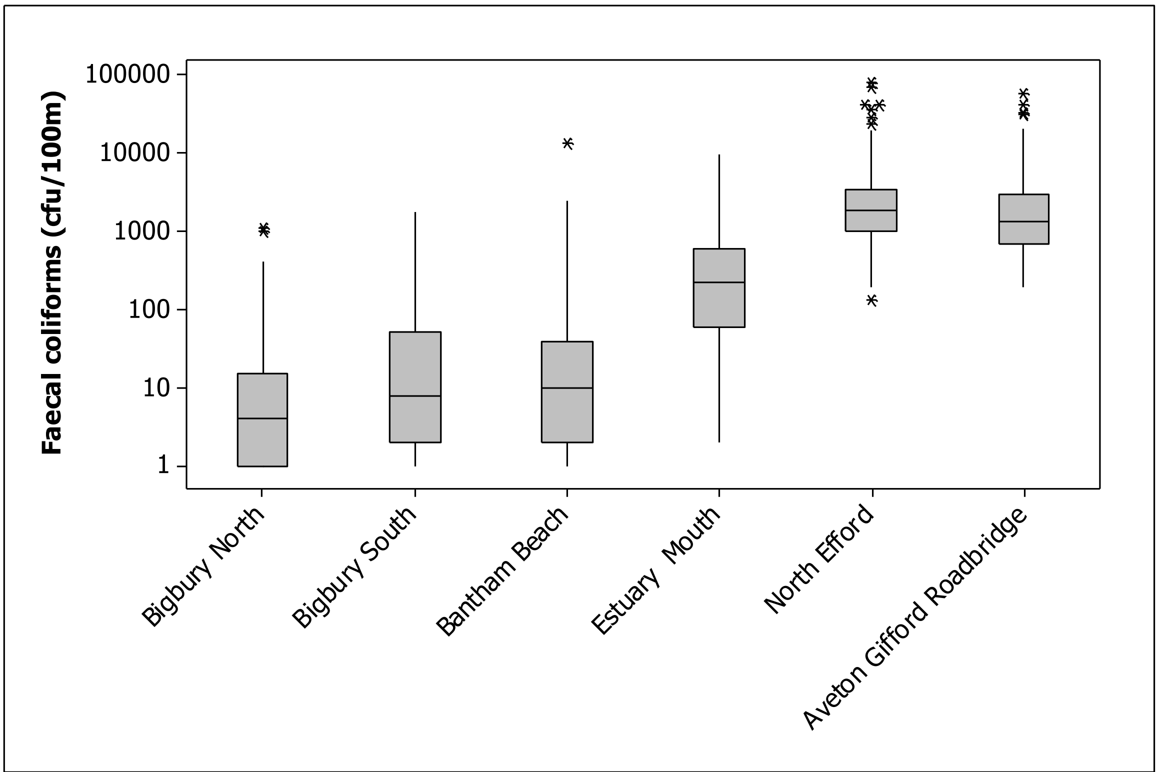


Figure X.2: Box-and-whisker plots of all faecal coliforms results by site
Data from the Environment Agency

There is a clear increase in the levels of faecal indicator bacteria from the estuary mouth to the tidal limit. One-way ANOVA tests showed that there were significant differences in faecal coliform levels between sites (p<0.000). Post-ANOVA Tukey tests showed that results at North Efford and Aveton Gifford Road bridge were significantly higher than all other sites, Estuary Mouth was significantly higher than Bantham Beach, Bigbury North and Bigbury South, and Bigbury South and Bantham Beach were significantly higher than Bigbury North.

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. There were significant correlations ($p < 0.05$) between all site pairings with sufficient samples, suggesting that they are all influenced by similar sources.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at bathing water sites sampled for two years or longer is shown in Figure X.3.

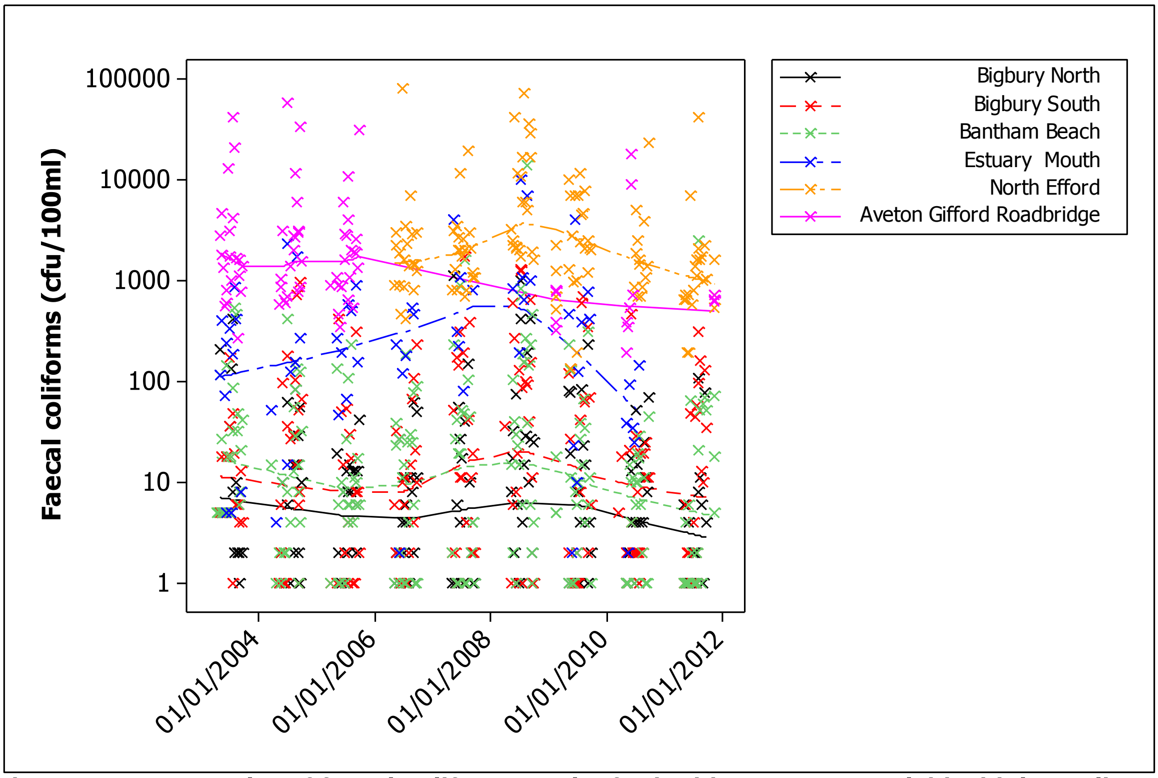


Figure X.3: Scatterplot of faecal coliform results for bathing waters overlaid with loess lines.
Data from the Environment Agency

Faecal coliform levels have remained stable at all bathing waters sites except Avon Estuary Mouth since 2003. At Avon Estuary Mouth, there appeared to be a reduction in faecal coliform concentrations in the 2010 season, after which monitoring ceased.

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**
Bigbury North	0.146	0.022	0.182	0.003
Bigbury South	0.380	0.000	0.355	0.000
Bantham Beach	0.385	0.000	0.355	0.000
Estuary Mouth	0.418	0.000	0.297	0.006
North Efford	0.306	0.000	0.256	0.000
Aveton Gifford Road bridge	0.108	0.432	0.154	0.179

Data from the Environment Agency

Correlations were found for both tidal cycles at all sites apart from Aveton Gifford Road bridge, which is close to the tidal limit and so conditions here are more riverine than estuarine. Figure X.4 presents polar plots of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle for significant correlations. High water 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.

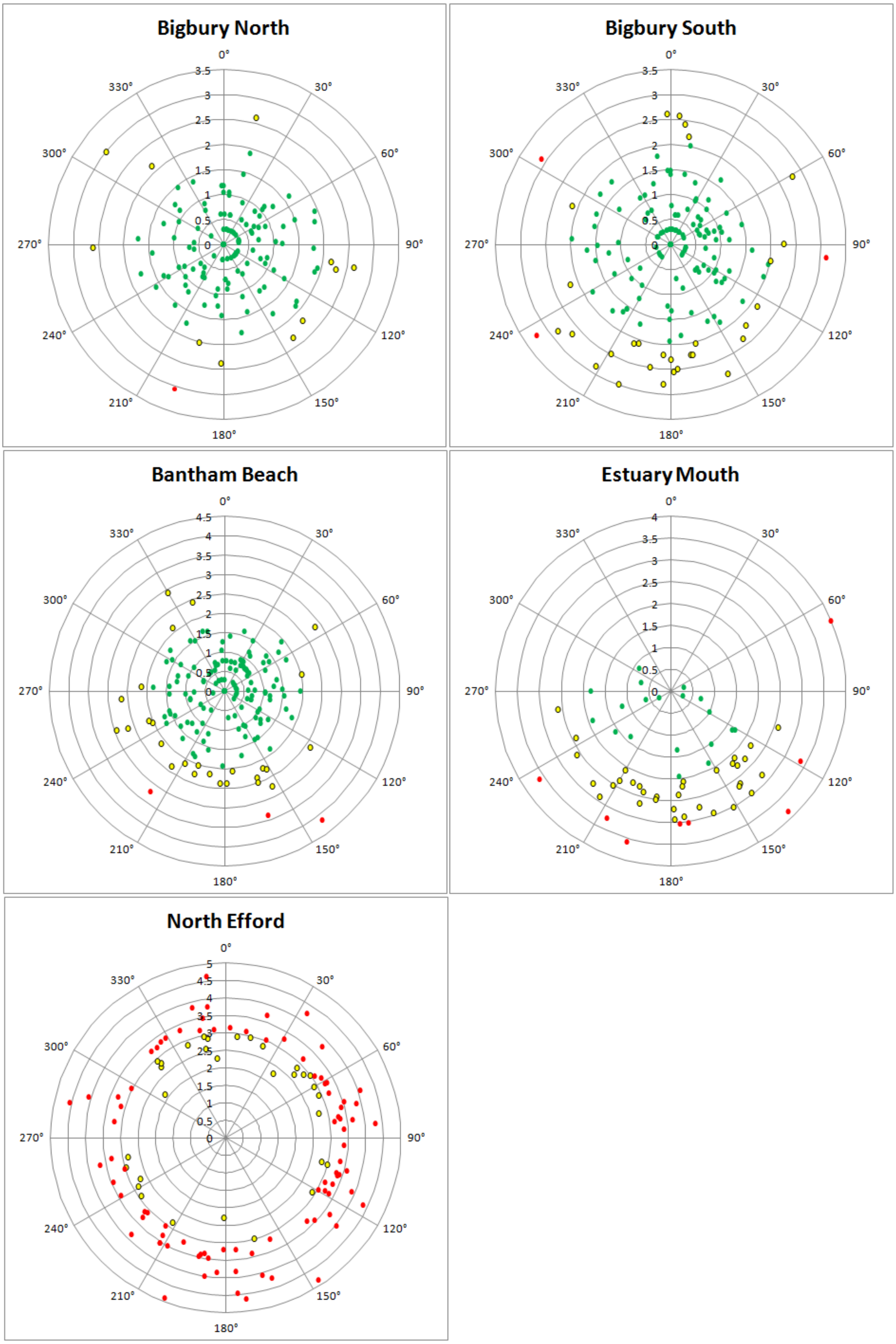


Figure X.4: Polar plots of log_{10} faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations

Data from the Environment Agency

At Bigbury South, Bantham Beach, and tentatively at Bigbury North and North Efford, lower results tended to occur around high water. No pattern is apparent on the polar plot for Estuary Mouth, where sampling was targeted towards low water.

Figure X.5 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.

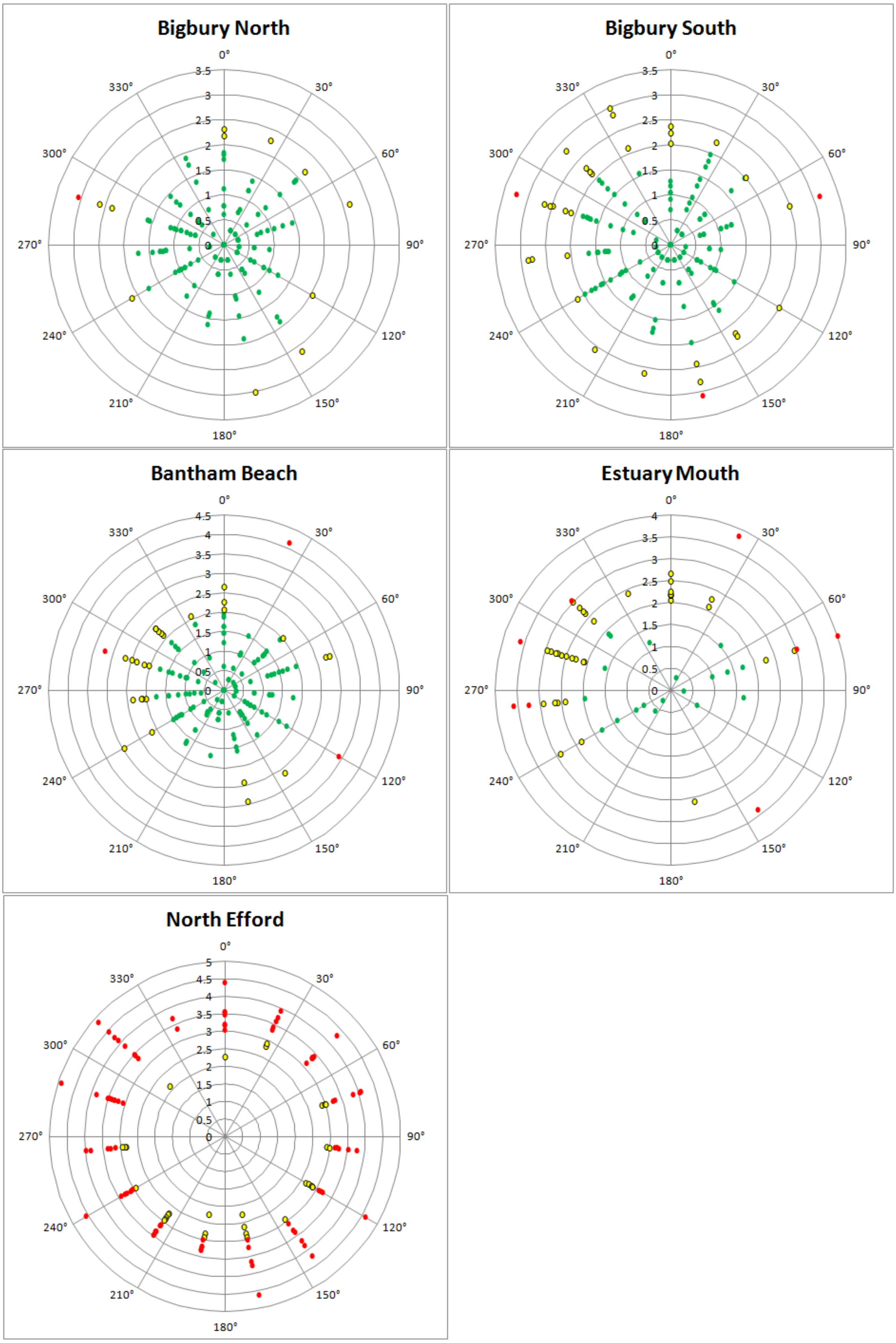


Figure X.5: Polar plots of log_{10} faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

There appears to be a general tendency for higher results as tide sizes increase from neaps to springs, although this is more obvious at some locations than others.

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 Sheerness Golf Course 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

	Site	Bigbury North	Bigbury South	Bantham Beach	Estuary Mouth	North Efford	Aveton Gifford Road bridge
	n	182	185	190	61	120	75
24 hour periods prior to sampling	1 day	0.498	0.427	0.423	0.352	0.484	0.537
	2 days	0.195	0.292	0.251	0.246	0.310	0.249
	3 days	0.044	0.176	0.220	0.138	0.098	0.128
	4 days	0.079	0.160	0.130	0.091	-0.005	0.021
	5 days	0.069	0.163	0.103	0.279	-0.021	-0.007
	6 days	0.092	0.160	0.184	0.110	0.056	-0.220
	7 days	-0.005	0.078	0.161	-0.006	0.009	-0.141
Total prior to sampling over	2 days	0.443	0.419	0.405	0.373	0.484	0.519
	3 days	0.402	0.420	0.391	0.400	0.505	0.512
	4 days	0.357	0.392	0.424	0.439	0.439	0.485
	5 days	0.340	0.385	0.407	0.431	0.401	0.415
	6 days	0.327	0.389	0.391	0.465	0.385	0.417
	7 days	0.330	0.399	0.396	0.445	0.378	0.389

Data from the Environment Agency

A strong influence of antecedent rainfall is apparent at all six monitoring points. This persisted for longer after a rainfall event at the sites in the outer estuary (with the exception of Bigbury North) compared to the two sites in the upper reaches.

Influence of Salinity

Salinity was recorded on most sampling occasions. Figure X.6 shows scatter-plots of those sites with significant correlations between faecal coliforms and salinity. Pearson's correlations were run to determine the effect of salinity on faecal coliforms at shellfish waters sites. There were significant correlations between salinity and faecal coliform concentrations at all sites apart from Bigbury North and Aveton Gifford Road bridge. There was little variation in salinity at these two locations, with the former being largely fully saline, and little saline influence at the latter. The correlations were very strong at all other sites indicating that land runoff is a highly significant contaminating influence.

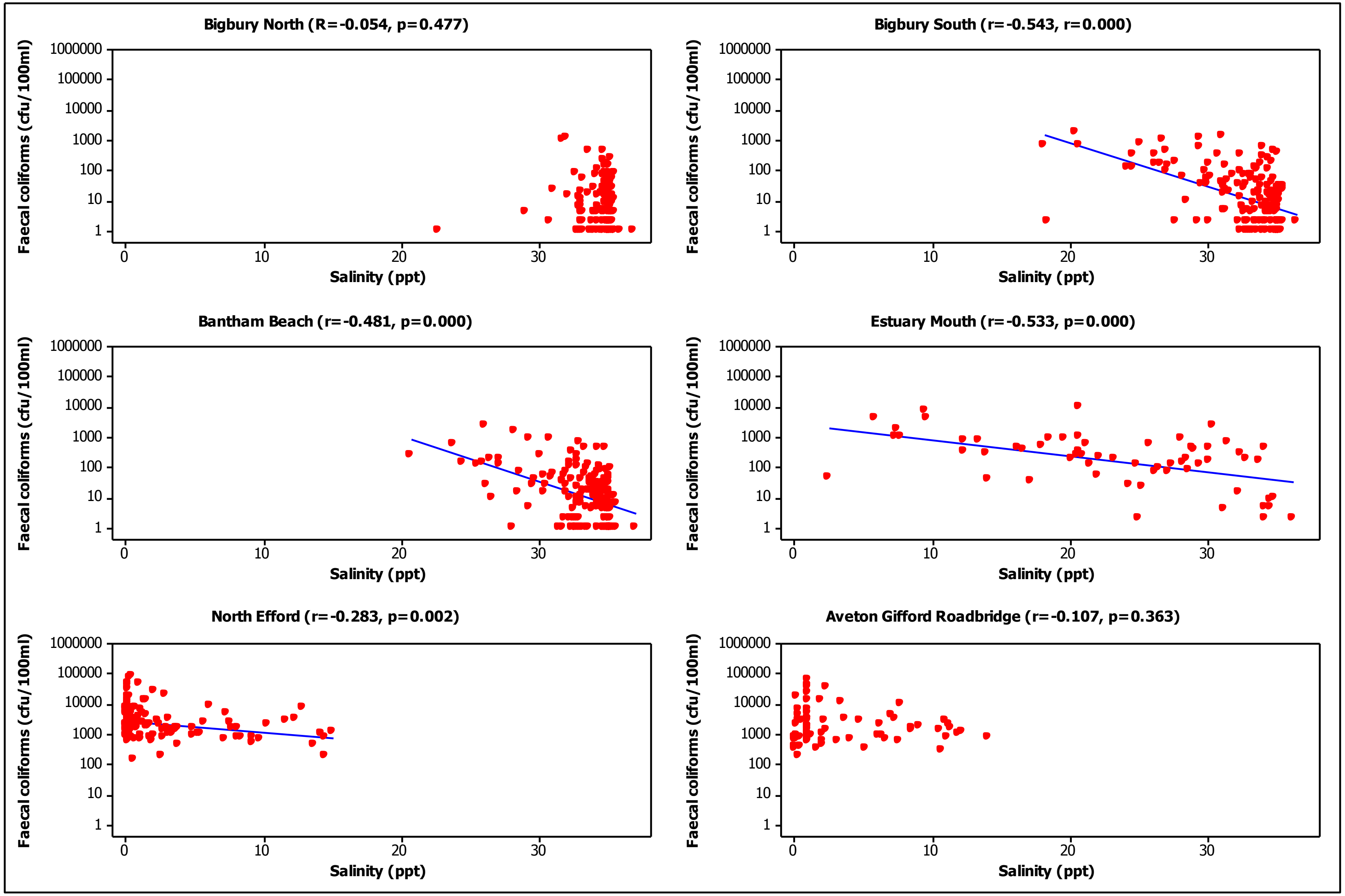


Figure X.6: Scatter-plots of salinity against faecal coliforms.
Data from the Environment Agency

X.2. Shellfish Waters

Summary statistics and geographical variation

There is one shellfish water monitoring point designated under Directive 2006/113/EC (European Communities, 2006) in the Avon estuary. Figure X.1 shows the location of this site. Table X.4 presents summary statistics for bacteriological monitoring results and Figure X.7 presents a boxplot of faecal coliform levels from the monitoring point. Results for presumptive faecal coliforms are presented to allow direct comparability with bathing waters results.

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	% over 10,000
Bigbury & Avon	59	23/01/2003	11/07/2013	369.9	15	39000	76.3%	25.4%	1.7%

Data from the Environment Agency

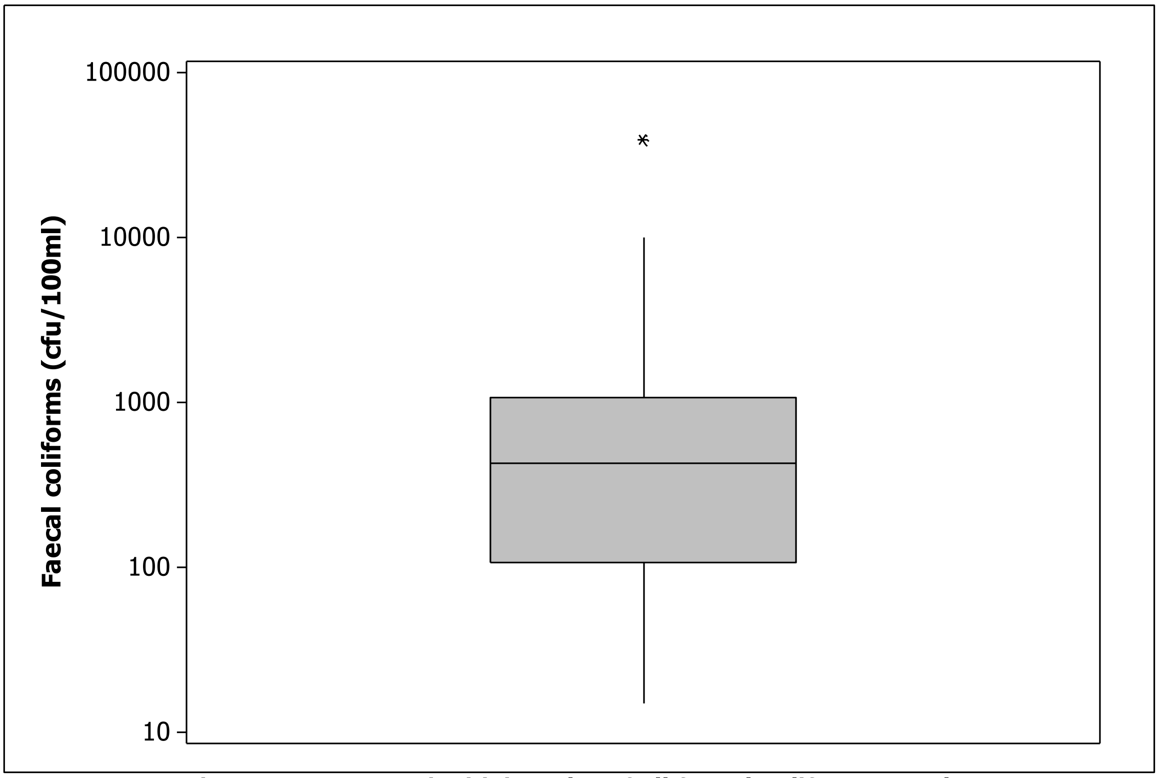


Figure X.7: Box-and-whisker plot of all faecal coliforms results
Data from the Environment Agency

Levels of faecal indicator bacteria here were quite high for a shellfish water. The majority (76.3 %) of samples had faecal coliform concentrations above 100 cfu/100 ml and 1.7 % of samples had faecal coliform concentrations above 10,000 cfu.100 ml.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at shellfish water sites over time is shown in Figure X.8.

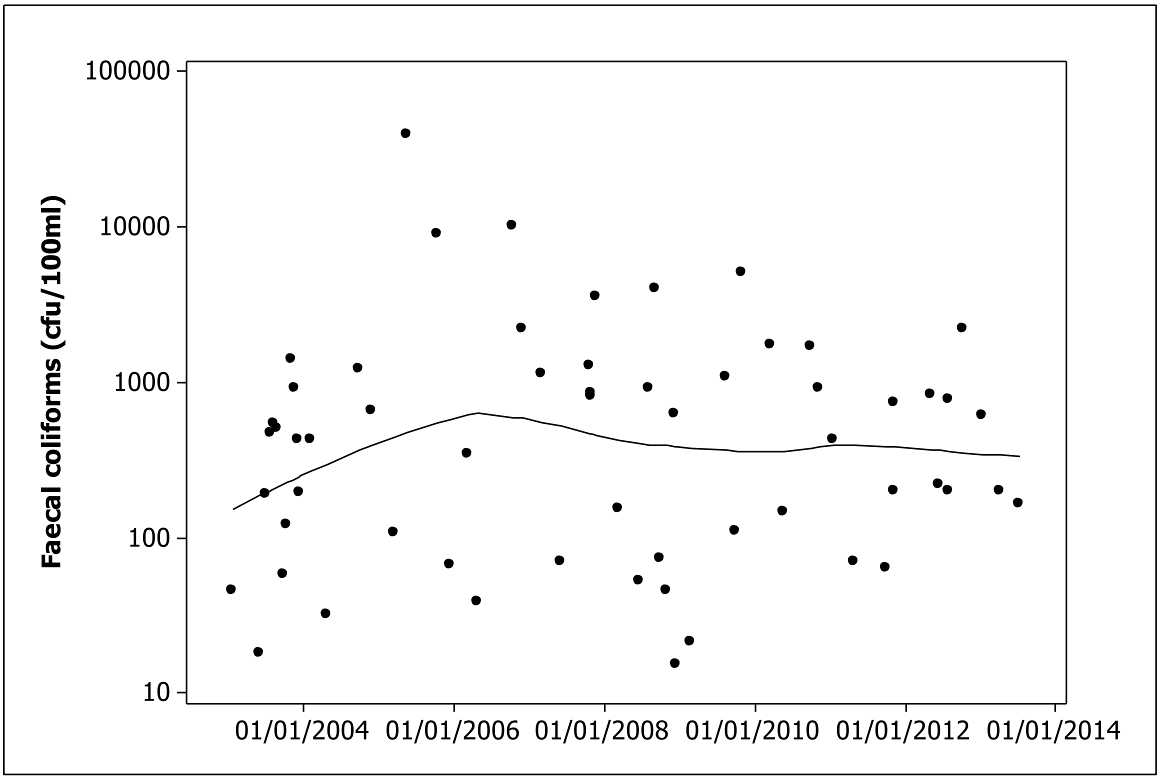


Figure X.8: Scatterplot of faecal coliform results by date, overlaid with loess lines
Data from the Environment Agency

Faecal coliform concentrations have remained stable since 2003.

Seasonal patterns of results

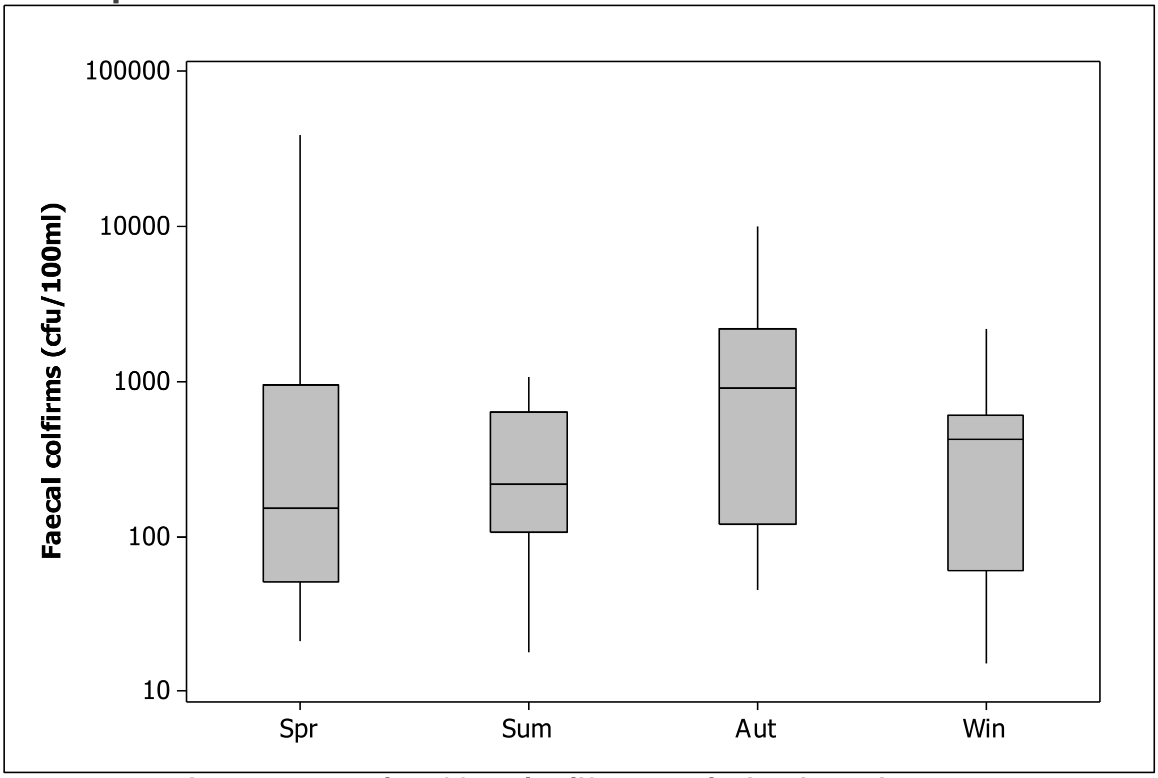


Figure X.9: Boxplot of faecal coliform results by site and season
Data from the Environment Agency

There appeared to be a tendency towards higher results in autumn. However, one-way ANOVA tests showed no significant differences in faecal coliform levels between seasons (p=0.120).

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 these shellfish waters sampling points. 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**
Bigbury and Avon	0.454	<0.001	0.559	<0.001

Data from the Environment Agency

Figure X.10 presents a polar plot of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle. High water 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.

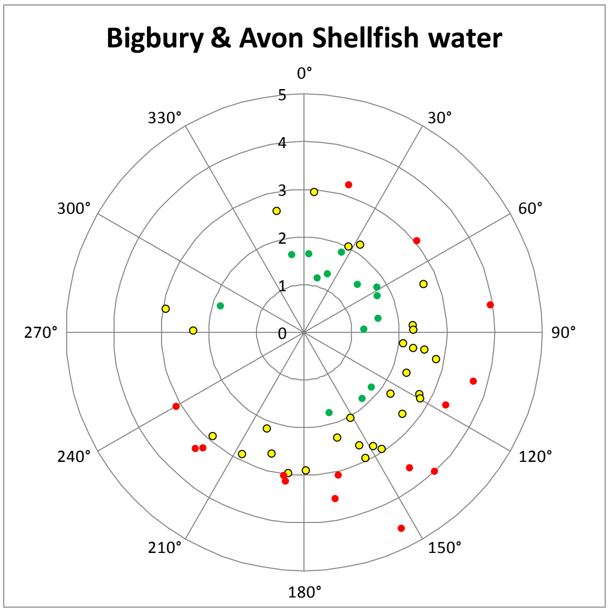


Figure X.10: Polar plot of $\log_{10}$ faecal coliforms against tidal state on the high/low tidal cycle for Bigbury and Avon shellfish water
Data from the Environment Agency

The polar plot shows a tendency for highest results around low water and the early part of the flood tide, and for lowest results on the latter part of the flood tide.

Figure X.11 presents a polar plot 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.

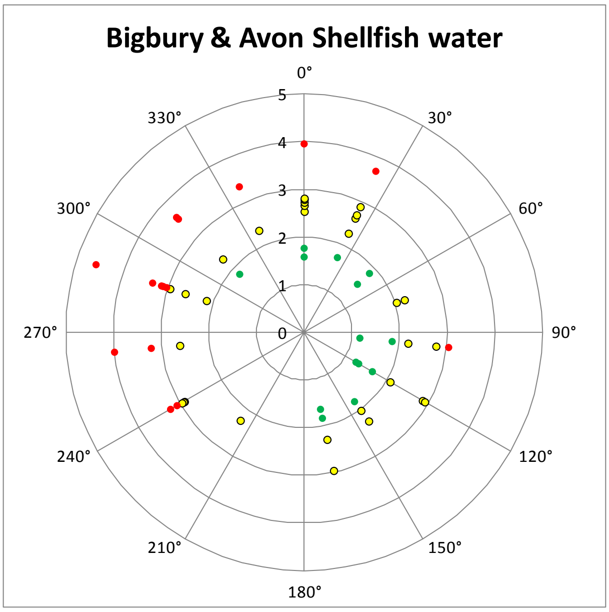


Figure X.11: Polar plot of $\log_{10}$ faecal coliforms against tidal state on the spring/neap tidal cycle for Bigbury and Avon shellfish water
Data from the Environment Agency

Highest results occurred on neap tides and the first few days of increasing tide sizes just after neap tides.

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 Hope Cove 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	Bigbury and Avon
	n	58
24 hour periods prior to sampling	1 day	0.333
	2 days	0.337
	3 days	0.137
	4 days	0.208
	5 days	0.096
	6 days	0.231
	7 days	0.418
Total prior to sampling over	2 days	0.313
	3 days	0.408
	4 days	0.393
	5 days	0.354
	6 days	0.372
	7 days	0.384

Data from the Environment Agency

Antecedent rainfall over various periods was a significant and consistent influence at the shellfish water monitoring point.

Influence of salinity

Salinity was recorded on most sampling occasions. Figure X.12 shows a scatter plot of faecal coliforms against salinity.

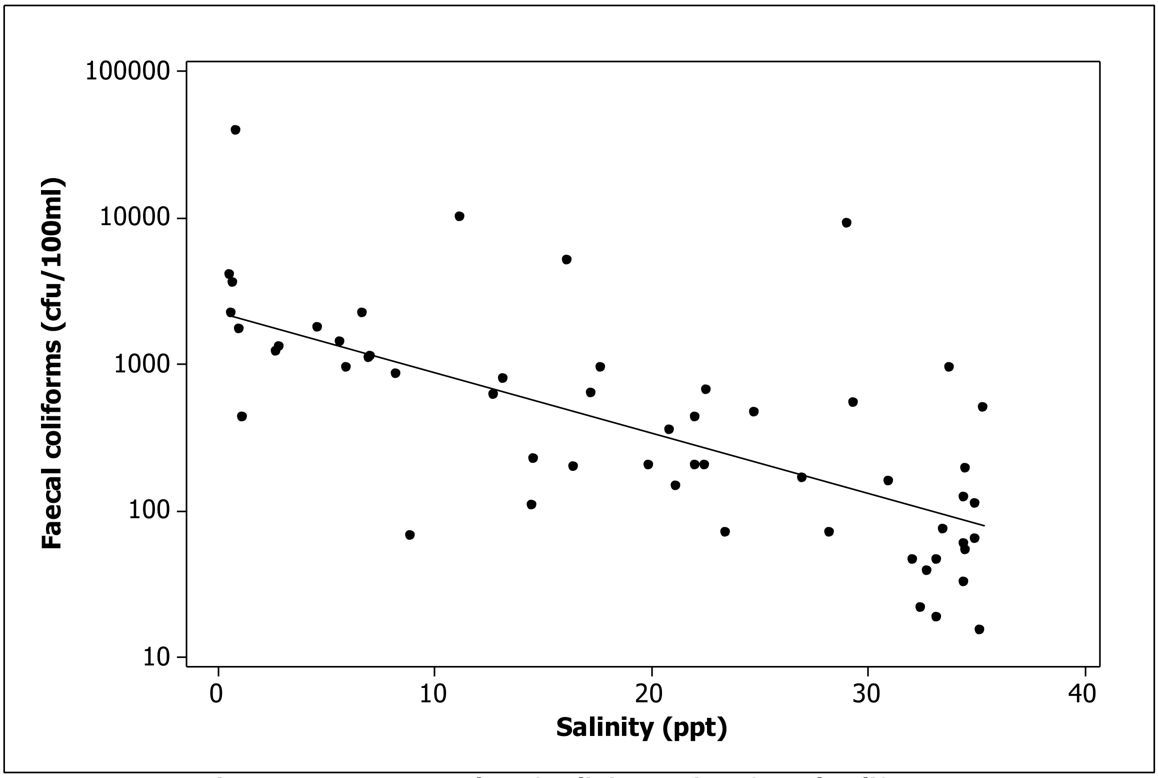


Figure X.12: Scatter-plot of salinity against faecal coliforms.
Data from the Environment Agency

A strong negative correlation was found between faecal coliforms and salinity (Pearson's correlation, $r=-0.689$, $p<0.001$) indicating the levels of faecal coliforms increase with the amount of freshwater in the system.

X.3. Microbial source tracking

Microbial source tracking techniques allow the source of faecal indicator organisms to be apportioned to various animal types. Results of such testing were provided by the Environment Agency for water samples taken from various locations within the Avon estuary, and from watercourses draining to it (Figure X.13). Only markers of human and ruminant origin were tested for. Whilst there is likely to be reasonable confidence in these assays in qualitative terms (i.e. the presence/absence of human and ruminant markers) there are many factors which could affect the accuracy of quantification. The relative proportions of human and ruminant markers should therefore be treated with caution.

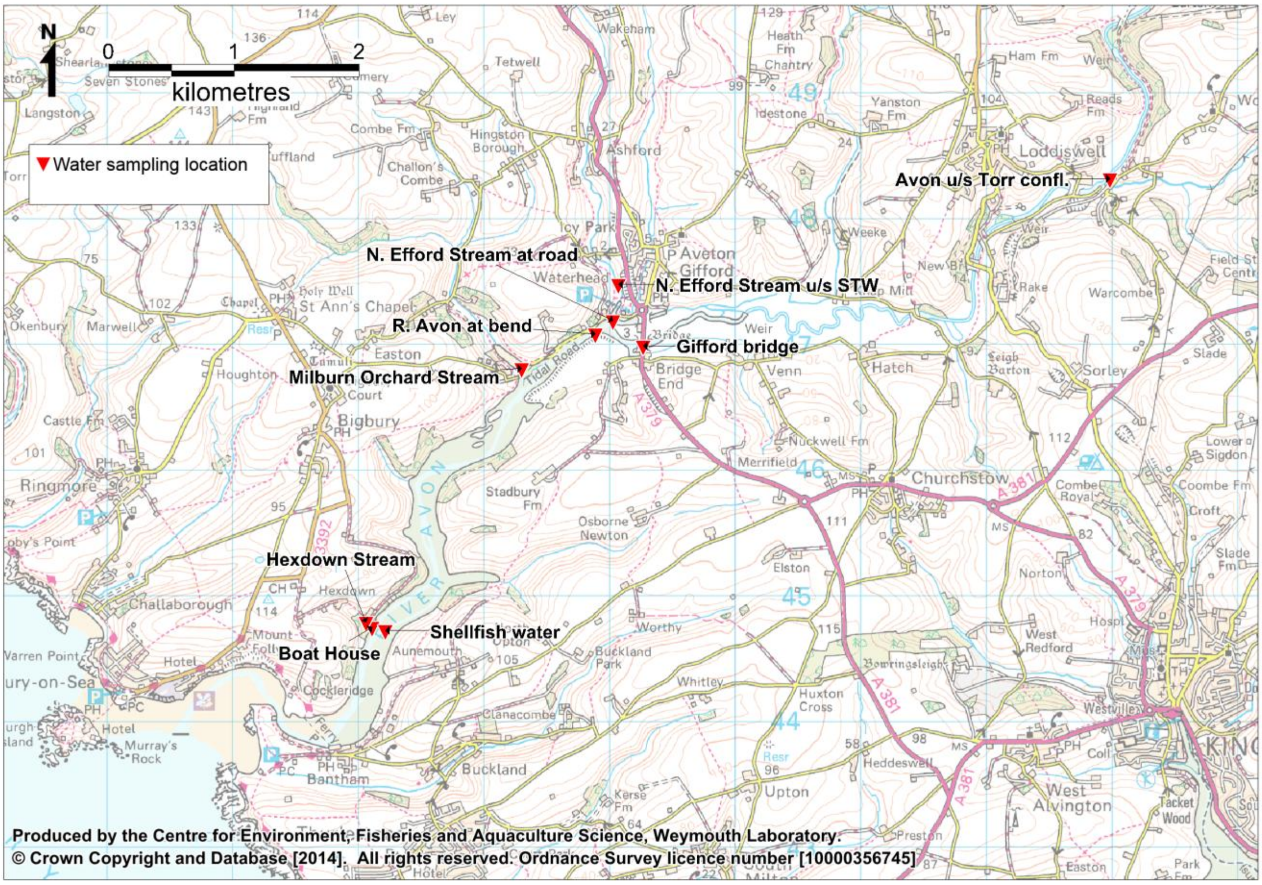


Figure X.13: Microbial source tracking sample locations
Data from the Environment Agency

Table X.7: Microbial source tracking results

Sample point	Date of collection	% Human	% Ruminant
Avon u/s Torr confl.	Feb-09	15%	85%
Boat House	Feb-09	4%	96%
Gifford bridge	Feb-09	17%	83%
Gifford bridge	Feb-09	2%	98%
Hexdown Stream	05/11/2007	7%	93%
Hexdown Stream	05/11/2007	25%	75%
Hexdown Stream	Feb-09	3%	97%
Hexdown Stream	Feb-09	2%	98%
Milburn Orchard Stream	Feb-09	4%	96%
Milburn Orchard Stream	Feb-09	1%	99%
N. Efford Stream at road	Feb-09	31%	69%
N. Efford Stream at road	Feb-09	17%	83%
N. Efford Stream at road	Feb-09	7%	93%
N. Efford Stream u/s STW	Feb-09	5%	95%
N. Efford Stream u/s STW	Feb-09	3%	97%
N. Efford Stream u/s STW	Feb-09	11%	89%
R. Avon at bend	Feb-09	18%	82%
R. Avon at bend	Feb-09	7%	93%
Shellfish water	05/11/2007	3%	97%
Shellfish water	15/11/2007	7%	93%

Shellfish water	Feb-09	9%	91%
Shellfish water	Feb-09	10%	90%
Shellfish water	Feb-09	14%	86%
Shellfish water	Feb-09	8%	92%
Shellfish water	Feb-09	8%	92%

Data from the Environment Agency

The results suggest that the dominant source of faecal indicator bacteria was consistently ruminants (cattle, sheep etc) at all locations. Only a small proportion was of human origin. The consistency of results suggests that, despite the quantitative uncertainties, the majority of faecal contamination in the estuary is of agricultural origin.

Appendix XI. Microbiological Data: Shellfish Flesh Hygiene

XI.1. Summary statistics and geographical variation

There are a total of six RMPs in the Avon estuary that have been sampled between 2003 and 2013; three mussel, and three Pacific oyster. The three mussel RMPs have not been sampled since 2006. 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 are shown in Figure XI.2 to Figure XI.3.

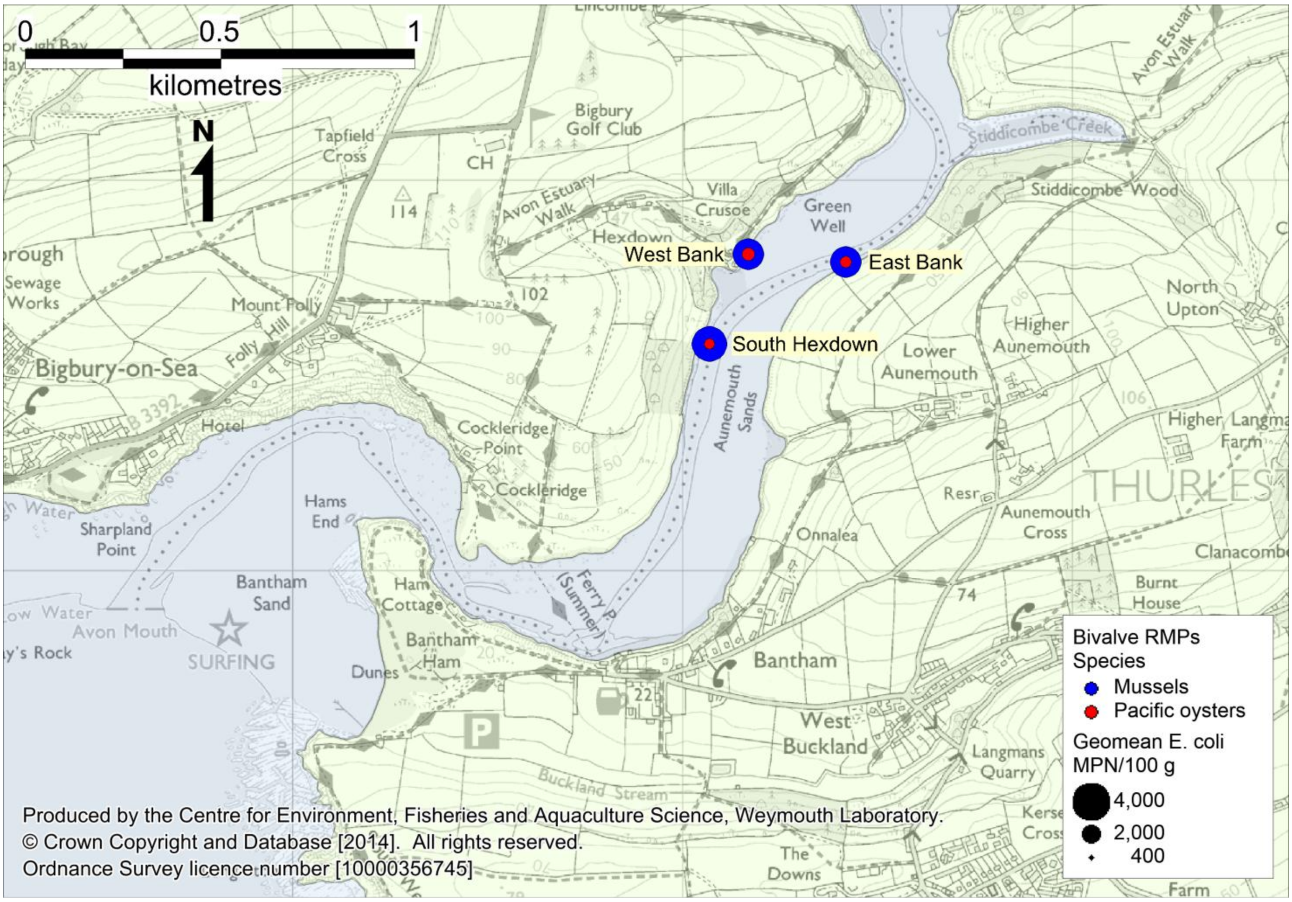


Figure XI.1: RMPs active since 2003

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) from mussel and Pacific oyster 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
West Bank	Mussel	43	30/01/2003	26/07/2006	3310.9	160	54000	95.3	32.6	7.0
East Bank	Mussel	13	30/01/2003	26/07/2006	3287.6	290	17000	100.0	53.8	0.0
South Hexdown	Mussel	39	30/01/2003	26/07/2006	3799.8	220	50000	97.4	41.0	2.6
West Bank	Pacific oyster	136	30/01/2003	20/11/2013	1291.0	40	>18000	91.9	16.2	0.0
East Bank	Pacific oyster	99	30/01/2003	20/11/2013	1182.9	40	16000	86.9	21.2	0.0
South Hexdown	Pacific oyster	128	30/01/2003	20/11/2013	1137.7	40	24000	89.8	14.1	0.0

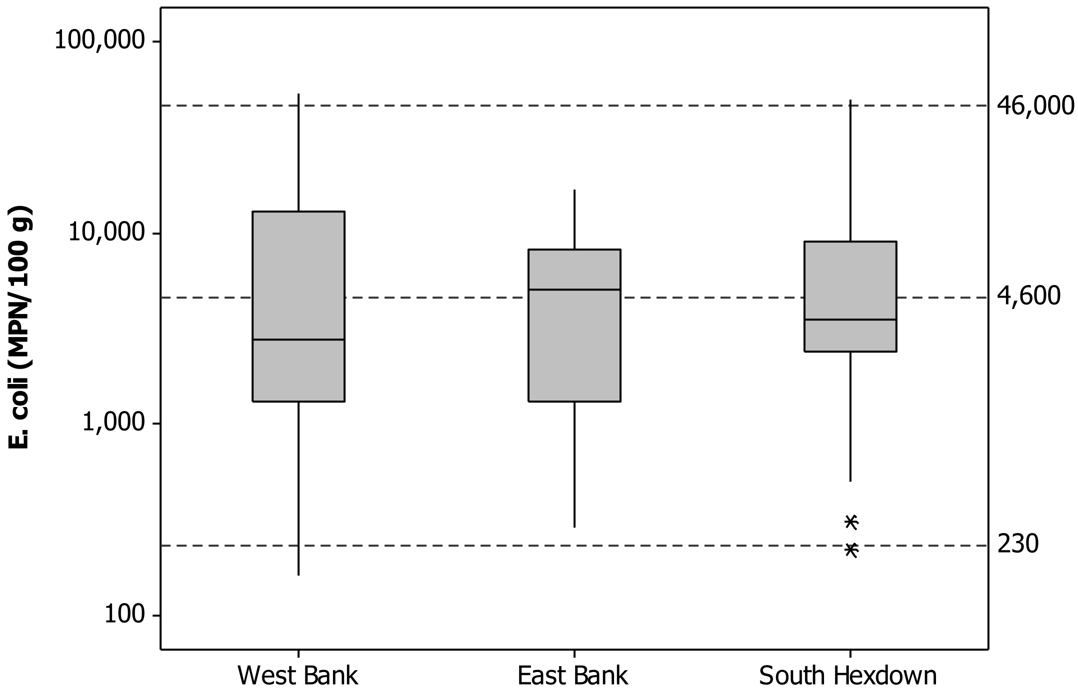


Figure XI.2: Boxplots of *E. coli* results from mussel RMPs from 2003 onwards.

E. coli levels exceeded 4,600 MPN/100 g in more than 10 % of samples at all mussel RMPs. East Bank was the only mussel RMP not to have any samples exceeding 46,000 *E. coli* MPN/100 g. One-way ANOVA tests showed that there was no significant variation in *E. coli* levels between sites (p=0.890).

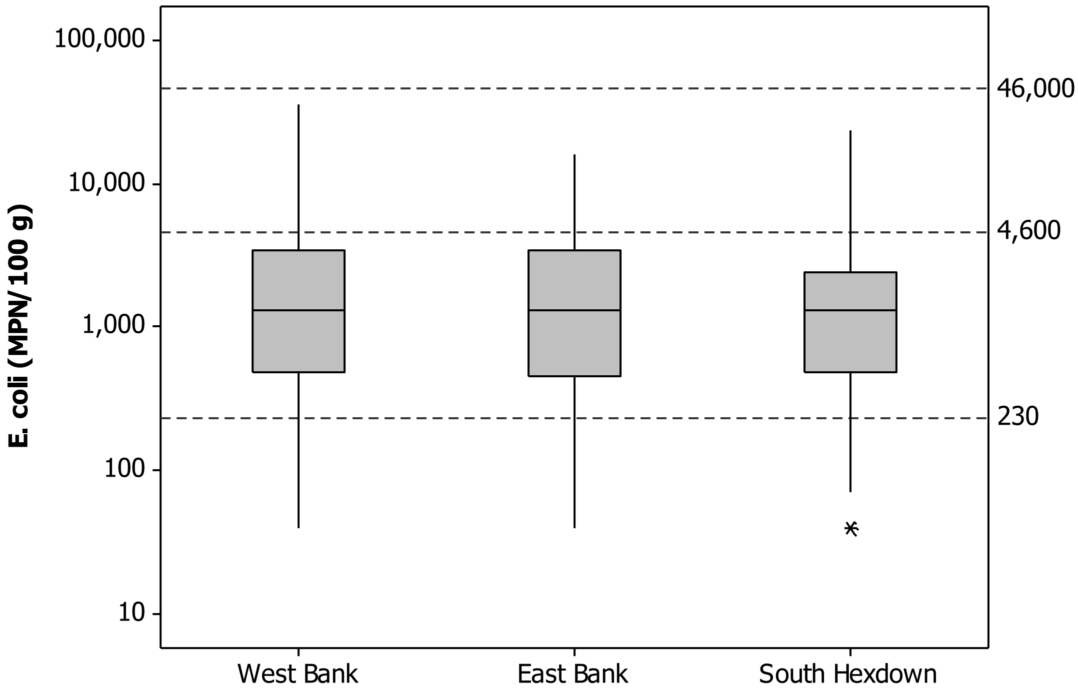


Figure XI.3: Boxplots of *E. coli* results from Pacific oyster RMPs from 2003 onwards.

E. coli levels exceeded 4,600 MPN/100 g in more than 10 % of samples at all Pacific oyster RMPs. None of the Pacific oyster RMPs had samples exceeding 46,000 *E. coli* MPN/100 g. One-way ANOVA tests showed that there was no significant variation in *E. coli* levels between sites (p=0.713).

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 not enough matching sampling days between East Bank mussels and either of the other two mussel RMPS for correlations to be run. There was a significant correlation between West Bank and South Hexdown mussel RMPs (p<0.001). There were significant correlations between all Pacific oyster RMP site pairings (p<0.001 in all cases). These significant correlations indicate that the sites share similar contamination sources.

XI.2. Overall temporal pattern in results

The overall variation in *E. coli* levels found in bivalves at sites sampled for two years or longer is shown in Figure XI.4 to Figure XI.5.

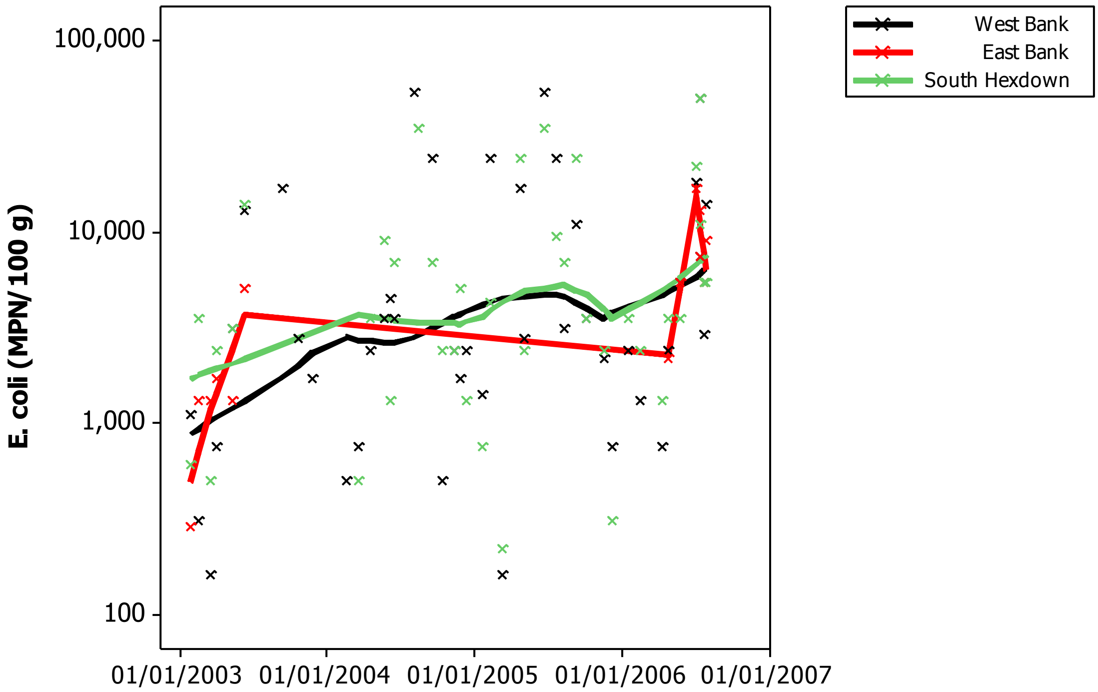


Figure XI.4: Scatterplot of *E. coli* results for mussels overlaid with loess lines.

At all three mussel RMPs, there was a trend of slightly increasing *E. coli* levels from 2003 to 2006.

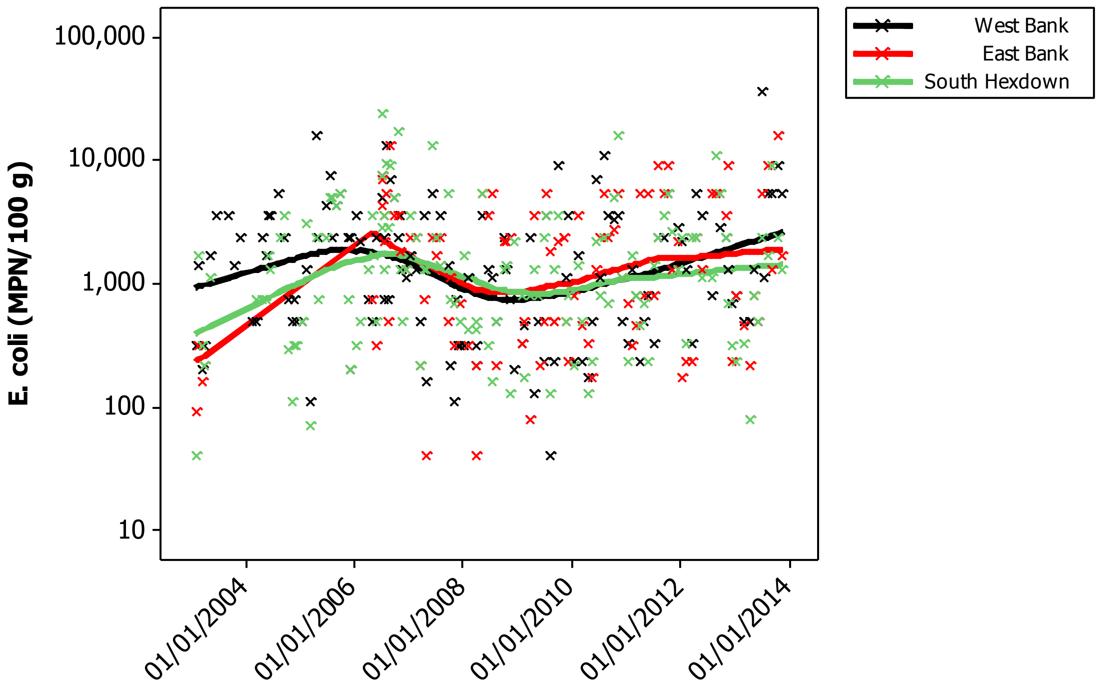


Figure XI.5: Scatterplot of *E. coli* results for Pacific oysters overlaid with loess lines.

E. coli levels at Pacific oyster sites have remained reasonably stable since 2003, with a slight peak in 2006.

XI.3. Seasonal patterns of results

The seasonal patterns of results from 2003 to 2013 were investigated by species and RMP. Figure XI.6 to Figure XI.7 show the variation in *E. coli* levels between seasons at different RMPs sampled for two years or longer.

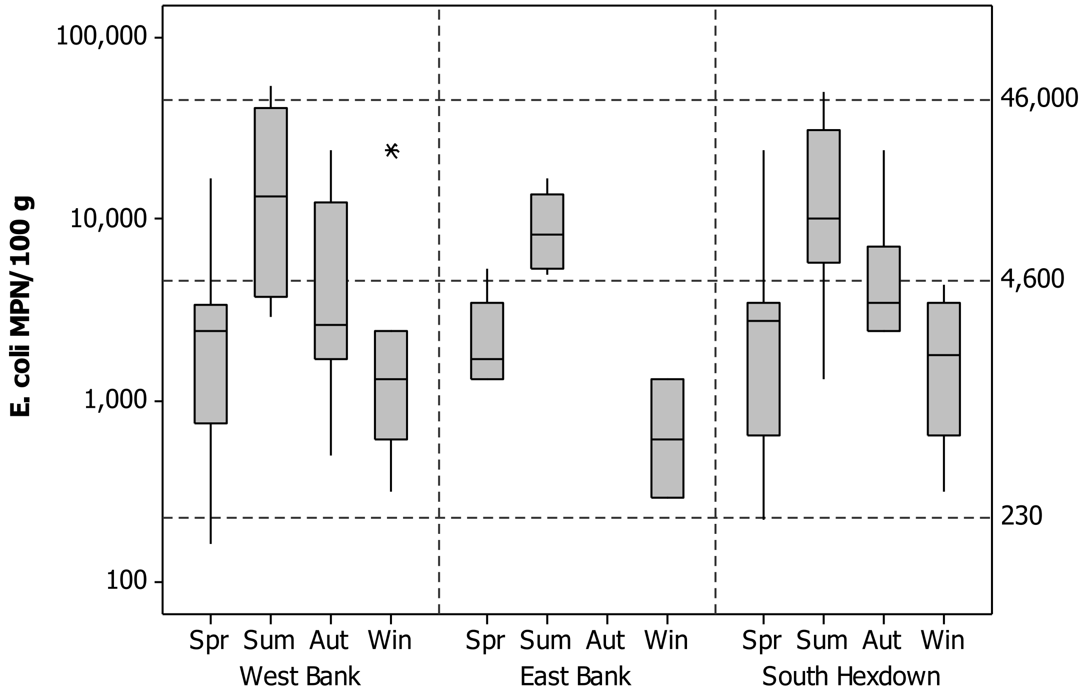


Figure XI.6: Boxplot of *E. coli* results in mussels by RMP and season

At all mussel RMPs One-way ANOVAs showed there were significant differences in *E. coli* levels between seasons (p=0.001 in all cases). Post ANOVA Tukey tests showed that at all three mussel RMPs, there was significantly higher levels of *E. coli* in summer than in spring and winter.

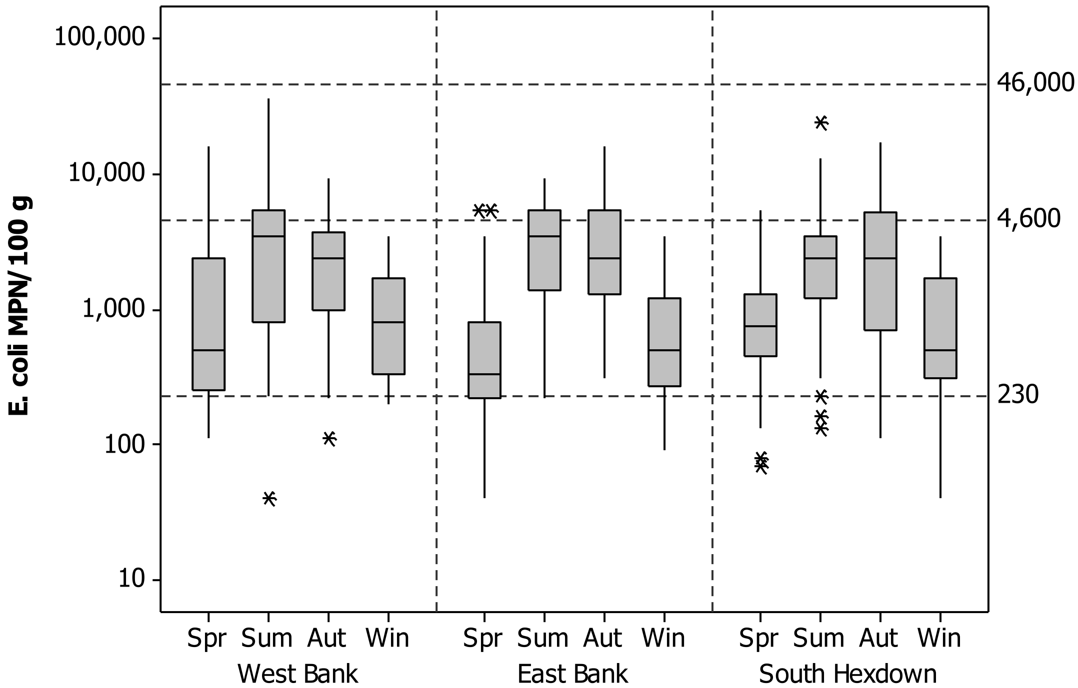


Figure XI.7: Boxplot of *E. coli* results in Pacific oysters by RMP and season

At all Pacific oyster RMPs One-way ANOVAs showed there were significant differences in *E. coli* levels between seasons (p<0.001 in all cases). Post ANOVA Tukey tests showed that at all Pacific oyster RMPs, there was significantly higher levels of *E. coli* in summer and autumn than in spring and winter.

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**
West Bank	Mussel	0.291	0.033	0.262	0.064
South Hexdown		0.198	0.243	0.234	0.138
West Bank	Pacific oyster	0.294	0.000	0.035	0.852
East Bank		0.114	0.287	0.053	0.762
South Hexdown		0.085	0.401	0.101	0.278

Figure XI.8 and Figure XI.9 present 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 Plymouth (+15 minutes) 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 4,600 are plotted in yellow, and those exceeding 4,600 are plotted in red.

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

Figure XI.9: Polar plot of $\log_{10}$ *E. coli* results (MPN/100g) from Pacific oyster RMPs against high/low tidal state.

For both species sampling was strongly targeted towards low water and no patterns are apparent in either of the polar plots.

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 Hope Cove weather station (Appendix II for details) over various periods running up to sample collection. Only those sites with ten or more samples corresponding to dates for which rainfall data were available were analysed. Correlation results are presented in Table XI.3, and statistically significant positive correlations ($p<0.05$) are highlighted in yellow and significant negative correlation are highlighted in blue. It should be noted that on average, one in twenty correlations will return a significant r value by chance alone.

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

	Site	West Bank	East Bank	South Hexdown	West Bank	East Bank	South Hexdown
	Species		Mussel			Pacific oyster	
	n	43	13	39	132	96	125
24 hour periods prior to sampling	1 day	0.100	-0.251	0.091	-0.101	-0.008	-0.018
	2 days	-0.083	-0.563	-0.142	0.080	0.030	0.069
	3 days	0.152	0.336	0.125	0.081	0.043	0.032
	4 days	-0.104	-0.058	-0.156	-0.061	-0.025	-0.114
	5 days	0.057	0.292	0.024	-0.034	0.031	-0.011
	6 days	0.126	0.361	0.121	0.024	0.097	0.101
	7 days	-0.097	-0.092	-0.221	-0.092	0.005	0.013
Total prior to sampling over	2 days	0.049	-0.251	-0.024	-0.024	0.024	0.004
	3 days	0.195	0.031	0.128	-0.003	0.035	-0.006
	4 days	0.171	0.024	0.171	-0.026	-0.029	-0.064
	5 days	0.101	0.014	0.115	-0.006	0.001	-0.034
	6 days	0.124	0.142	0.181	0.000	0.033	-0.019
	7 days	0.084	0.025	0.101	-0.064	0.047	-0.023

The negative correlation observed at East Bank mussels was likely to be a chance occurrence. Aside from this no significant correlations were detected, indicating that antecedent rainfall does not have an influence on levels of faecal indicator bacteria in shellfish here. This is perhaps surprising given the fishery is within the estuary of a significant river that drains an agricultural catchment. It may be that the changes in salinity here associated with heavy rainfall are sufficiently acute and abrupt to cause the shellfish to cease feeding. The range of salinities recorded at the bathing and shellfish water monitoring points, and the clear associations between salinity/rainfall and levels of faecal coliforms in the water column (Appendix X) would lend support to this assertion.

Appendix XII. Shoreline Survey Report

Date (time):

17th February 2014 (11:20 - 15:30)
18th February 2014 (08:50 – 16:00)

Cefas Officer:

David Walker

Survey Partner:

Dan Blackley (South Hams DC)

Area surveyed:

Spot samples upstream and downstream of Loddiswell STW. Spot samples near Aveton Gifford. Survey from Doctors Wood (near Bigbury) to Cockleridge Ham. Bantham to Aveton Gifford Bridge.

Weather:

17th February 12:00, overcast, moderate rainfall, 10°C, wind bearing 141° at 14.4 km/h.
18th February 12:00, clear, 10°C, wind bearing 270° at 6.4 km/h.

Tides:

Admiralty TotalTide© predictions for Plymouth (50°22'N 4°11'W) +15 minutes. All times in this report are GMT.

17/02/2014			18/02/2014		
High	07:27	5.4 m	High	08:01	5.3 m
High	19:47	5.2 m	High	20:17	5.1 m
Low	01:18	1.0 m	Low	01:36	1.0 m
Low	13:37	1.0 m	Low	14:03	1.0 m

XII.1. 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 sample all freshwater inputs to the oyster beds, it was not possible to sample the River Avon where it joins the estuary due to a lack of safe sampling points. However, the river was sampled further upstream near Loddiswell.

XII.2. Description of Fishery

During the shoreline survey, the Cefas officer accompanied the LEA and the harvester to collect this month's classification sample. No sample was collected for the East Bank classification area as it was not accessible due to unusually high water levels (due to recent heavy rainfall). The two samples taken, one from West Bank and one from South Hexdown were collected by the harvester. It was not possible to determine the exact extent of the entire beds due to the tidal conditions. However, aerial photography is available that shows the extent of all three beds. Cockle dead shell was seen across the sandy areas of the estuary.

XII.3. Sources of contamination

Sewage discharges

The Loddiswell and Aveton Gifford STW discharges were not directly observed. However, the River Avon was sampled 540 m upstream (observation 1, sample A01) and 370 m downstream (observation 2, sample A02) of the Loddiswell STW. The concentration of *E. coli* downstream of the STW was more than twice that upstream. However, the flow of water downstream was half that measured upstream, effectively cancelling out this increase in *E. coli* concentration. However, this difference in flow rate is due to inaccurate measurements rather than a real decrease in flow.

Approximately 130 m downstream of the Aveton Gifford STW (observation 5, sample A05) an *E. coli* concentration of 2,800 cfu/100 ml and a loading of 1.99×10^{12} cfu/day was measured.

No other water company discharges were represented in this survey. The location of a private septic tank discharge on the EA discharge consent database coincides with observation 22, which was two pipes in a wall. These pipes were not flowing at the time of the survey.

Freshwater inputs

Most of the major freshwater inputs to the Avon estuary are located in the north-east, with the River Avon being the largest input. While the River Avon was not sampled at the point at which it joins the estuary, upstream samples suggest that it was contributing at least 1.66×10^{14} *E. coli* cfu/day at the time of the survey. Additionally, a smaller stream (observation 4) just to the north of the River Avon at Aveton Gifford had an *E. coli* concentration of 3,300 cfu/100 ml and a loading of 2.79×10^{10} cfu/day (sample A04).

Further downstream, a small creek on the northern side of the estuary (observation 6) had an *E. coli* concentration of 5,600 cfu/100 ml and a loading of 6.66×10^{12} cfu/day (sample A06).

Throughout the survey, there were several small streams and springs none of which had loadings of above $5x10^{10}$ *E. coli* cfu/day. A marsh to the south-west of Aveton Gifford had a drainage sluice. The flow through this sluice had an *E. coli* concentration of 130 cfu/100 ml and a loading of $1.38x10^{11}$ cfu/day.

Livestock & wildlife

Very little livestock was seen throughout the survey. A solitary sheep was seen at observation 17 next to the water. This animal had probably escaped so access to this part of the estuary by sheep may not be a regular occurrence. What appeared to be a cattle pen was observed at observation 41, but there was no evidence that it had been used recently to hold cattle. While very little livestock was observed, the topography of the land surrounding the estuary means that it would be impossible to see any grazing livestock that were more than about 50 m from the waters' edge. Small flocks of seagulls were seen throughout the estuary on exposed mud and sand banks. Around 20 swans were seen on the marsh to the south-west of Aveton Gifford (observation 40).

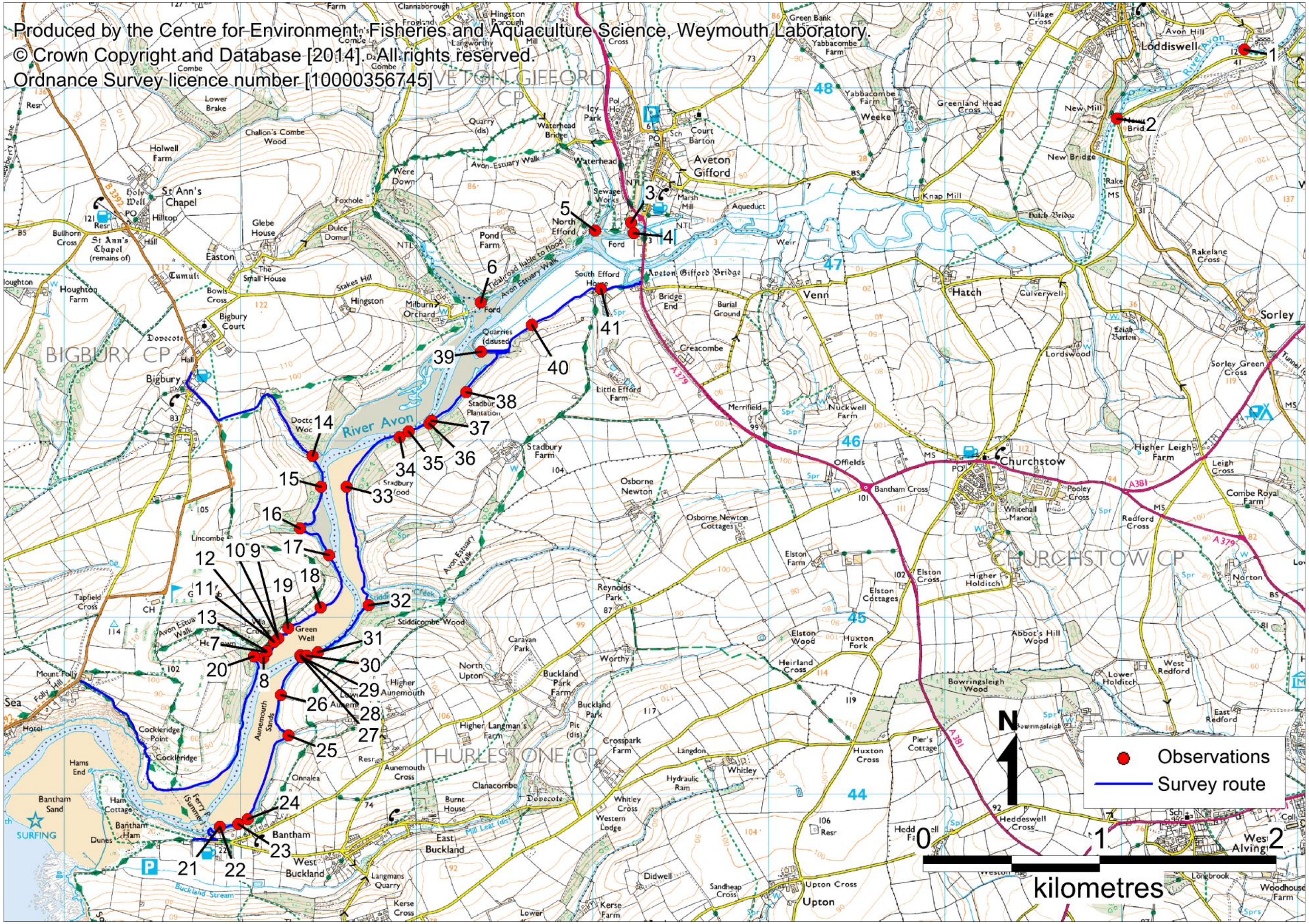


Figure XII.1: Locations of shoreline observations (Table XII.1 for details).

Table XII.1: Details of Shoreline Observations.

Observation no.	NGR	Date & time	Description	Photo
1	SX 72700 48220	17/02/2014 12:09	River Avon (11.6 m x 1.5 m x 1.7 m/s, sample A01)	
2	SX 71975 47827	17/02/2014 12:09	River (14.7 m x 1 m x 1.2 m/s, sample A02)	
3	SX 69217 47239	17/02/2014 12:40	Stream (2 m x 0.65 m x 0.355 m/s, sample A03)	Figure XII.4
4	SX 69233 47177	17/02/2014 12:48	River (7 m x 0.3 m x 0.103 m/s, sample A04)	Figure XII.5
5	SX 69013 47193	17/02/2014 12:58	Stream (2.75 m x 0.45 m x 0.664 m/s, sample A05)	Figure XII.6
6	SX 68365 46785	17/02/2014 13:15	Stream (2 m x 0.4 m x 1.720 m/s, sample A06)	
7	SX 67147 44802	17/02/2014 13:47	Downstream of West Bank oyster bed (sample A07)	
8	SX 67129 44769	17/02/2014 14:01	Upstream of South Hexdown oyster bed (sample A08)	
9	SX 67214 44881	17/02/2014 14:12	Upstream of West Bank oyster bed (sample A10)	
10	SX 67214 44881	17/02/2014 14:12	Upstream of West Bank oyster bed (sample AS01)	
11	SX 67190 44860	17/02/2014 14:12	Middle of West Bank oyster bed (sample A11)	
12	SX 67190 44860	17/02/2014 14:12	Middle of West Bank oyster bed (sample AS02)	
13	SX 67410 45915	18/02/2014 09:27	Downstream of West Bank oyster bed (sample AS03)	
14	SX 67148 44809	18/02/2014 09:27	Stream (0.6 m x 0.15 m x 0.358 m/s, sample A21)	Figure XII.7
15	SX 67456 45739	18/02/2014 09:48	Spring (too small to sample)	Figure XII.8
16	SX 67339 45503	18/02/2014 10:10	Stream (1.5 m x 0.05 m x 0.686 m/s, sample A22)	Figure XII.9
17	SX 67503 45352	18/02/2014 10:28	Solitary sheep	
18	SX 67454 45056	18/02/2014 10:44	Spring (too small to measure flow, sample A23)	
19	SX 67270 44939	18/02/2014 11:06	Spring (too small to measure flow, sample A24)	
20	SX 67077 44778	18/02/2014 11:21	Culvert through 30 cm ceramic pipe (0.1 m flow depth x 1.443 m/s, sample A25)	Figure XII.10
21	SX 66883 43812	18/02/2014 13:13	Cockle dead shell along sandy shore	
22	SX 66883 43812	18/02/2014 13:13	Two 30 cm drainage pipes in wall (not flowing)	Figure XII.11
23	SX 66988 43829	18/02/2014 13:17	Ground water seepage	
24	SX 67041 43857	18/02/2014 13:21	Spring (200 ml/s, sample A26)	
25	SX 67273 44331	18/02/2014 13:34	Stream (0.2 m x 0.08 m x 0.373 m/s, sample A27)	Figure XII.12
26	SX 67229 44560	18/02/2014 13:40	Ground water seepage	
27	SX 67345 44775	18/02/2014 13:44	East Bank oyster bed	
28	SX 67341 44785	18/02/2014 13:45	East Bank oyster bed (sample A28)	

29	SX 67347 44775	18/02/2014 13:49	East Bank oyster bed (sample AS21)	
30	SX 67376 44782	18/02/2014 13:52	East Bank oyster bed (sample AS22)	
31	SX 67440 44802	18/02/2014 13:54	East Bank oyster bed (sample AS23)	
32	SX 67727 45069	18/02/2014 14:10	Water from creek (1.8 m x 0.35 m x 0.423 m/s, sample A29)	Figure XII.13
33	SX 67603 45740	18/02/2014 14:40	Water from creek (0.5 m x 0.15 m x 0.560 m/s, sample A30)	Figure XII.14
34	SX 67902 46021	18/02/2014 14:40	Stream (0.5 m x 0.07 m x 0.085 m/s, sample A31)	
35	SX 67955 46053	18/02/2014 14:59	Spring (too small to sample)	
36	SX 68071 46100	18/02/2014 15:04	Spring (Flow too spread to measure, sample A32)	
37	SX 68085 46115	18/02/2014 15:08	Spring (too small to sample)	
38	SX 68282 46276	18/02/2014 15:14	Spring (too small to measure flow, sample A33)	
39	SX 68367 46507	18/02/2014 15:30	Sluice for marsh (1.3 m x 1.1 m x 0.858 m/s, sample A35)	Figure XII.15 & Figure XII.16
40	SX 68654 46658	18/02/2014 15:44	Around 20 swans on marsh	
41	SX 69047 46861	18/02/2014 15:51	Possible cattle penn	Figure XII.17

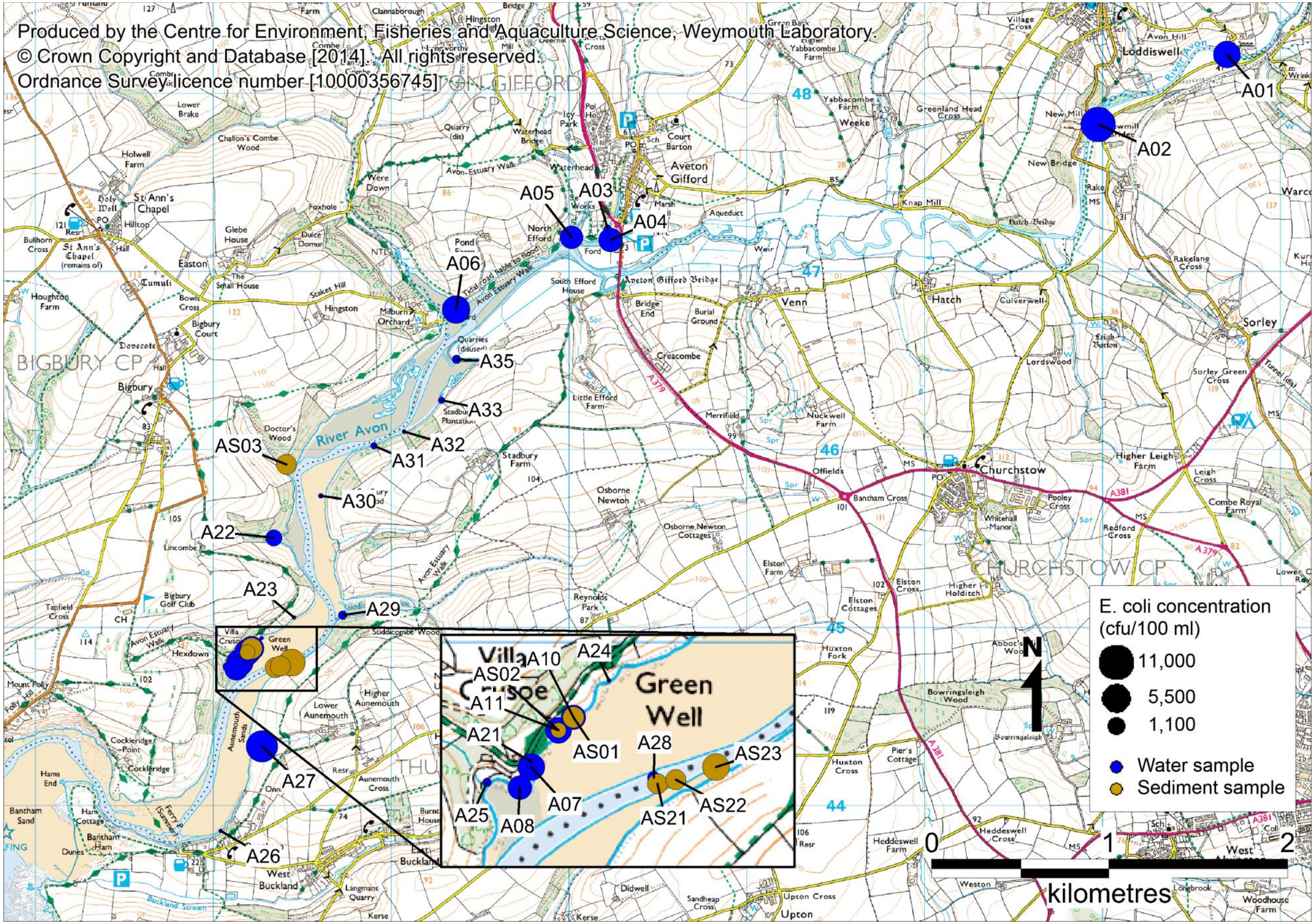


Figure XII.2: Sample results (Table XII.2 and Table XII.3 for details).

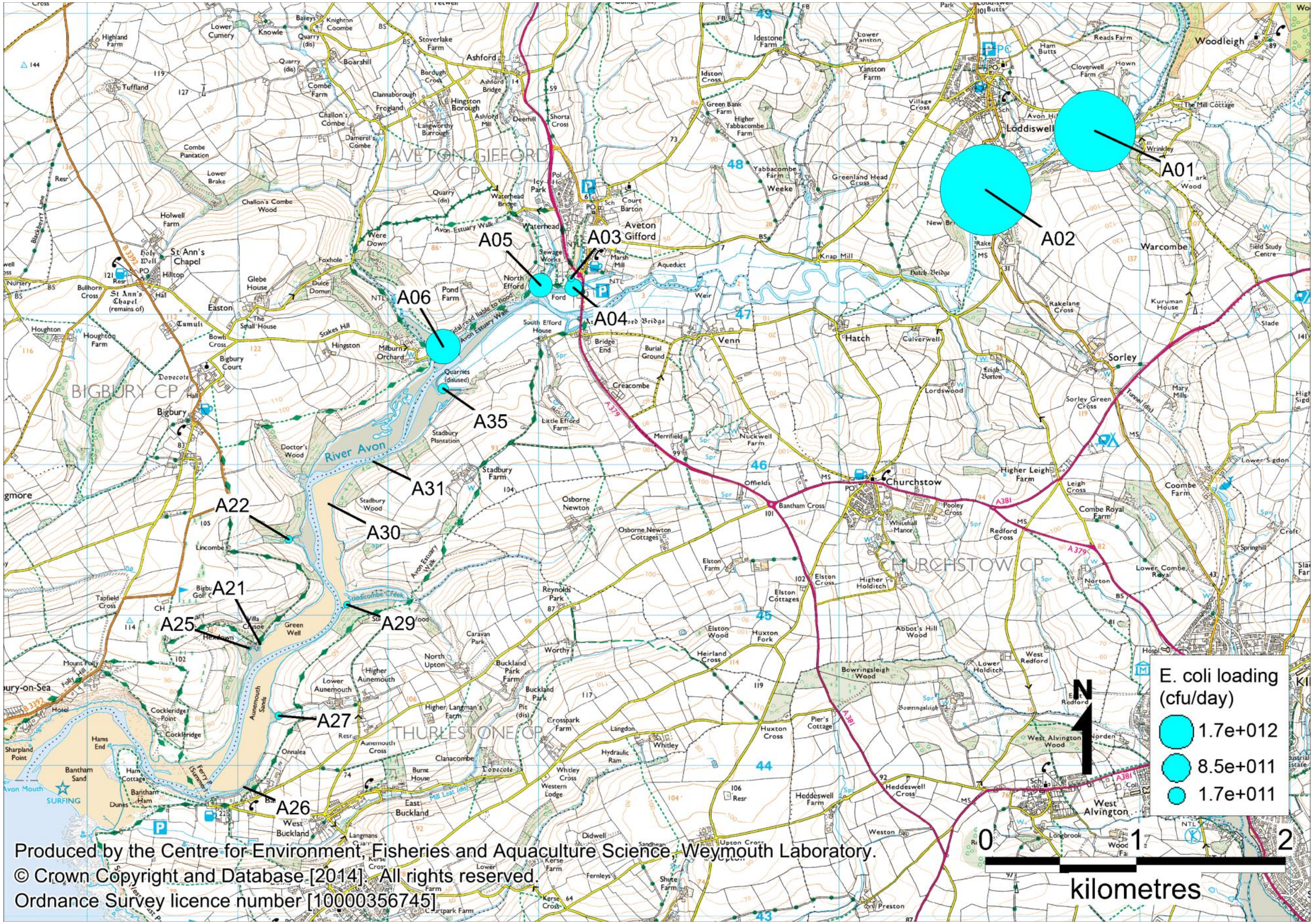


Figure XII.3: *E. coli* loadings (Table XII.2 for details).

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

Sample ID	Observation number	Date & time	Description	Flow (m^3/s)	*E. coli* concentration (cfu/100 ml)	*E. coli* loading (cfu/day)	NGR
A01	1	17/02/2014 12:09	River Avon	29.0	4,600	$1.15x10^{14}$	SX 72700 48220
A02	2	17/02/2014 12:09	River Avon	17.4	11,000	$1.66x10^{14}$	SX 71975 47827
A03	3	17/02/2014 12:40	Stream	0.5	70	$2.79x10^{10}$	SX 69217 47239
A04	4	17/02/2014 12:48	Stream	0.2	3,300	$6.17x10^{11}$	SX 69233 47177
A05	5	17/02/2014 12:58	Stream	0.8	2,800	$1.99x10^{12}$	SX 69013 47193
A06	6	17/02/2014 13:15	Stream	1.4	5,600	$6.66x10^{12}$	SX 68365 46785
A07	7	17/02/2014 13:47	Estuary water		4,900		SX 67147 44802
A08	8	17/02/2014 14:01	Estuary water		3,200		SX 67129 44769
A10	9	17/02/2014 14:12	Estuary water		3,900		SX 67214 44881
A11	11	17/02/2014 14:12	Estuary water		4,200		SX 67190 44860
A21	14	18/02/2014 09:27	Stream	0.03	70	$1.95x10^{9}$	SX 67148 44809
A22	16	18/02/2014 10:10	Stream	0.1	1,000	$4.45x10^{10}$	SX 67339 45503
A23	18	18/02/2014 10:44	Spring		<10		SX 67454 45056
A24	19	18/02/2014 11:06	Spring		<10		SX 67270 44939
A25	20	18/02/2014 11:21	Culvert	0.03	130	$3.34x10^{9}$	SX 67077 44778
A26	24	18/02/2014 13:21	Spring	$2.0x10^{-4}$	<10	$8.64x10^{5}$	SX 67041 43857
A27	25	18/02/2014 13:34	Stream	0.01	8,000	$4.13x10^{10}$	SX 67273 44331
A28	28	18/02/2014 13:45	Estuary water		360		SX 67341 44785
A29	32	18/02/2014 14:10	Stream	0.3	100	$2.30x10^{10}$	SX 67727 45069
A30	33	18/02/2014 14:40	Stream	0.04	20	$7.26x10^{8}$	SX 67603 45740
A31	34	18/02/2014 14:40	Stream	$3.0x10^{-3}$	50	$1.29x10^{8}$	SX 67902 46021
A32	36	18/02/2014 15:04	Spring		10		SX 68071 46100
A33	38	18/02/2014 15:14	Spring		50		SX 68282 46276
A35	39	18/02/2014 15:30	Marsh drainage	1.2	130	$1.38x10^{11}$	SX 68367 46507

Table XII.3: *E. coli* results for sediment samples.

Sample ID	Observation number	Date & time	*E. coli* concentration (cfu/100 ml)	NGR
AS01	10	17/02/2014 14:12	2,300	SX 67214 44881
AS02	12	17/02/2014 14:12	800	SX 67190 44860
AS03	13	18/02/2014 09:27	1,800	SX 67410 45915
AS21	29	18/02/2014 13:49	1,900	SX 67347 44775
AS22	30	18/02/2014 13:52	1,900	SX 67376 44782
AS23	31	18/02/2014 13:54	4,900	SX 67440 44802

Figure XII.4

Figure XII.5


Figure XII.6


Figure XII.7

Figure XII.8

Figure XII.9

Figure XII.10

Figure XII.11

Figure XII.12

Figure XII.13


Figure XII.14


Figure XII.15

Figure XII.16

Figure XII.17

References

ADAS, 2003. Evaluation of the impact on shellfisheries production of runoff from land receiving organic wastes. Project B05006. Technical Report. March 2003.

Ashbolt, J. N., Grabow, O. K., Snozzi, M., 2001. Indicators of microbial water quality. In Fewtrell, L. and Bartram, J. (Eds). Water quality: guidelines, standards and health. IWA Publishing, London. pp. 289−315.BTO, 2014. WEBS counts online interface. Available at: http://blx1.bto.org/webs-reporting/?tab=lowtide&locid=LOC675352. Accessed March 2014.

Brown J., 1991. The final voyage of the Rapaiti. A measure of surface drift velocity in relation to the surface wind. Marine Pollution Bulletin 22: 37-40.

Devon Mammal Group, 2014. Available at: http://www.devonmammalgroup.org/devons-mammals/otter/ Accessed February 2014.

Environment Agency, 2009. South Devon Catchment Flood Management Plan. Summary Report December 2009.

EU Working Group on the Microbiological Monitoring of Bivalve Harvest Areas (2010). Microbiological Monitoring of Bivalve Harvest Areas. Guide to Good Practice: Technical Application. Issue 4, August 2010.

European Communities, 2004. EC Regulation No 854/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules on products of animal origin intended for human consumption. Official Journal of the European Communities L226: 83-127.

European Communities, 2006. Directive 2006/113/EC of the European parliament and of the Council of 12 December 2006 on the quality required of shellfish waters (codified version). Official Journal of the European Communities L376: 14-20.

Futurecoast, 2002. Department of Environment, Food and Rural Affairs (Defra), Halcrow Group Ltd 3 CD set.

Geldreich, E.E., 1978. Bacterial and indicator concepts in feces, sewage, stormwater and solid wastes. In Berg, G. (ed.). Indicators of Viruses in Water and Food. MI: Ann Arbor.

Holt, C., Austin, G., Calbrade, N., Mellan, H., Hearn, R., Stroud, D., Wotton, S., Musgrove, A., 2012. Waterbirds in the UK 2010/11. The Wetland Bird Survey.

Kay, D., Crowther, J., Stapleton, C.M., Wyler, M.D., Fewtrell, L., Anthony, S.G., Bradford, M., Edwards, A., Francis, C.A., Hopkins, M. Kay, C., McDonald, A.T., Watkins, J. and Wilkinson, J., 2008a. Faecal indicator organism concentrations and catchment export coefficients in the UK. Water Research 42, 442-454.

Met Office, 2012. Regional Climates. Available at: http://www.metoffice.gov.uk/climate/regional/ Accessed February 2014.

Mitchell, P. Ian, S. F. Newton, N. Ratcliffe & T. E. Dunn, 2004. Seabird Populations of Britain and Ireland, Results of the Seabird 2000 Census (1998-2002). T&AD Poyser, London.

NERC, 2012. National River Flow Archive, Catchment Spatial Information. Available at: http://www.ceh.ac.uk/data/nrfa/data/search.html. Accessed September 2013.

Obiri-Danso, K. and Jones, K., 2000. Intertidal sediments as reservoirs for hippurate negative campylobacters, salmonellae, and faecal indicators in three EU recognised bathing waters in North-West England. Water Research 34(2): 519−527.

SCOS, 2012. Special Committee on Seals. Scientific Advice on Matters Related to the Management of Seal Populations: 2012. http://www.smru.st-andrews.ac.uk/pageset.aspx?psr=411. Accessed February 2014.

South Devon Area of Outstanding Beauty. Available at: http://www.southdevonaonb.org.uk/coast-countryside/estuaries/avon-estuary. Accessed February 2014.

South West Coast Path website, 2013. Walk – The Avon Estuary. Available at: http://www.southwestcoastpath.com/walksdb/702/. Accessed February 2014

South West Tourism (2004), South Hams Visitor Survey 2003. Accessed on 16/01/2014. Available from http://www.tourisminsights.info/ONLINEPUB/SOUTH%20WEST%20TOURISM/SWT%20PDFS/SOUTH%20HAMS%20DISTRICT%20COUNCIL%20(2004),%20Visitor%20Survey%202003,%20Report%20Prepared%20by%20South%20West%20Tourism%20for%20South%20Hams%20District%20Council,%20Totnes.pdf

The Aune Conservation Association (ACA), 2009. Fishing on and around the Avon Available at: http://auneconservation.org.uk/wp-content/uploads/2011/02/A-conservationists-guide-to-fishing-around-the-Avon-estuary.pdf Accessed February 2014

The Green Blue, 2010. Pump Out Directory. Available at: http://www.thegreenblue.org.uk/pump_out_directory.aspx. Accessed February 2014

Tree, J.A., Adams, M.R., Lees, D.N., 1997. Virus inactivation during disinfection of wastewater by chlorination and UV irradiation and the efficacy of F+ bacteriophage as a ‘viral indicator’. Water Science and Technology, Volume 35 (11–12), 227-232

Uncles, R.J., Stephens, J.A. and Harris, C., 2007. Final Report on the Sediments and Hydrography of the Devonshire Avon Estuary. Avon Siltation Study

Visit South Devon (2012), Visit South Devon Marketing Strategy 2013/14. Accessed on 16/01/2014. Available from: http://www.southhams.gov.uk/CHttpHandler.ashx?id=5258&p=0

Younger, A.D., Lee, R.J. and Lees, D.N. 2003. Microbiological monitoring of bivalve mollusc harvesting areas in England and Wales: rationale and approach. In: Villalba, A., Reguera, B., Romalde, J. L. and Beiras, R. (eds). Molluscan Shellfish Safety. Consellería de Pesca e Asuntos Marítimos de Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO, Santiago de Compostela, Spain. pp. 265−277.

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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