EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Yealm Estuary (Devon)

2010

Cover photo: Bivalve mollusc bed at Thorn South.

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STATEMENT OF USE: This report provides information from a study of the information available relevant to perform a sanitary survey of bivalve mollusc classification zones in the Yealm Estuary (Devon). Its primary purpose is to demonstrate compliance with the requirements for classification of bivalve mollusc production areas, determined in EC Regulation No. 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. The Centre for Environment, Fisheries & Aquaculture Science (Cefas) undertook this work on behalf of the Food Standards Agency (FSA).

DISSEMINATION: Food Standards Agency, Plymouth Port Health Authority, Environment Agency, Devon Sea Fisheries Committee.

RECOMMENDED BIBLIOGRAPHIC REFERENCE: Cefas, 2010. Sanitary survey of the Yealm Estuary (Devon). 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, 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. Infectious disease outbreaks are more likely to occur in coastal areas, where bivalve mollusc production areas (BMPAs) are impacted by sources of microbiological contamination of human and/or animal origin.

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 the BMPA. 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 information relevant to undertake a sanitary survey for farmed mussels (*Mytilus* spp.) and Pacific oysters (*Crassostrea gigas*) commercially harvested in the Yealm Estuary together with new information obtained from a shoreline survey undertaken in the estuary.

1.2 SITE DESCRIPTION

YEALM ESTUARY

The Yealm Estuary (NGR) SX545495 is located in Devon, south west coast of England. The estuary is sheltered, branching and narrow (Figure 1.1) and has a relatively short shoreline (Table 1.1). It is a type 3b ria[1] without spits with a relatively low river plume discharge (Halcrow Group Ltd, 2002).

Figure 1.1 Aerial view of the Yealm Estuary.
Reproduced under licence Google Earth™ mapping service.

The main river channel meanders from Steer Point to the mouth at Season Point is 3.7km long. This stretch of the channel is fairly narrow throughout (approximately 160m wide).

The estuarine coastal area is predominantly formed by rocky shores bordered by woodland and agricultural land. Sandflats, mudflats and small areas of

[1] Drowned river valley in origin, with exposed rock platform and no linear banks.

saltmarsh in the upper reaches (2.5 hectares in total; Boorman, 2003) dominate the intertidal area.

Table 1.1 Main characteristics of the Yealm Estuary.

Geomorphological type	Ria
Shoreline length (km)	28.1
Core area (ha)	445.8
Intertidal area (ha)	154

Data from the Estuary Guide (ABPmer and Wallingford, 2009).

The lower estuary contains extensive intertidal mudflats. There is a sand bar at the mouth sheltering the main estuary from swell and wave exposure.

Commercial uses of the estuary include fisheries and tourism. Tourism-related activities are both water-based (e.g. rowing, canoeing, fishing, swimming) and land-based (walking, cultural).

CATCHMENT

The BMPA is under the influence of pollution sources from river catchments show in Figure 1.2. These catchments are essentially rural in character and include upland moor, steep sided, wooded river valleys and low-lying, undulating land in the lower reaches. The elevation in the Yealm river catchment ranges between 7.4–492m (weighted average = 169m). Steep land may generate significant volumes of surface runoff and potentially microbiological contamination of faecal origin, which can be drained into watercourses under heavy and/or prolonged rainfall.

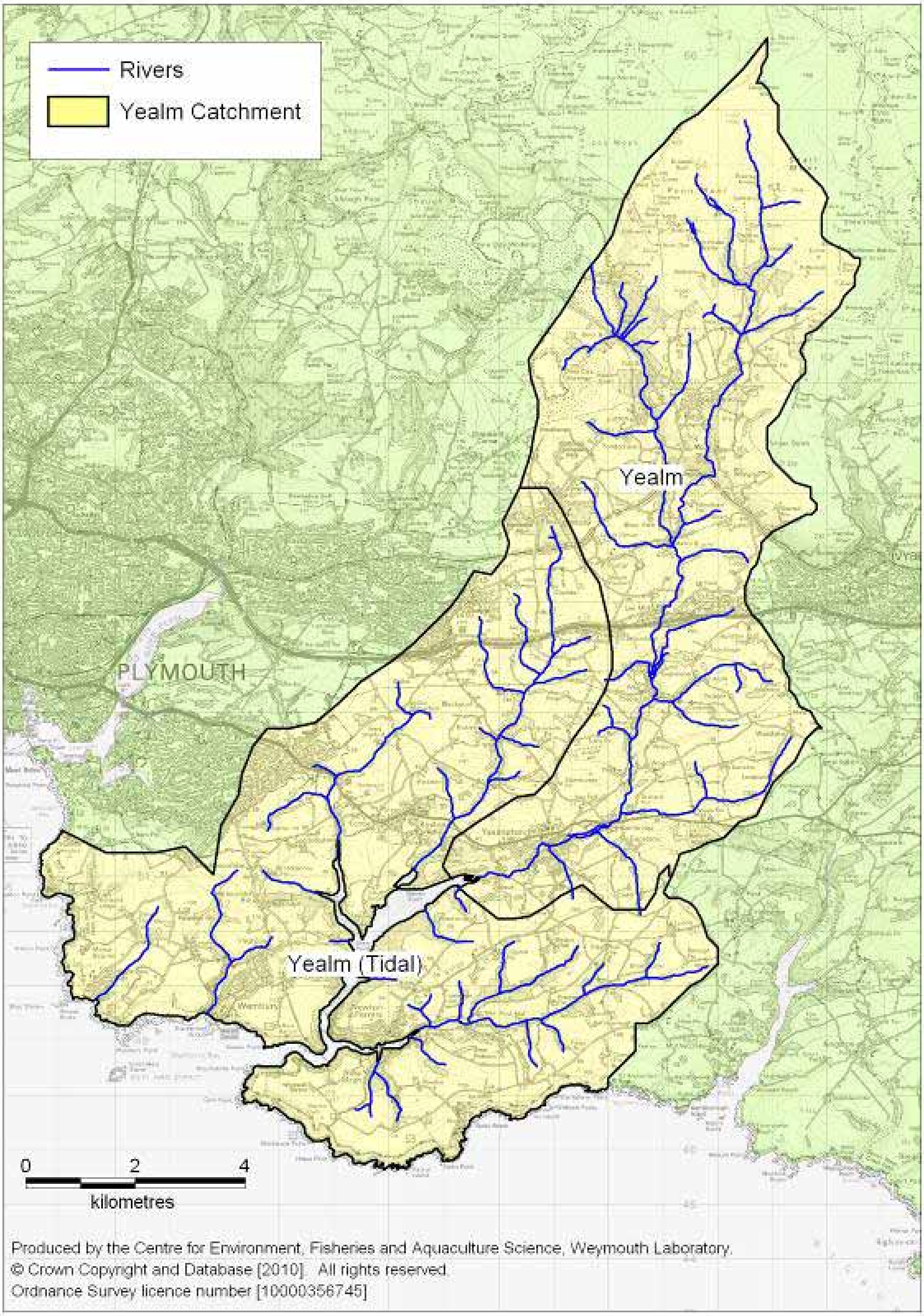

Figure 1.2 Catchments draining to the Yealm Estuary.

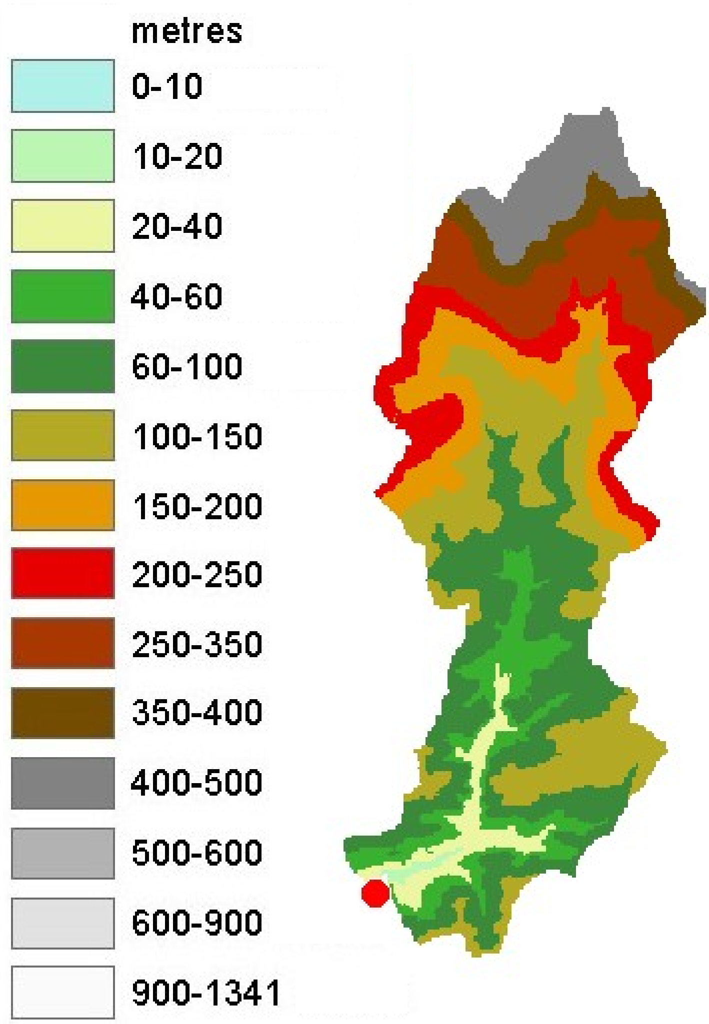

Figure 1.3 Elevation in the River Yealm catchment.
Data from NERC (2005).

Natural and improved grassland is the dominant land cover, with significant patches of woodland in river valley sides.

The solid geology of the upper catchment comprises of Upper and Lower (Dartmouth) Devonian Slates, whereas the middle reaches are essentially formed by Mid Devonian Slates. The lower catchment comprises of Lower Devonian rocks of the Meadfoot Group (Environment Agency, 1996). These rocks have low primary permeability and porosity which limits groundwater flow and storage (Environment Agency, 1996).

Grassland on impermeable soils means that surface or sub-surface runoff is the most likely route of pollution across the catchment (Mawdsley *et al*., 1995).

Various habitat conservation designations occur within the catchment, including the Yealm Site of Special Scientific Interest (SSSI), Dendies Wood and South Dartmoor (SSSI), Plymouth Sound, Tamar & Yealm Special Maritime Area and Plymouth Sound and Estuaries Special Area of Conservation (Tonkin *et al.*, 1997).

2. SHELLFISHERIES

2.1 SPECIES, LOCATION AND EXTENT

The harvesting of bivalve molluscs for human consumption is a century old activity in the Yealm Estuary. Detailed descriptions of oyster rearing in tanks can be found in Hughes (1940) and Wilson (1941).

The estuary had an important role early in the introduction of Pacific oysters (*Crassostrea gigas*) in the UK. In April 1967, growing trials took place with 19 month old juvenile oysters of 16g suspended from a raft (Spencer, 1971). Davidson (1976) described that a private hatchery was mainly producing this species and MacAllister Elliot & Partners Ltd. (1999) pointed out that these experiments resulted in the highest Shell Condition Index of all of the 10 trials being undertaken at the time in the UK.

Native oysters (*Ostrea edulis*) were also cultivated in the Yealm (Laing *et al.*, 2005), but commercial operations for this species were severely affected by *Bonamia*. Since the 1970s, bivalve mollusc production has focused on fattening Pacific oysters (MacAllister Elliot & Partners Ltd., 1999) and mussels (*Mytilus* spp.). Pacific oysters grow well in sandy and firm/solid substrata under salinities of 20–30psu and 8–30°C (minimum for growth = 8–9°C) (Laing and Spencer, 2006). Natural spatfall has been recorded in the estuary with episodes of settlement being associated with warmer years (Sivret *et al.*, 2008). This was the case in 2003–2004, when extensive wild spat settled on harvestable stock and trestles (Sivret *et al.*, 2008). Currently, commercial operations are established at Fox Cove and Thorn (Figure 2.1).

Mussels are often found in sheltered estuaries, just below the low water mark, where a food supply of suspended organic detritus and phytoplankton is available (Tebble, 1976). The optimum salinity range for mussel growth is 20–35psu (Laing and Spencer, 2006).

Both *Mytilus galloprovincialis* and *Mytilus edulis* have been recorded along the coasts of southwest England (National Biodiversity Gateway, 2009). Literature indicates that both species present large morphological, physiological and behavioural similarities and are therefore difficult to differentiate for commercial purposes due to adaptations to environmental conditions (see Wijsman and Smaal, 2006 and references therein). Data from molecular analyses have demonstrated high levels of hybridisation[2] and gene introgression[3] between these species along the coast of Cornwall. Therefore, in the context of the present sanitary survey, taxonomy of mussels is referred at genus level.

The common cockle *Cerastoderma edule* has been recorded in the estuary (Hiscock and Moore, 1986). There is no commercial interest for this species at the moment. A sample collected at Steer Point in March 2004 for the purposes of investigating the microbial quality of this resource returned an *E. coli*

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[2] The formation of a hybrid organism, e.g. by a cross between genetically dissimilar organisms.
[3] The incorporation of the genes of one species into the gene pool of another species.

concentration of 54,000 MPN 100g-1 FIL. It was not ascertained whether this high result was typical for this species at this site or due to an exceptional pollution event.

Figure 2.1 Location of bivalve mollusc beds and representative monitoring points in the Yealm Estuary.

2.2 GROWING METHODS AND HARVESTING TECHNIQUES

Mussels and Pacific oysters are grown in bags supported above the riverbed on trestles (Figure 2.2) and are harvested by hand during periods of low water.

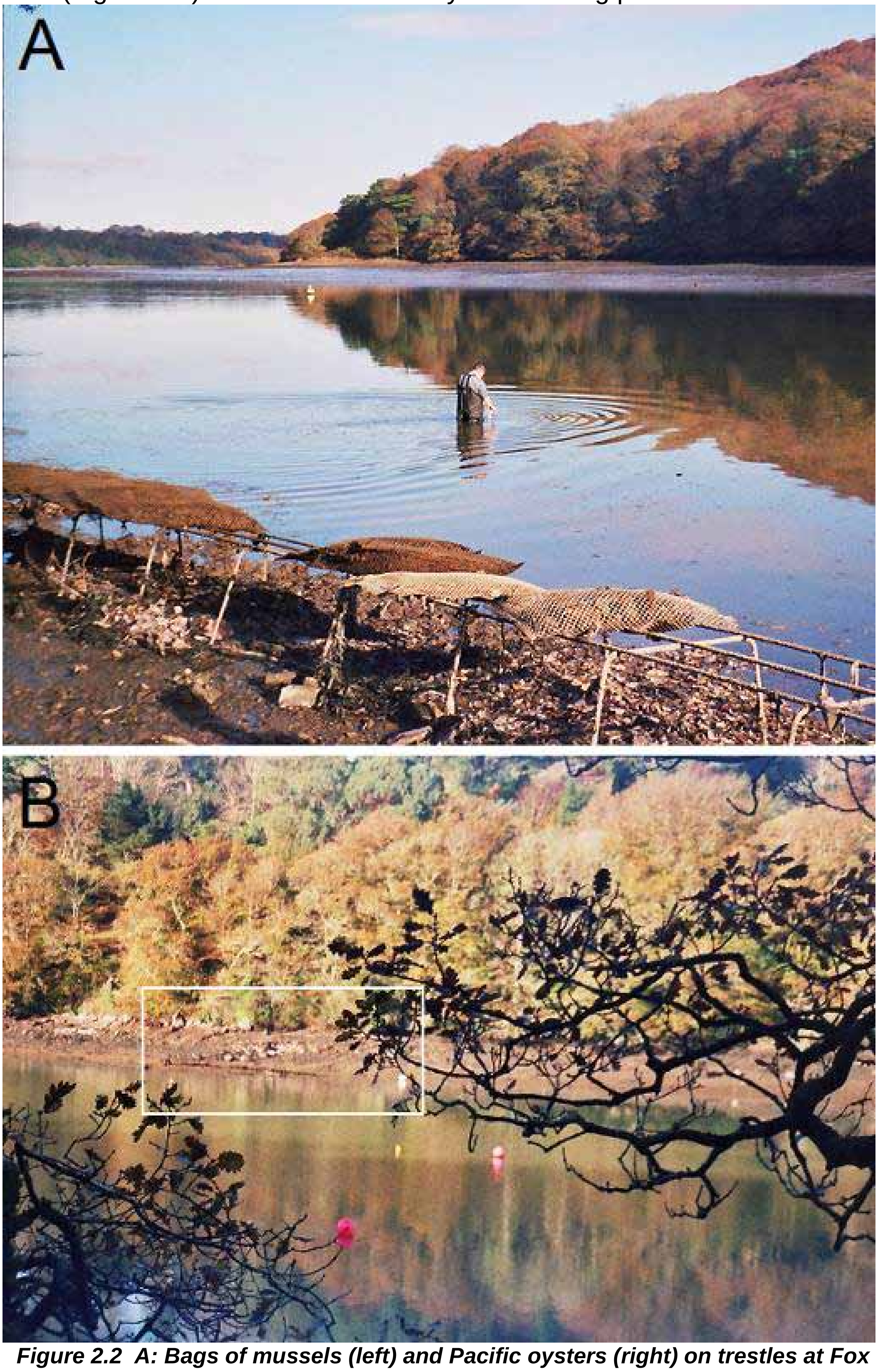


Figure 2.2 A: Bags of mussels (left) and Pacific oysters (right) on trestles at Fox Cove; B: bivalve mollusc bed at Thorn.

NB. Note relative position of bags in the intertidal and the proximity of moorings in 2.1B.

2.3 SEASONALITY OF HARVEST, CONSERVATION CONTROLS AND DEVELOPMENT POTENTIAL

All bivalve molluscs in the Yealm Estuary are harvested on a year-round basis.

The estimated annual mussel and Pacific oyster productions for 2008 are 5 and 30 tonnes, respectively. Three people work full time in the activity.

The commercial production of bivalve molluscs on the Yealm is not covered by Several, Regulating or Hybrid Order.

The fundus is owned by the Duchy of Cornwall and Kitley Estates (parts of the upper estuary only).

2.4 HYGIENE CLASSIFICATION

Classifications for mussels at Fox Cove and Pacific oysters at Happy Cove were initially given in 1993 (Table 1.2), following the implementation of statutory controls on the commercial production of bivalve molluscs in England and Wales in 1992. The commercial interest for these beds was lost and classification allowed to lapse and a number of years later re-gained. In 1994, commercial operations for Pacific oysters were extended to Fox Cove and Thorn in 1994 and these have maintained stability in classification over the years (Table 1.2).

Table 1.2 Historical classifications of bivalve mollusc beds in the Yealm Estuary.

Bed name	Fox Cove	Fox Cove	Thorn - Relay	Thorn	Happy Cove
Bed ID	B031E	B031H	B031F	B031J	B031G
Species	*C. gigas*	*Mytilus* spp.	*Mytilus* spp.	*C. gigas*	*C. gigas*
1993	-	B	-	-	B
1994	B	-	-	B	-
1995	B	-	-	B	-
1996	B	-	-	B	-
1997	B	-	-	B	-
1998	B	-	-	B	-
1999	B	-	-	B	-
2000	B	B	-	B	-
2001	B	B	B	B	B
2002	B	B	B	B	B
2003	B	B	B	B	n/c
2004	B-LT	B	B	B	n/c
2005	B-LT	C	B-LT	B-LT	n/c
2006	B-LT	C	B[2]	B-LT[2]	n/c
2007	B-LT	C	B[2]	B-LT[2]	n/c
2008	B-LT	C	B-LT[2]	B-LT	n/c
2009	B-LT[2]	C[1]	C	B-LT	n/c

N/c - not classified. 1 - Classification is provisional due to insufficient sample results, either in number or period of time covered. 2 - Results close to the tolerance limit. A downgrade may be possible if further failures are returned.
LT - Long-Term classification system applies. NB. Long-Term (LT) classification system was introduced in England and Wales alongside the annual classification system, and applies to class B areas only. New class B areas will initially be given annual classification until they meet criteria for a long-term classification.

A second mussel bed at Thorn used for relaying purposes obtained its first classification in 2001 and, since then, has maintained class B. Mussels at Fox Cove are class C.

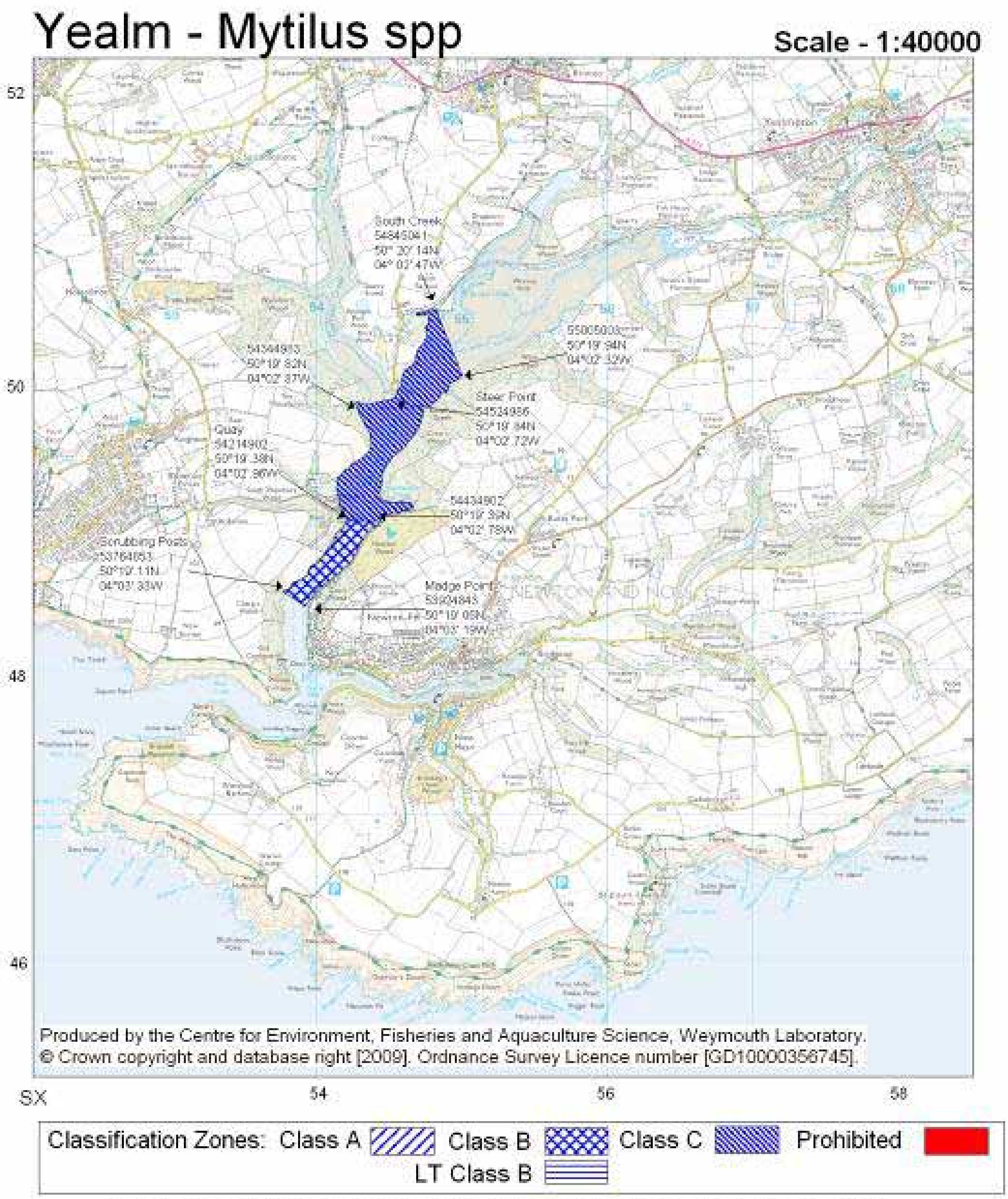
Table 1.3 summarises the post-harvest treatment required before bivalve molluscs can be sold for human consumption.

Table 1.3 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	>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.

Classification zone boundaries are shown in Figures 2.3−2.4.



Classification of Bivalve Mollusc Production Areas: Effective from 15 September 2009

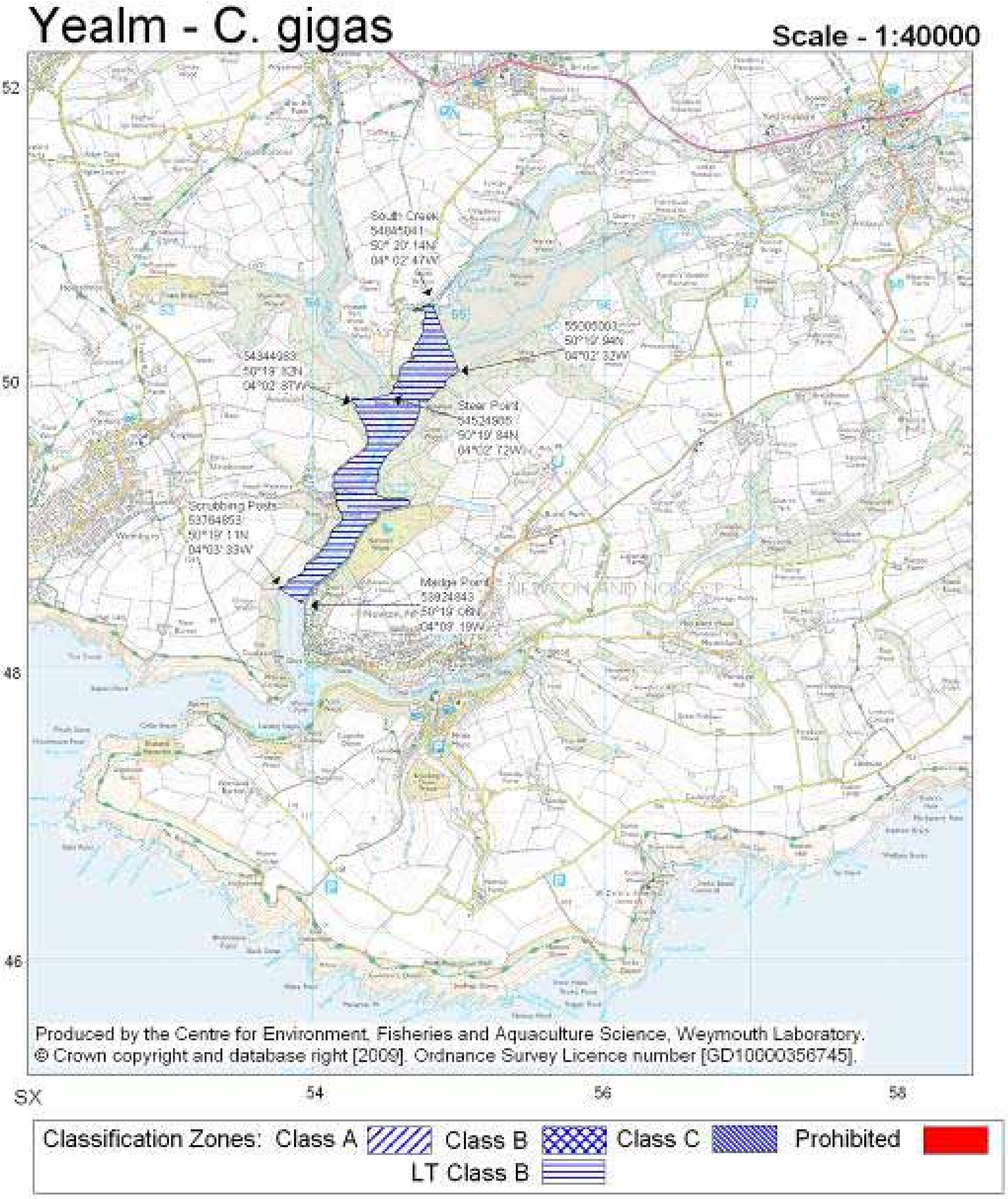
The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

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 WGS 84
Mytilus spp. at Thorn are seasonal Class B from 1 October to 30 April (reverting to Class C at all other times)
Separate map available for C. gigas at Yealm

Food Authority: Plymouth Port Health Authority

Figure 2.3 Classification zones and current classification status for mussels in the Yealm Estuary.



Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2009

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
Separate map available for Mytilus spp. at Yealm

Food Authority: Plymouth Port Health Authority

Figure 2.4 Classification zones and current classification status for Pacific oysters in the Yealm Estuary.

3. OVERALL ASSESSMENT

AIM

This section presents an overall assessment of pollution sources on the microbiological contamination of bivalve mollusc beds in the Yealm Estuary as a result of a sanitary survey undertaken by Cefas on behalf of the Food Standards Agency. Its main purpose is to inform the sampling plan for the microbiological monitoring and classification of the bivalve mollusc production area (BMPA) in this geographical area.

SHELLFISHERIES

The currently classified beds for mussels (*Mytilus* spp.) and Pacific oysters (*Crassostrea gigas*) include intertidal areas in the mid reaches of the estuary.

These beds fall under the jurisdiction of Plymouth Port Health Authority.

POLLUTION SOURCES

FRESHWATER INPUTS

The catchment (total area = 12,430 hectares) assessed for the purposes of this sanitary survey is drained by a river network formed by the River Yealm (total length = 18.5km; mean flow = 1.670m^3 s^{-1}) and other less significant freshwater inputs discharging to the upper estuary and to Newton Creek, at the mouth of the estuary. The River Yealm constitutes the main route of microbiological contamination from the wider catchment.

Hydrographs for the River Yealm at Puslinch show higher flows during the autumn–winter months than those during the summer. Water levels in this river are characterised by a fast response to rainfall events and a relatively sharp recession limb. This response is caused by the steep topography of the catchment, relatively high rainfall totals and low permeability of the main geological formations. This suggests that the Yealm is highly responsive catchment and that the winter corresponds to the period of higher risk of runoff contamination.

AGRICULTURE

The Yealm is a rural and sparsely populated catchment, predominantly used for agriculture. It was one of the priority catchments identified by the Environment Agency and Natural England as being at risk of diffuse water pollution from agricultural land. Cattle having direct access and defecating in watercourses, erosion of river banks and runoff from fields where animal manures have been applied were the main problems identified.

Soil erosion and compaction and over application of slurry at the wrong time of year may promote periods of water quality deterioration in watercourses. Information on sewage sludge spreading to agricultural land across the catchment indicates that the periods of higher risk of microbial loads to estuary from these diffuse sources would be January–March and August–October and both the upper and lower reaches of the estuary are likely to be vulnerable.

Livestock production (total number of farmed animals is over 24,700) is based on sheep farming, predominantly in the uplands and mixed cattle and sheep in areas of improved and natural grassland in the valleys.

Deteriorated microbial water quality is expected to occur from faecal matter deposited in these areas when farm yard manure and slurries are spread in agricultural fields from the wider catchment shortly before/during rainfall events, in particular when these are spread near a watercourse.

HUMAN POPULATION

Human population (approximately 18,450) is considerable lower than the total number of animals farmed in the catchment. Bivalve mollusc beds in the vicinity of the urbanised areas of Yealmpton (resident population = 1,561 people) at the head and Newton Ferrers (1,195 people) at the mouth of the estuary will be liable to impact from point source discharges and runoff from impermeable land.

Water-based tourism activities in the estuary are likely to increase the background levels of contamination in the estuary. Furthermore, the contribution of pollution sources of human origin is expected to markedly increase during the summer tourist season.

SEWAGE DISCHARGES

A programme of work has been undertaken by South West Water to upgrade a number of sewage discharges that have, or once had, the potential to influence the Yealm Estuary Shellfish Water. The most significant upgrade was the installation of UV disinfection at Brixton Sewage treatment Works (STW) in 2004.

A number of continuous and intermittent water company sewage discharges representing a significant or potentially significant impact on the microbial water quality of the estuary occur within 10km of the estuary and its tidal limit. The most significant continuous discharges to bivalve molluscs are associated with the urbanised areas at the head and the mouth of the estuary:

- Newton Ferrers STW (DWF = 720 $m^3 d^{-1}$);
- Yealmpton STW (DWF = 250 $m^3 d^{-1}$); and
- Brixton STW (DWF = 215 $m^3 d^{-1}$).

A number of intermittent discharges (combined sewer overflows, emergency overflows and overflows from pumping stations) discharge to the estuary or its tributaries. Those considered to have a potential local significance are:

- Brixton STW storm;
- Courtwood Road PS;
- Winston Lane CSO;

- Kiln Quay PSCSO;
- Riverside CSO;
- Bridge End PSCSO;
- Collaton Cross PS; and
- Noss Mayo PS.

Analysis of sewage spill event monitoring data indicated an increase in the total duration of spills from Courtwood Road PS in 2008/09 relative to previous years. Time series analysis evidenced that although elevated *E. coli* results seemed to be associated to periods of prolonged or high rainfall, no consistent pattern could be detected in relative *E. coli* contamination and sewage spill event/duration at these sites.

BOATS

There are approximately 600 moorings operated by the Yealm Harbour Authority and a further 70 moorings privately owned by the Kitley Estate.

It has long been established that sewage discharged from boats could represent a significant public health risk for bivalve mollusc beds. A significant number of people are likely to stay overnight. The existence of pump out facilities at Yealm Steps pontoon may contribute to minimise the risk of sewage pollution from boats. However, the contribution of these sources is difficult to quantify due to the intermittent nature of these discharges. Bivalve mollusc beds will be vulnerable to pollution from moored boats.

SUMMARY OF POLLUTION SOURCES

An overview of sources of pollution likely to affect the levels of microbiological contamination in the Yealm Estuary is shown in Table 3.1 and Figure 3.1.

Table 3.1 Qualitative assessment of variation in microbiological pollution load to the Yealm Estuary.

Pollution source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sewage treatment works	Orange	Orange	Orange	Red	Red	Red	Orange	Orange	Orange	Orange	Orange	Orange
Farmyard manure/slurries application to land	Red	Red	Red						Red	Red	Red	Red
Sewage sludge application to land		Red	Red						Red			
Freshwater inputs						Orange	Orange	Orange	Red	Red	Red	Red
Rainfall						Orange	Orange	Orange	Red	Red	Red	Red
Peak human population (tourist season)			Red	Red	Red	Red	Red	Red	Red			
Boats†			Red	Red	Red	Red	Red	Red	Red			

** Assessment based on the quality of UV-treated effluent discharges from Brixton STW and therefore merely indicative of the load attributed to these sources.*
† Increased number of days on board.
Red - high risk; orange - moderate risk.

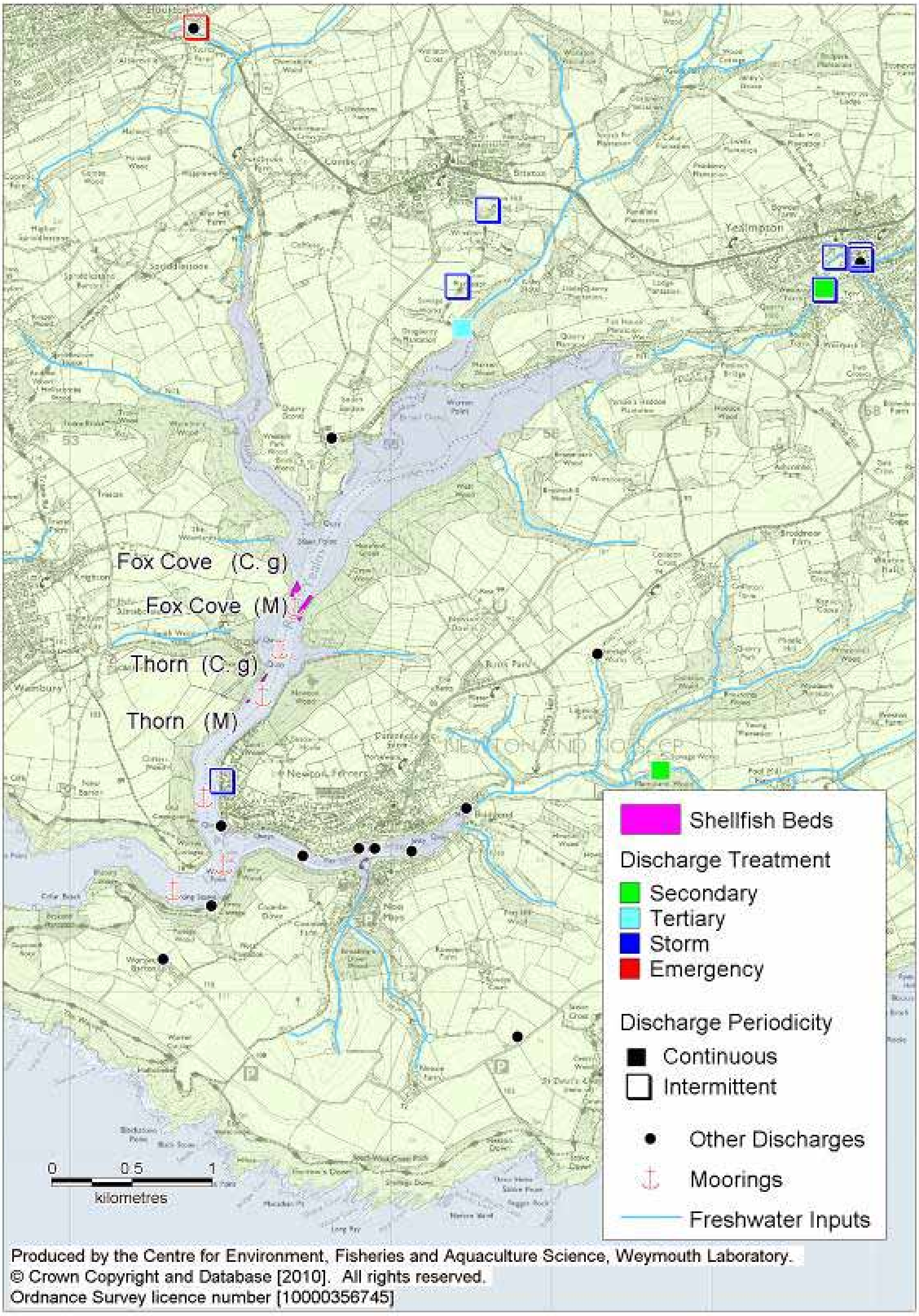


Figure 3.1 Significant sources of microbiological pollution to the Yealm Estuary.

HYDRODYNAMICS

The upper reaches of the estuary contain significant proportions of intertidal drying areas at Low Water Springs. The main river channel is relatively shallow and meandering, in particular the stretch where bivalve mollusc beds are established. Depths increase to 3.8m relative to Chart Datum at Red Cove at the mouth of the estuary. A sand bar lies immediately seaward of Red Cove and crosses the mouth of the estuary as it meets Wembury Bay.

Bivalves growing at Fox Cove and Thorn will not be exposed to contamination during periods of low water. Contaminated runoff from retained seawater and/or washed off by rainfall falling on the surface of mudflats into these creeks will be conveyed to the main estuary during the ebb tide. Therefore, nearshore shallow areas are likely to represent worst-case conditions.

Overall, the Yealm is a flood dominant macro-tidal estuary (mean range on springs = 4.7m; mean range on neaps = 2.2m). The longer and slower flood tide is likely to promote the transport of pollution towards the inner areas of the estuary, in particular that from sources situated near the mouth of the estuary.

The long tidal incursion (approximately 6.2km to Puslinch) indicates that short distances may be involved in the transport of microbial contaminants across the estuary between developed areas at the mouth (Newton Ferrers) and the upper reaches.

There is a substantial attenuation in current speeds towards the middle reaches of the estuary. During most of the time, wind driven currents are not expected to significantly influence water movements within the estuary. Strong wind conditions may however impinge effluent plumes upon the shore in the broader and shallower areas of the estuary.

Freshwater flows could be more important than tidal flows in determining the persistence of faecal contamination in the upper/middle reaches of the estuary. Low salinities recorded in the shellfish bed at Fox Cove indicate a significant influence of freshwater inputs in the middle reaches of the estuary and suggest the formation of partially-mixing conditions. These may determine absence of filter-feeding activity in bivalves.

SUMMARY OF EXISTING MICROBIOLOGICAL DATA

Analysis of historical data (2000–2009) from the Bathing Waters (BW) monitoring programme indicated low levels of faecal contamination in surface waters in Wembury Bay (outside the estuary and approximately 4.5km from the nearest bivalve mollusc bed). However, the microbial quality of waters at this site showed levels of the microbial indicator above the Imperative value in 2001 and 2009 suggesting some vulnerability to intermittent episodes of contamination in the outer estuary mouth. Literature suggests that this deterioration is more frequent outside the bathing season, particularly during adverse weather conditions. The nearest sewage discharges are combined sewer overflows at Gabber Head (outside the Yealm catchment; 3km) and X (mouth of the estuary; 3km).

Levels of faecal coliforms in the designated Shellfish Water during the period 2004–2006 were generally lower than those during the preceding four years. These samples are collected over periods of High Water and are therefore indicative of contamination when maximum dilution is likely to occur. An increase in the levels of the microbial indicator was detected in 2007, indicating that, despite remedial action to reduce microbial pollution in the estuary, the Yealm Shellfish Water is still vulnerable to episodes of microbial contamination impacting the quality of the waters and shellfish.

Historical data from the Shellfish Hygiene monitoring programme confirmed this vulnerability. Descriptive statistics indicated that overall Fox Cove is more contaminated than Thorn for both mussels and Pacific oysters. However, the differences between species/beds are less than 1Log. The lack of spatial differences between monitoring points could be due to the proximity of these beds relative to significant pollution sources.

The lack of statistically significant seasonal differences in the levels of *E. coli* in bivalves suggests that the monthly monitoring regime adequately reflects the risk of microbial contamination in the Yealm.

Statistically significant positive relationships were detected between rainfall and levels of *E. coli* in bivalves from all current representative monitoring points in the estuary. Therefore, rainfall seems an adequate parameter to predict levels of *E. coli* in bivalves in this estuary. However, the strength of the association varied according to the monitoring point and the time of sampling relative to the rainfall event. Higher coefficients were computed when sampling took place 1–2 days after the rainfall event. No positive associations were found between flows in the River Yealm and levels of *E. coli* in bivalves. Taken together, these results indicate that rainfall-depended discharges and dairy washings/surface runoff from agricultural land are the most likely significant sources of faecal contamination impacting the quality of bivalves in the Yealm.
This is confirmed by microbial source tracking studies undertaken by the Environment Agency across the Yealm catchment, which have indicated mixed dominance of animal/human sources across the catchment.

The shoreline survey on 10–11 March 2009 under dry/drizzle weather evidenced the following decreasing gradient of *E. coli* loading to the estuary:

- River Yealm;
- Stream at the head of Newton Creek≈stream at the head of Mudbank Lake≈stream at the head of Cofflete Creek;
- Noss Mayo Stream≈Stream near Kitley House;
- Stream at the head of Shortaflete Creek≈stream from sluice below pond at South Wembury; and
- Stream north of Fox Cove shellfish site.

Freshwater discharges to Cofflete Creek had previously been identified by Cefas and the LEA as a significant route of faecal indicator microorganisms to the estuary.

4. RECOMMENDATIONS

4.1 It is recommended that the number and location of the current representative monitoring points (RMPs) be maintained.

4.2 It is recommended that the currently classified mussel and Pacific oyster beds in the Yealm Estuary be represented by two classification zones (CZs), each with its own RMP.

4.3 The CZ at Fox Cove for mussels and Pacific oysters will be defined by lines crossing the main river from the Mean High Water Mark at SX 5438 4958-SX 5465 4958 (northern boundary) and SX 5430 4944-SX 5445 4927 (southern boundary).

4.4 A representative monitoring point (RMP) situated in the centroid of the bed for mussels and Pacific oysters at Fox Cove will be representative of microbial contamination delivered from the catchment via Cofflete Creek and the River Yealm.

4.5 The recommended maximum tolerance for this RMP is 10m. It is considered that this tolerance preserves the fixed location concept and minimises the effect of spatial variability in the extent of microbial contamination.

4.6 The recommended CZ at Thorn-South will encompass the mussel bed at Thorn and will be defined by lines extending from Mean High Water Mark to the middle of the main river channel at the Civil Parish boundary, north boundary referred to SX 5407 4879 and south boundary referred to SX 5407 4879.

4.7 The recommended CZ at Thorn-North will encompass the Pacific oyster bed at Thorn and will be defined by lines extending from Mean High Water Mark to the middle of the main river channel at the Civil Parish boundary, north boundary referred to SX 5421 4900 and south boundary referred to SX 5415 4893.

4.8 A representative monitoring point (RMP) situated in the centroid of the northern bed for Pacific oysters at Thorn will be representative of microbial contamination delivered from the catchment via Cofflete Creek and the River Yealm.

4.9 A representative monitoring point (RMP) situated in the centroid of the south bed for mussels at Thorn will be representative of microbial contamination delivered from the catchment via Cofflete Creek and the River Yealm.

4.10 The recommended maximum tolerance for RMPs referred in 4.7–4.8 is 10m. It is considered that this tolerance preserves the fixed location concept and minimises the effect of spatial variability in the extent of microbial contamination.

4.11 Consideration could be given by the Local Enforcement Authority (LEA) to sampling mussels and Pacific oysters during/immediately after rainfall events in order to reflect the worst-case scenario of contamination, potentially ensuring that the effects of land runoff and sewage spill events are identified, if the recommendations of the Good Practice Guide for Microbiological monitoring of Bivalve Mollusc Harvesting Areas (Cefas-CRL) are adopted in England and Wales at some time in the future.

5. SAMPLING PLAN

General Information

Location Reference

Production Area	Yealm Estuary
Cefas Main Site Reference	M031
Cefas Area Reference	FDR3029
Ordnance survey 1:25,000 map	OS Explorer OL20: South Devon - Brixham to Newton Ferrers, showing the district of South Hams, and parts of the Dartmoor National Park and South West Coast Path
Admiralty Chart	

Shellfishery

Species	Culture	Seasonality of harvest
Mussels (*Mytilus* spp.)	Farmed	Year round
Pacific oysters (*C. gigas*)	Farmed	Year round

Local Enforcement Authority

Name of Local Enforcement Authority	Plymouth Port health Authority, Environmental Health & port health Authority Civic centre Plymouth, Devon PL1 2EW
Telephone number (	01752 304141
Environmental Health Officer	Katharine O'Connor
Telephone number (	01752 304142
E-mail š	Katharine.OConnor@plymouth.gov.uk
Sampling Officer	John Wilde
Telephone number (	01752 304846
Fax number	01752 226314
E-mail š	john.wilde@plymouth.gov.uk

Requirement for Review

The need for this sampling plan to be reviewed will be assessed by the competent authority within six years or in light of any obvious known changes in sources of pollution of human (e.g. improvements in sewage treatment works) or animal origin likely to be a source of contamination for the bivalve mollusc production area.

Table 5.1 Number and location of representative monitoring points (RMPs) and frequency of sampling for classification zones in the Yealm Estuary.

Classification zone			**Fox Cove**	**Fox Cove**	**Thorn**	**Thorn**
RMP			**B031E**	**B031H**	**B031J**	**B031F**
RMP name			**Fox Cove**	**Fox Cove**	**Thorn North**	**Thorn South**
Geographic grid references (datum) of sampling points	**NGR**		SX 5440 4952	SX 5440 4952	SX 5421 4897	SX 5411 4882
	WGS84	**Latitude**	50°19.65'	50°19.65'	50°19.36'	50°19.27'
		Longitude	04°02.81'	04°02.81'	04°02.96'	04°03.04'
Species			*C. gigas*	*Mytilus* spp.	*C. gigas*	*Mytilus* spp.
Growing method			Farmed	Farmed	Farmed	Farmed
Harvesting technique			Hand-picking from bags	Hand-picking from bags	Hand-picking from bags	Hand-picking from bags
Sampling method			Hand-picking from bags	Hand-picking from bags	Hand-picking from bags	Hand-picking from bags
Depth (m)			Depth of bags	Depth of bags	Depth of bags	Depth of bags
Tolerance for sampling points (m)			10	10	10	10
Frequency of sampling			At least monthly	At least monthly	At least monthly	At least monthly

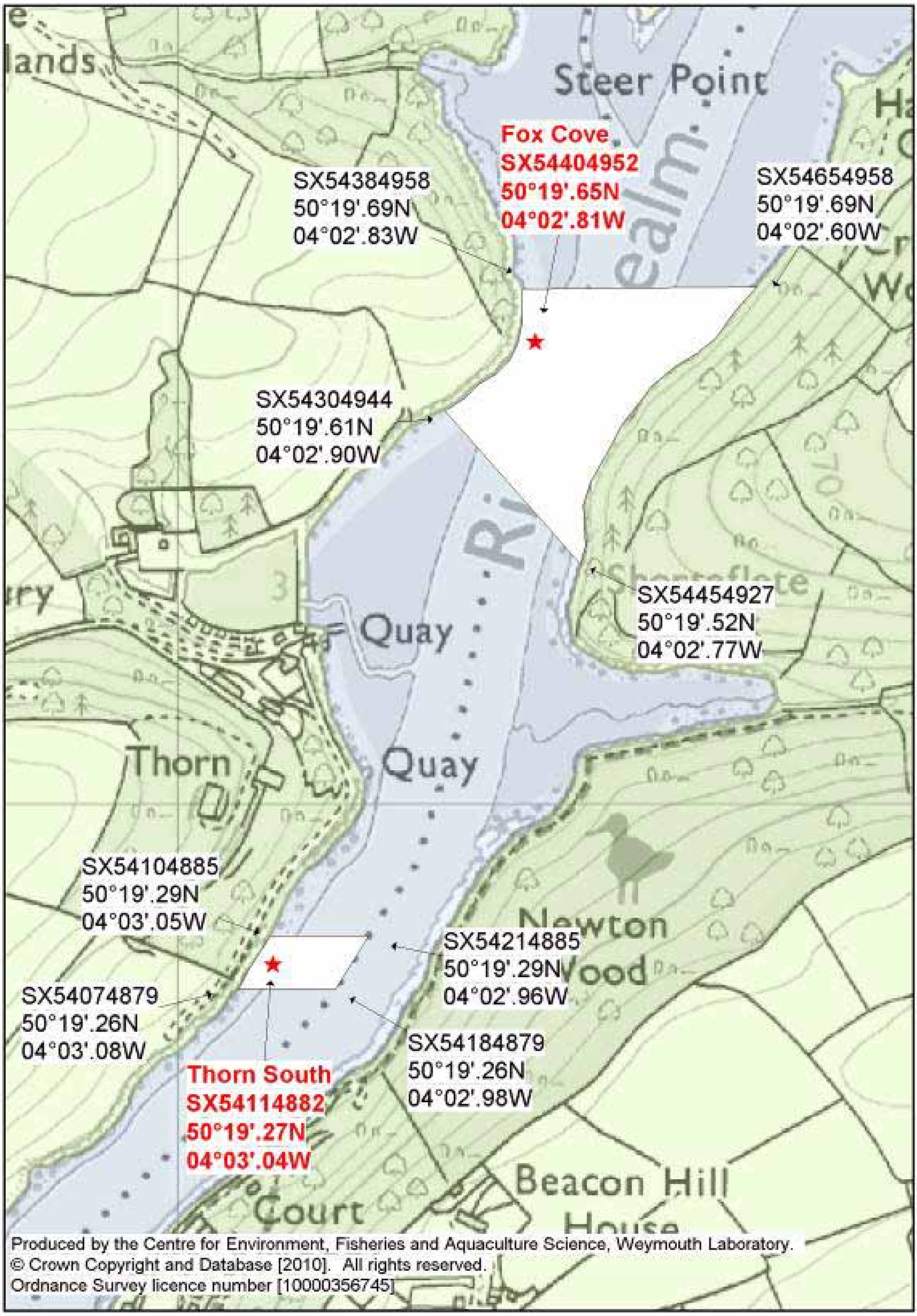


Figure 5.1 Location of recommended representative monitoring points (RMPs) and classification zone boundaries for mussels in the Yealm Estuary.

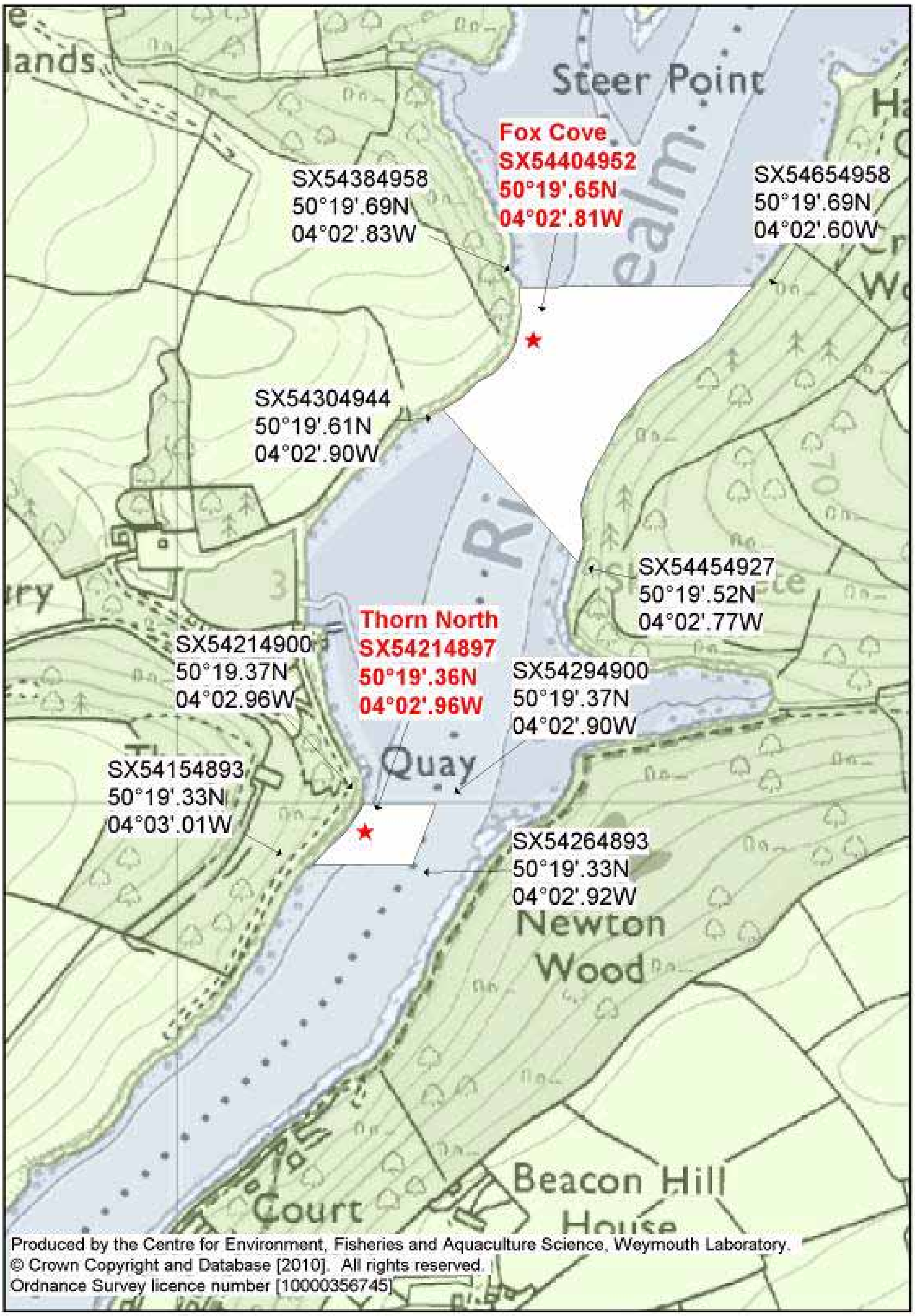


Figure 5.2 Location of recommended representative monitoring points (RMPs) and classification zone boundaries for Pacific oysters in the Yealm Estuary.

APPENDICES

APPENDIX I
HUMAN POPULATION

The distribution of resident human population by Super Output Area Boundary[4] totally or partially included within the river catchment areas is shown in Figure I.1. The main urbanised areas within river catchments are Yealmpton (total population=1,561), Brixton (1,054) (at the head of the estuary), Wembury (1,072) and Newton Ferrers (1,195) (at the mouth of the estuary) (mid-2006 estimates derived from 2001 census; Office for National Statistics, pers. comm.).

Table I.1 Human population in the river catchments.

River catchment	Resident population
Yealm	3,834
Yealm (tidal)	14,614
Total	18,448

Source: Office for National Statistics, Crown copyright 2007.
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NB. Based on provisional mid-2005 population estimates for river catchment areas within England and Wales.

Urbanised areas contain the majority of point-sources of pollution (continuous and intermittent sewage discharges) in these catchments. Urbanised areas also contain the majority of impervious surfaces[5] (e.g. roads, parks, pavements), which are known to contribute with significant loads of microbiological contaminants (Ellis and Mitchell, 2006)[6]. Bivalve molluscs commercially harvested in the vicinity of urbanised areas tend to show deteriorated microbiological quality.

Human population in these catchments fluctuates seasonally due to tourism. In 2007/08, the Dartmoor National Park Information Centres recorded over 200,000 visitors (Dartmoor National Park Authority, 2008). Other tourist attractions in Plymouth area (e.g. National Marine Aquarium) will contribute to increase human population in towns in the vicinity of the estuary.

Seasonal changes in human population due to tourism will result in increased microbiological loads from sewage treatment plants on a seasonal basis (Younger *et al.*, 2003). An assessment of the impact of the most significant sewage discharges to the estuary is given in the Appendix VII.

[4] Super Output Area (SOA) boundaries are in part derived from Ordnance Survey information and some SOA boundaries which follow ward or parish boundaries reproduce limited parts of the OS Boundary-Line product.
[5] In the context of the present report, impervious surfaces are any surface in the urban landscape that does not infiltrate rainfall.
[6] Concentrations of *E. coli* (MPN 100ml^{-1}) quoted in literature are: $10-10^3$ for residential areas and highways and 10^2-10^4 for roof runoff and commercial areas (Ellis and Mitchell, 2006)

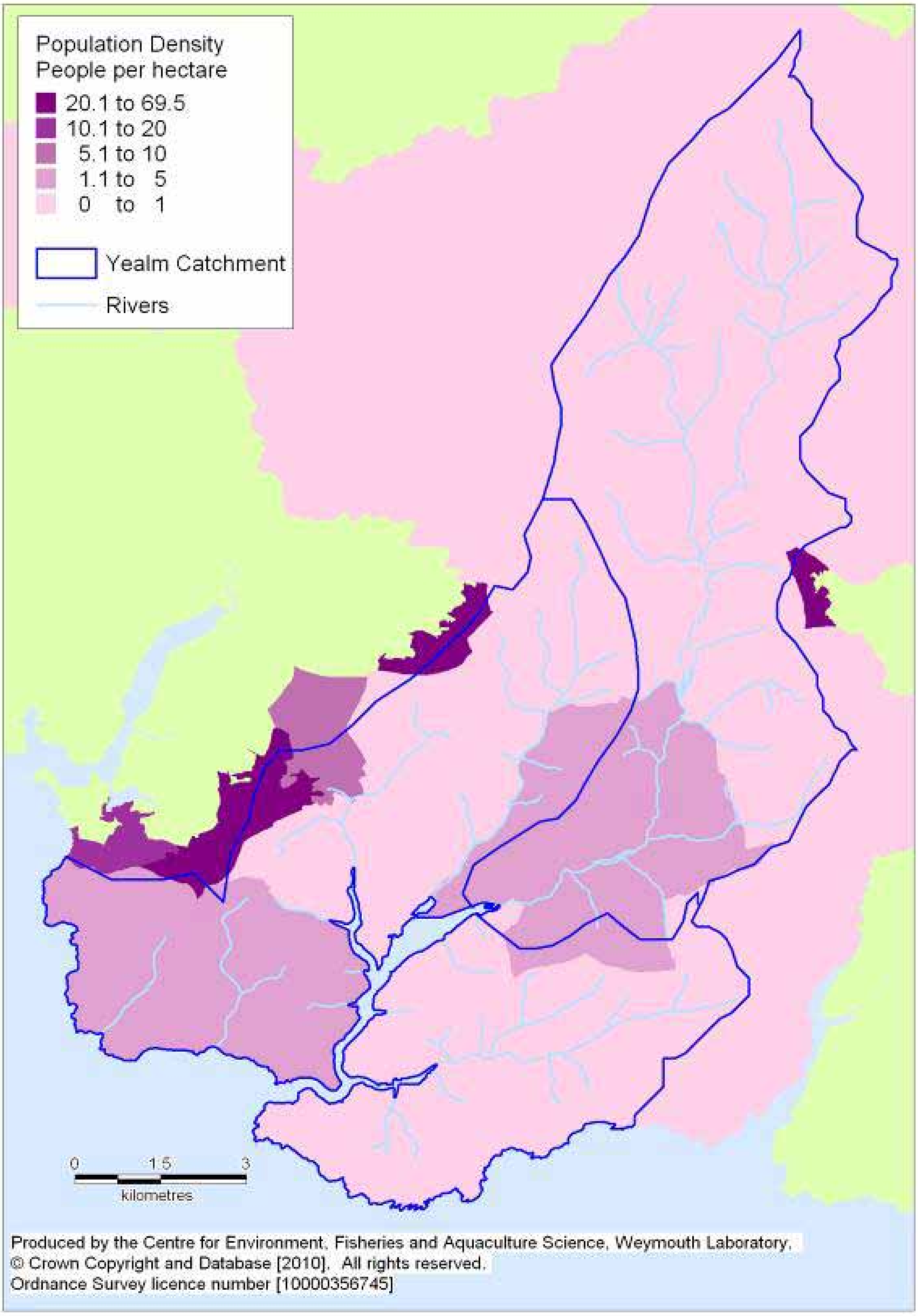

Figure I.1 Human population density in the Yealm catchment.
Source: ONS, Super Output Area Boundaries. Crown copyright 2010. Crown copyright material is reproduced with the permission of the Controller of HMSO.

APPENDIX II
HYDROMETRIC DATA: RAINFALL

The southwest of England is one of the wettest regions in the UK. The rainfall pattern is heavily influenced by the topography, which forces the moisture-laden air to precipitate high levels of rainfall across the upper reaches of catchments.

The coastal area at Plymouth experiences less than 1,000mm of rainfall per annum, whilst the upper reaches of the catchment may receive as much as 2,000mm per annum (Met Office, 2007). This compares with an average annual rainfall for England and Wales of approximately 1,250mm (Perry, 2006).

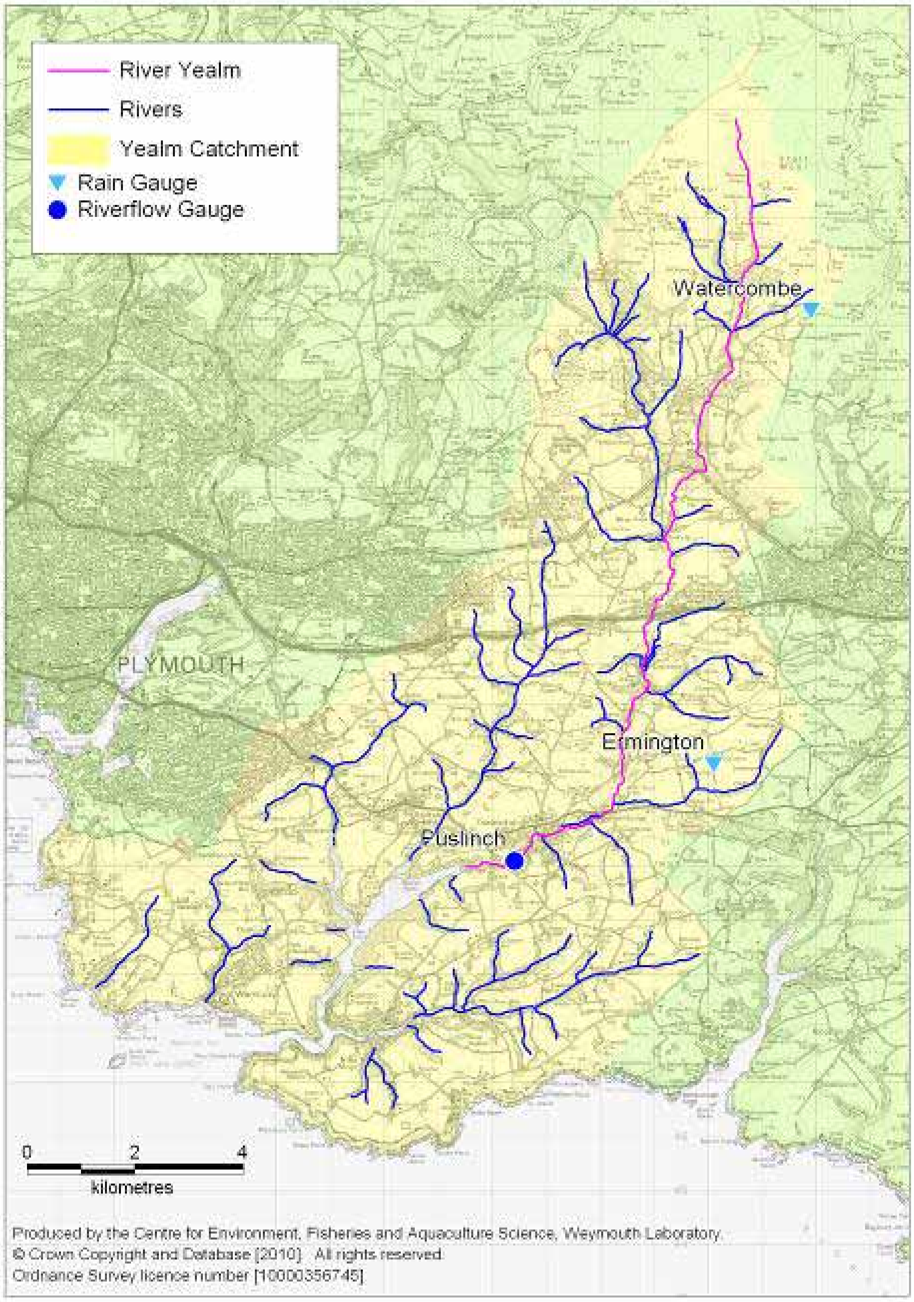

Figure II.1 Rivers and streams in the Yealm catchment showing the location of the rain and river flow gauging stations.

Figure II.2 shows monthly averaged and monthly total rainfall monitored daily in a tipping bucket gauge operating at Greenfields (Easting/Northing: 5484/5219) representative of the lower catchment.

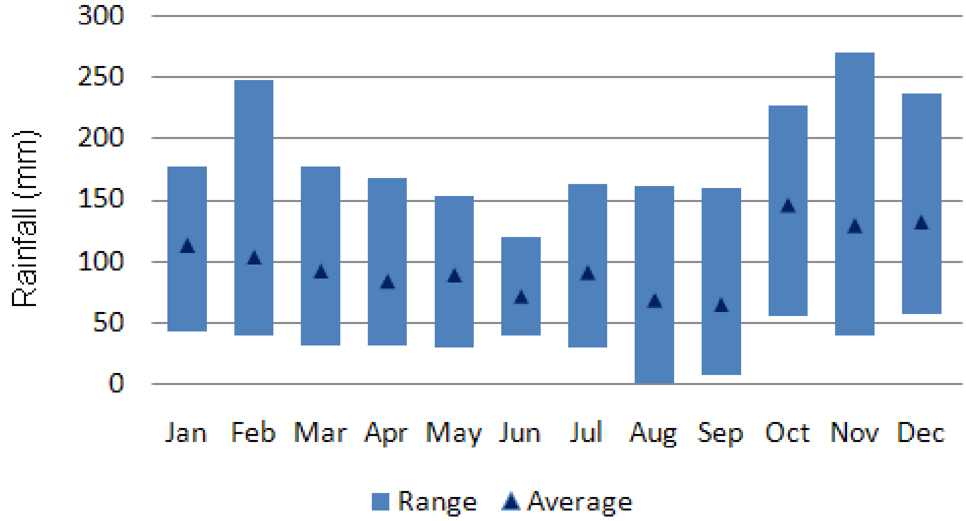

Figure II.2 Monthly variation of rainfall recorded at Ermington gauging station for the period 2000–2008.
Data from the Environment Agency.

Average rainfall levels above 200mm occurred during the period October–December and February (overall wettest period). The driest period is May–September. The number of days with rainfall totals≥1mm tend s to follow a similar seasonal pattern (Met Office, 2007).

Rainfall may lead to the discharge of raw or partially treated sewage from combined sewer overflows (CSO) 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 discharges and freshwater inputs will reflect the combined effect of rainfall on the contribution of individual pollution sources.

Results from analyses of the relationships between the levels of *E. coli* in bivalve molluscs commercially harvested in the Yealm and rainfall levels are given in the Appendix XII.

APPENDIX III
HYDROMETRIC DATA: FRESHWATER INPUTS

The River Yealm is the main freshwater input to the estuary. There are a number of other smaller tributaries in the catchment such as streams discharging to Silverbridge Lake at the head of the estuary and to Newton Creek at Bridgend.

The River Yealm (total length = 18.5km) has its headwaters on the Stall Moor mires (altitude = 430m above Ordnance Datum) on Dartmoor and meanders through Cornwood, Lee Mill (175m above OD at Ford Brook) and Yealmpton (25m above OD at Long Book) before reaching the tidal limit of the estuary, East of Plymouth Sound.

Table III.1 summarises the hydrological characteristics of the River Yealm at Puslinch. Q95 and Q10 represent the averaged flow that is exceeded for 95% and 10% of the time, respectively.

Table III.1 Hydrological characteristics in the River .

	Gauging station at Puslinch [a]
Catchment Area (km^2)	54.9
Level of Station (m OD)	5.5
Maximum altitude (m OD)	492
Mean flow ($m^3 s^{-1}$)	1.670
95% exceedance (Q95) ($m^3 s^{-1}$)	0.206
10% exceedance (Q10) ($m^3 s^{-1}$)	3.856

[a] data for the period 1960−1990.
Data from the National River Flow Archive (NERC-CEH, 2008).

Table III.2 shows the low flows characteristic of the main tributaries of the River Yealm and the relatively high flows in this river in the upper catchment at Lee Mill Bridge.

Table III.2 Spot gauging river flows measured in the River Yealm and its tributaries.

River	Gauging station	Flow ($m^3 s^{-1}$)
Newton Creek	Bridgend	0.214
	Upstream Yealm Intake	0.115
	Downstream Yealm Intake	0.094
Yealm	Lee Mill Bridge	1.209
	Broadhall Lake	0.023
	Broadlake Lake	0.025
	Wisdome Bridge	0.707
Ford Brook	Downstream abstraction point	0.006
	Upstream abstraction point	0.012
Cofflete Creek	-	0.109

Data supplied by the Environment Agency.

The steep topography of the catchment combined with the relatively high rainfall totals and low permeability of the geological formations result in a “flashy” hydrological regime in this river (Q95/Qmean≈0.1), i.e. with a quick time to peak and a relatively sharp recession limb characteristic of hydrographs.

Figure III.1 shows a very consistent inter-annual variability in flow rates. The number of peak flows above $10m^3\ s^{-1}$ has increased in recent years. This variability is expected to exert a significant effect in delivery of microbiological contamination to the estuary, in particular during the winter floods, when greater percentage of water runs off quickly with water saturation in soils.

Table III.3 shows faecal coliform loads to the River Yealm in three sampling occasions in May 2004. Results indicate that loads to the River Yealm are, at least, two orders of magnitude higher than those at Silverbridge Stream and Cofflete Stream.

Table III.3 Faecal coliform loadings in freshwater inputs to the Yealm Estuary.

	Faecal coliforms sec^{-1}
4 May 2004	
River Yealm at Puslinch Bridge	$1.62x10^8$
Silverbridge Stream at Kitley Hotel	$1.99x10^6$
Cofflete Stream prior to estuary	$7x10^6$
Newton Stream at Bridgend	$5.5x10^6$
5 May 2004	
River Yealm at Puslinch Bridge	$9.62x10^8$
21 May 2004	
Silverbridge Stream at Kitley Hotel	$5.33x10^5$
Cofflete Stream prior to estuary	$4.7x10^6$
Newton Stream at Bridgend	$1.07x10^6$

NB. All samples collected under dry weather conditions.
Data from the Environment Agency.

These results are consistent with loadings of *E. coli* obtained following the shoreline survey undertaken by Cefas in March 2009. In terms of absolute concentrations, the results from the survey showed higher levels of the microbiological indicator in the stream at the head of Cofflete Creek and the River Yealm.

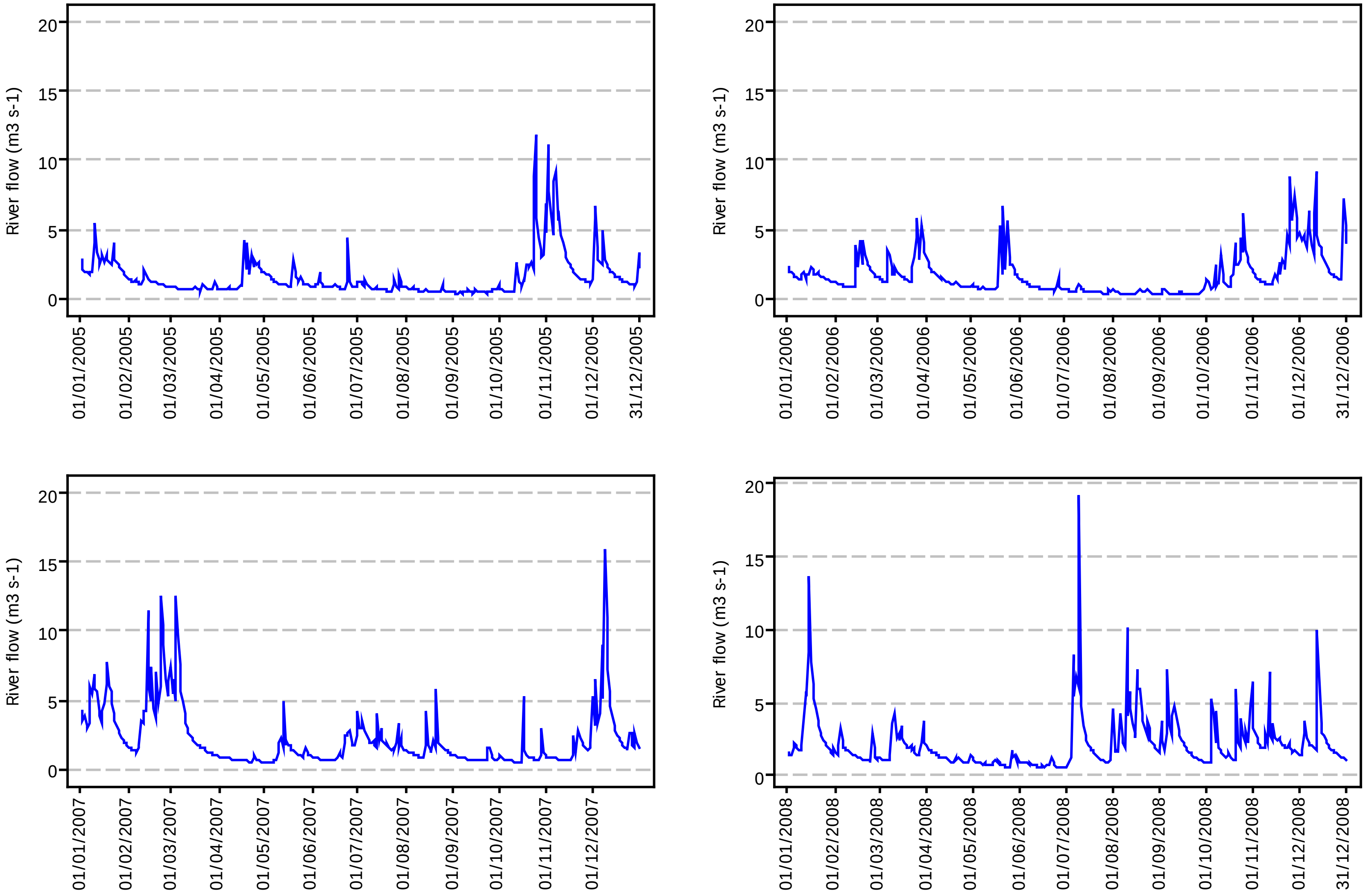

Figure III.2 Hydrographs for the period January 2000−December 2008.
Data supplied by the Environment Agency.

APPENDIX IV
HYDROGRAPHIC DATA: BATHYMETRY

The Yealm Estuary is very shallow and dendritic. Most of the upper reaches of the estuary and Newton Creek dry on low water springs. Figure IV.1 shows that the currently classified bivalve mollusc beds occur in intertidal areas.

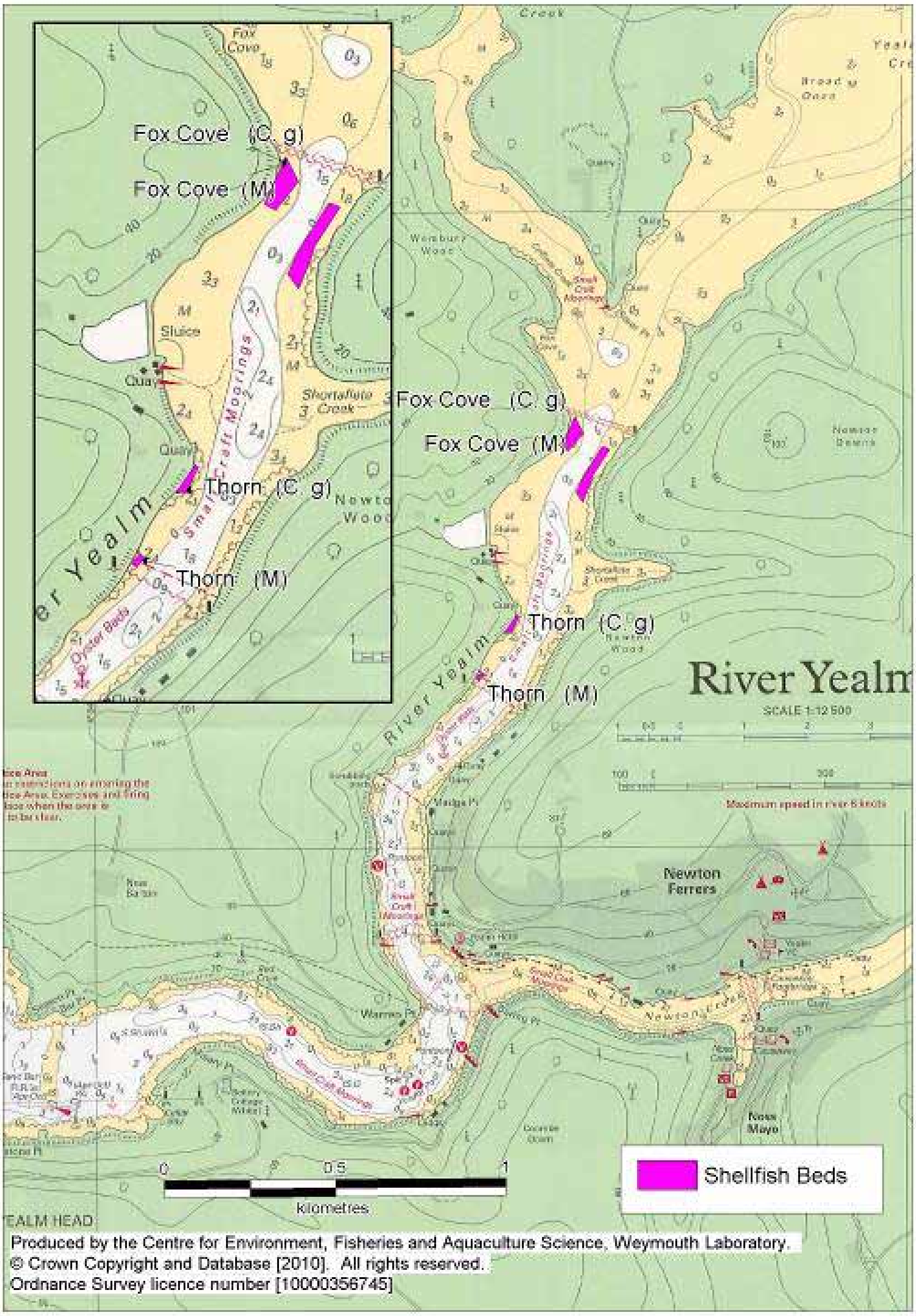

Figure IV.1 Bathymetry in the Yealm Estuary showing location of classified bivalve mollusc beds.
Reproduced from Imray Chart C14 –Plymouth Harbour and Rivers with the permission of the publishers.

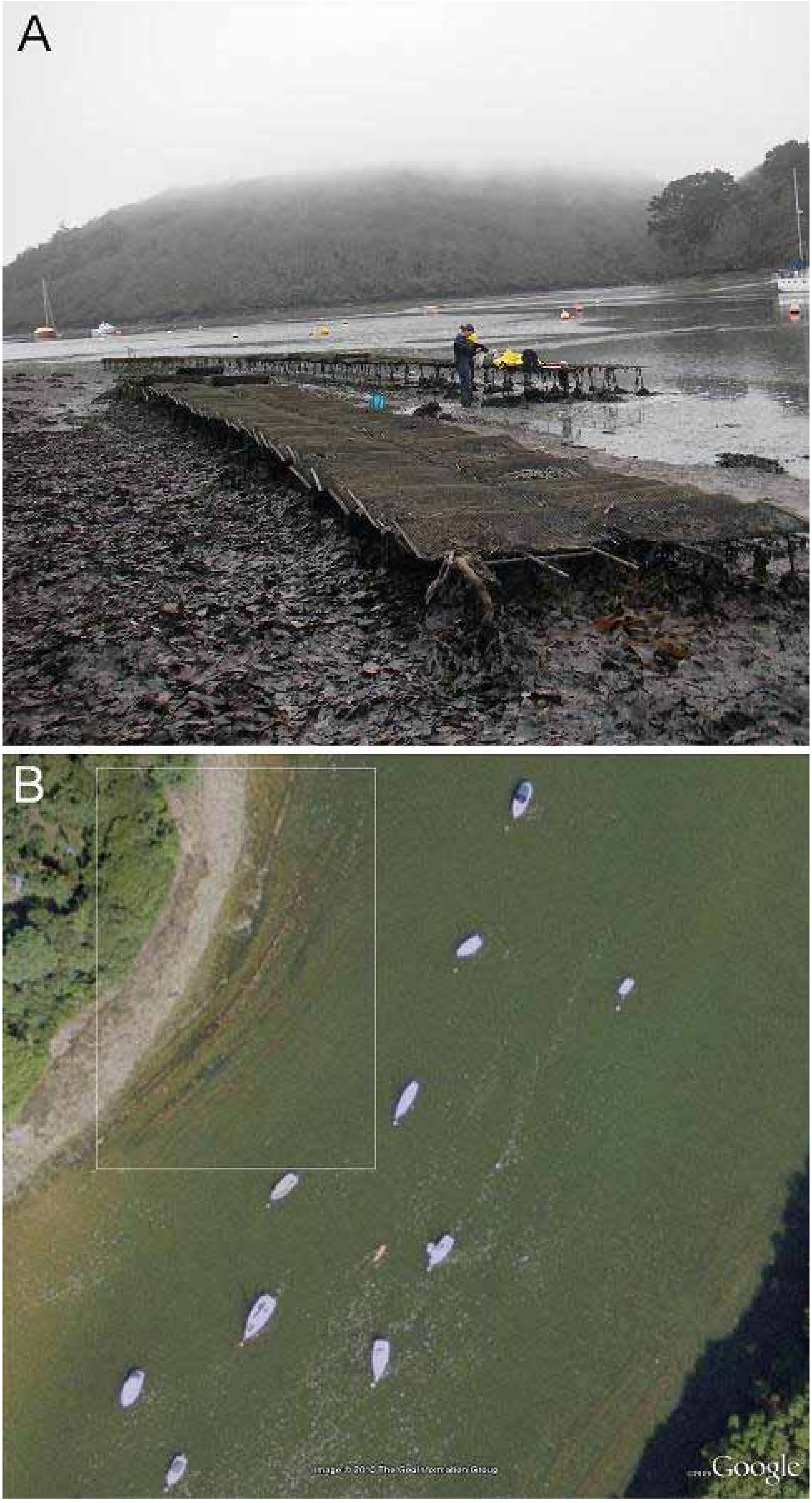

Figure IV.2 Bivalve mollusc beds at Fox Cove.

The overall bathymetric gradient increases towards the mouth of the estuary (averaged depth = 1.49m relative to Chart Datum. Soundings increase from the mouth of Shortaflete Creek (2.4m deep relative to CD) to Red Cove, where there is a deeper pool which is 3.8m deep relative to CD. Further downstream, soundings decrease, where there is a sand bar between the mouth of the estuary and Wembury Bay.

There is a second pool (Yealm Pool) in the middle reaches of the estuary just North of Warren Point which is 4m deep.

Extensive drying areas often produce continued drainage long after the tide has receded and the mudflats are exposed (see Whitehouse *et al*., 2000). Contaminated runoff from retained seawater and/or washed off by rainfall falling on the surface of mudflats into these creeks will be conveyed along the channel(s). Therefore, nearshore shallow areas are likely to represent worst-case conditions. In contrast, deeper estuarine areas will contain more water for dilution and dispersion of contaminants.

Pacific oysters and mussels cultivated in intertidal areas are exposed during significant periods of the tidal cycle. Furthermore, solar radiation will increase decay rates of microbial contaminants in shallow areas, although there is growing evidence that wetting/drying may allow some microorganisms to persist or even replicate. Consideration is given to these factors for the purposes of informing the sampling plan.

APPENDIX V
HYDRODYNAMIC DATA: TIDES AND CURRENTS

The Yealm Estuary has an asymmetrical macro-tidal regime with semi-diurnal tides (i.e. two tidal cycles per day) at the entrance of the estuary (Table V.1).

Table V.1 Tide levels and ranges at the Yealm Estuary entrance.

	Height (m) above Chart Datum				Range (m)	
Port	MHWS	MHWN	MLWN	MLWS	Springs	Neaps
River Yealm (entrance)	5.4	4.3	2.1	0.7	4.7	2.2

Data from Imray C14 - Plymouth Harbour and Rivers.Imray Laurie Norie & Wilson (2007).

Tidal excursion (mouth to the limit of reversing tidal currents) between Puslinch and the sand bar at the mouth of the estuary is estimated to be approximately 6.2km (Uncles *et al*., 2002). Microbial contaminants may be transported over these distances with the tidal wave along the estuary.

Overall, the estuary is considered to be well-mixed and flood dominant (Halcrow Group Ltd, 2002), i.e. the flood tide is longer and slower than the ebb tide. Flood dominance means that contamination from sources at Newton Ferrers may be particularly relevant to the overall water quality at Fox Cove and Thorn.

Contamination from the wider catchment would be significant during periods of high river flows. The low salinity levels recorded at Fox Cove in March 2007 suggest a significant influence of freshwater inputs at this site (Figure V.1).

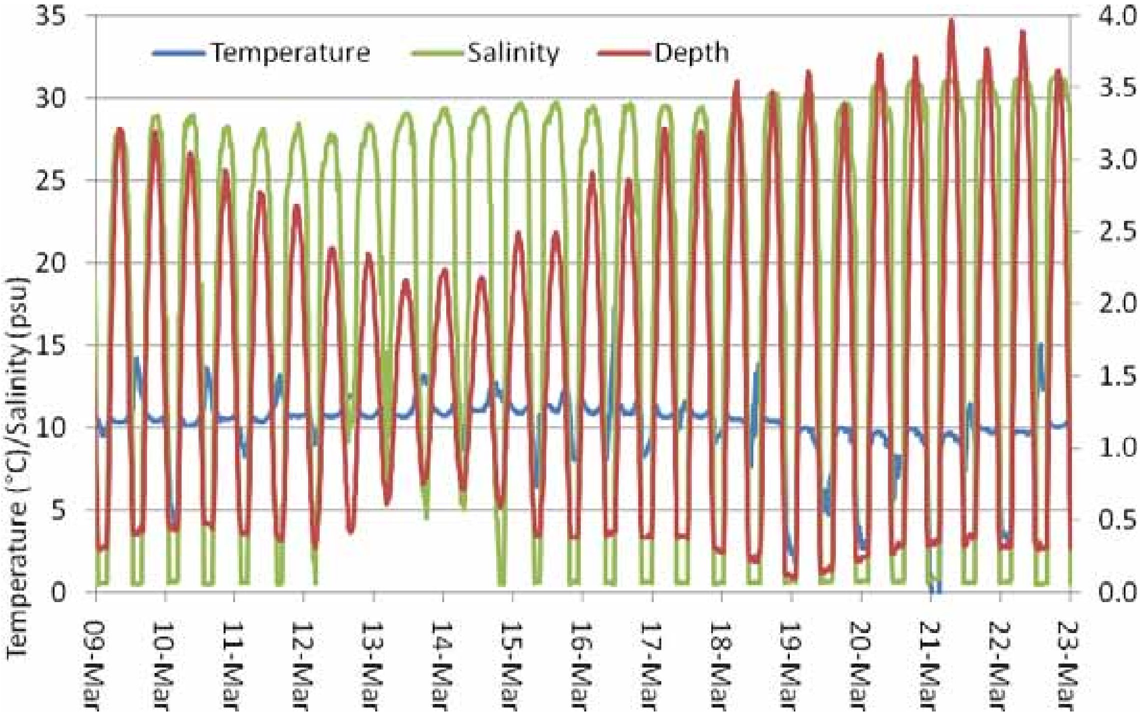

Figure V.1 Variation in temperature, salinity and depth at Fox Cove in March 2007.

Under these conditions, partially-mixing conditions are expected to occur in the middle reaches of the estuary and the limit of the influence of saline water would be restricted to the lower reaches of the estuary. At low salinities, filter-feeding activity is likely to cease along with the ingestion of microbial contaminants.

The estimated residence time in the Yealm (1.5 days) is slightly higher than that for other estuaries in the southwest of England with similar tidal lengths, such as the Devon Avon (1 day) and West Looe (0.5 days) (Uncles *et al.*, 2002). Although tidal flushing may exert a significant influence in flushing the estuary, under certain conditions river flows may extend the freshwater influence and contribute to the formation of density fronts. A significant fraction of contaminants may persist in the less flushed upper estuary and influence the microbial quality of bivalves. This is particularly relevant considering the potential effect of the sand bar at the mouth of the estuary restricting tidal flushing over the tidal cycle. During the desk study of the sanitary survey, Limosa Farms Ltd expressed concern on the retention of microbial contamination from sewage discharges at Noss Mayo and Newton Ferrers during neap tides (Martyn Oates, pers. comm.).

The Yealm Estuary Management Plan reports maximum flow rates of 2 knots on the ebb tides and 4 knots during periods of strong freshwater flow (Yealm Estuary Management Plan Steering Group, 2007). The bathymetric profile and the cross sectional area of the estuary suggest that rectilinear (back-and-forth) flows govern tidal currents in the estuary.

All areas of the Yealm Estuary are considered to be moderately vulnerable to the effects of siltation arising from activities such as dredging (English Nature, 2000).

APPENDIX VI
METEOROLOGICAL DATA: WIND

The southwest is one of the more exposed areas of the United Kingdom. The strongest winds are associated with the passage of deep depressions and the frequency and strength of depressions is greatest in the winter (Met Office, 2007). As Atlantic depressions pass the UK, the wind typically starts to blow from the south or southwest, but later comes from the west or northwest as the depression moves away.

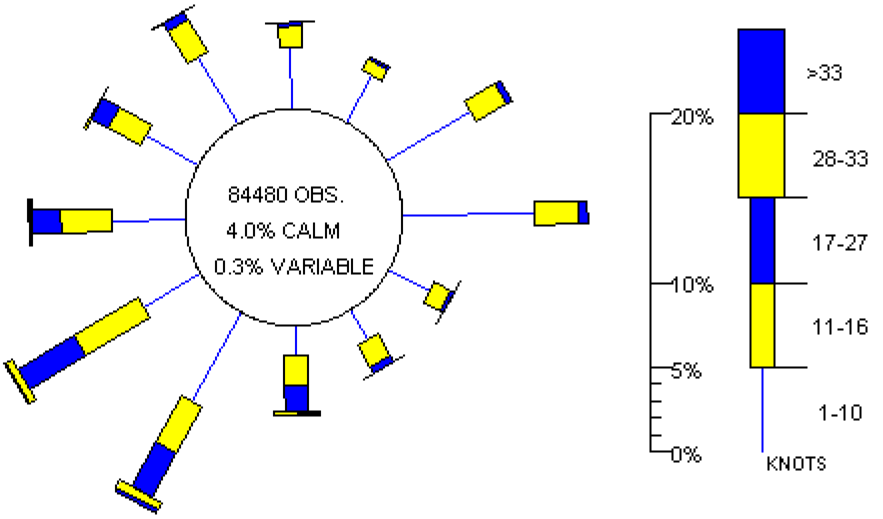

Figure VI.1 Wind speed and direction at Plymouth for the period 1991–2000.
Reproduced from Met Office (2007).

Wave action is significantly attenuated at the mouth of the estuary due to the presence of a sand bar.

Given the relatively sheltered location of the estuary, wind driven currents are not expected to significantly influence water movements and hence circulation of contaminants within the estuary. However, strong wind conditions are expected to impinge effluent plumes upon the shore in the broader and shallower areas of the estuary.

Appendix VII
Sources and Variation of Microbiological Pollution: Sewage Discharges

Sewage discharges pose a significant risk of contamination of faecal origin to bivalve molluscs. The risk is diverse and depends on the contributing human population and volume of discharge. Sewage effluents in the catchment draining to the Yealm Estuary are treated in a number of sewage treatment works (STWs).

Figure VII.1 shows the locations of continuous and intermittent sewage discharges likely to be a source of microbiological contamination to bivalve molluscs. The larger STWs are associated with the urbanised areas of Yealmpton, Brixton and further downstream at Newton Ferrers. Newton Ferrers STW and Yealmpton STW receive secondary treatments, whereas effluents from Brixton STW receive year-round UV disinfection (Table VII.1).

The sewerage infrastructure is also served by a number of combined sewer overflows (CSO), emergency overflows (EO) and overflows from sewage pumping stations (PS). Of particular significance to bivalve mollusc beds is the intermittent discharge at Courtwood Road Pumping Station and CSOs discharging to Newton Ferrers (Kiln Quay PSCSO, Riverside CSO, Bridge End PSCSO) and overflows from PSs (Collaton Cross PS, Noss Mayo PS).

In addition to water company discharges, there are numerous small sewage discharges from private properties discharging either directly to the estuary or slightly inland and may impact on shellfisheries and contribute to overall background levels of microbiological contamination, particularly during the flood stage of the tide. These are represented by black asterisks in Figure VII.1.

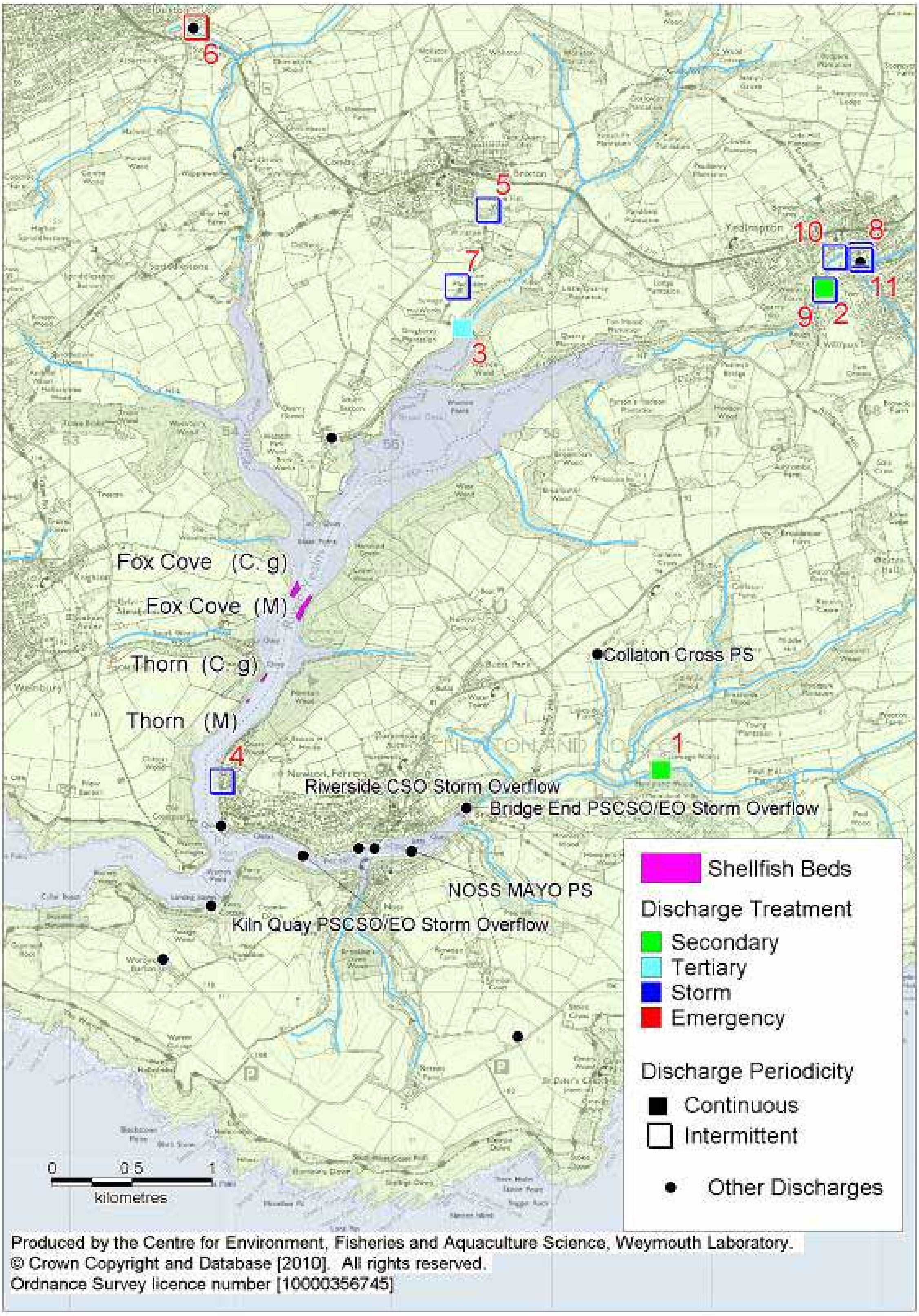

Figure VII.1 Significant sewage discharges to the Yealm Estuary.

Table VII.1 Significant continuous sewage discharges to the Yealm Estuary.

Discharge No.	Discharge name	Treatment	DWF ($m^3 d^{-1}$)	Population equivalent (annual)	Approximate (fluvial) distance to nearest edge of the nearest BMPA (km)	NGR (Easting/Northing)
1	Newton Ferrers STW	Secondary	720	n/a	4	256,680/48,390
2	Yealmpton STW	Secondary	250	1,750	4	257,690/51,380
3	Brixton STW	UV	215	980	1.9	255,400/51,400

DWF - dry weather flow.
STW - sewage treatment works.
UV - ultra-violet disinfection.
BMPA - bivalve mollusc production area.
[1] Maximum volume.
n/a - not available.

Table VII.2 Significant intermittent sewage discharges to the Yealm Estuary.

Discharge No.	Discharge name	Type	Approximate (fluvial) distance to nearest edge of the nearest BMPA (km)	NGR (Easting/Northing)
4	Courtwood Road PS	Storm overflow	0.4	253,930/48,310
5	Winston Lane CSO	Storm overflow (screened)	3.2	255,590/51,880
6	Elburton PS CSO/EO	Emergency sewage overflow/storm overflow	3.8	253,770/53,020
7	Brixton STW Storm	Storm tank discharge	2.3	255,440/51,400
8	Yealmpton PSEO	Storm tank discharge	4.4	257,920/51,600
9	Yealmpton STW	Storm tank discharge	4	257,690/51,380
10	Church Way CSO	Storm overflow	4.2	257,754/51,585
11	Torbridge North PS CSO/EO	Storm overflow	4.4	257,920/51,570

CSO - combined sewer overflow.
EO - emergency overflow.
PS - pumping station.
SPS- sewage pumping station.
SSO - sewage storm overflow.
STO - storm tank overflow.
STW - sewage treatment works.
BMPA - bivalve mollusc production area.

There have been operational problems with water company assets in the Yealm catchment from time to time.

Table VII.3 presents summary statistics for levels of faecal coliforms monitored in the final UV-treated effluent from Brixton sewage treatment works discharging to the Yealm Estuary during the period October 2006–June 2009. The geometric mean is higher than the average levels given in the literature for a range of UV-treated effluents in the UK (Kay *et al*., 2008).

Table VII.3 Summary statistics of presumptive levels of faecal coliforms in the final effluent post UV disinfection monitored in Brixton sewage treatment works discharging to the Yealm Estuary for the period October 2006–June 2009.

STW Name	Number of samples	CFU faecal coliforms 100ml^{-1}					
		Minimum	Maximum	Median	Geometric mean	95% CI for mean Lower	95% CI for mean Higher
Brixton STW	72	1	64,000	340	266	155	455

CI - Confidence interval.
STW - sewage treatment works.
CFU - colony forming units.

The quality of the final effluent has had periods of deterioration, in particular during the period April–June 2009. The symmetry (similar sizes of top and bottom halves) in the distribution of levels of faecal coliforms in effluent discharges for 2009 is evident in Figure VII.2, compared with skewed distribution of levels of the indicator in 2007, for example.

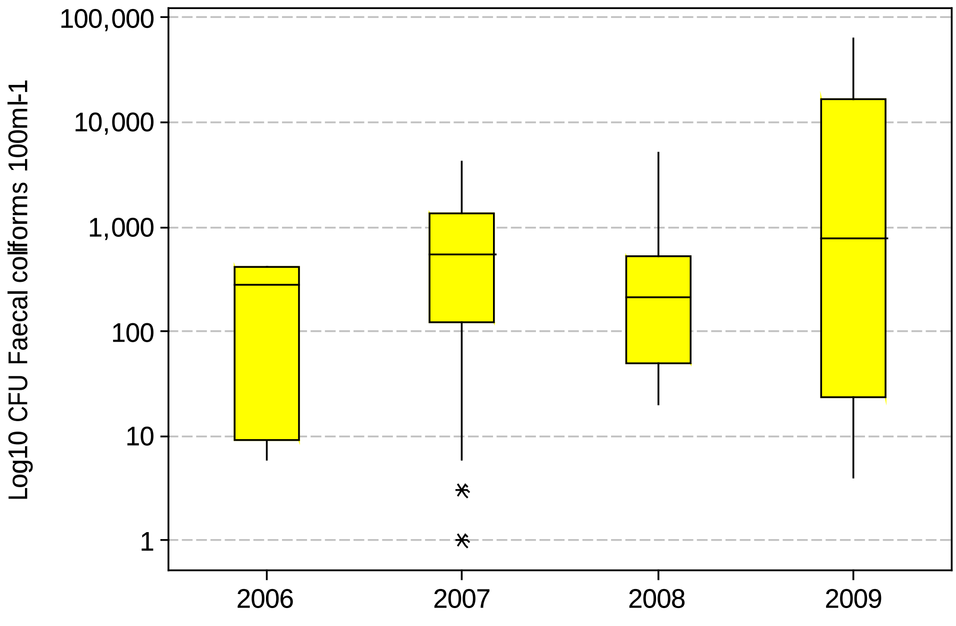

Figure VII.2 Box-and-whisker plots of annual levels of faecal coliforms in effluent discharges from Brixton sewage treatment works for the period October 2006–June 2009.

Figure VII.3 indicates an increased deterioration during the spring–early summer period. The difference in the microbial quality of the effluent between June and December was statistically significant (ANOVA; $F_{11,60} = 5.05$; p = 0.000) at 95% confidence level.

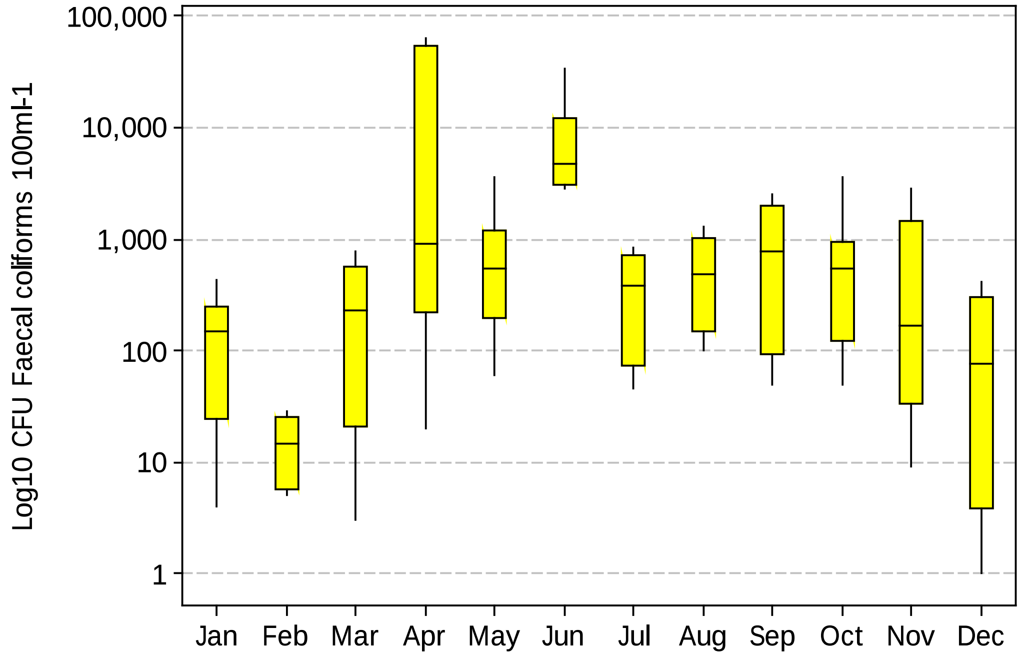

Figure VII.2 Box-and-whisker plots of monthly levels of faecal coliforms in effluent discharges from Brixton sewage treatment works for the period October 2006–June 2009.

Table VII.4 indicates a reduction in the total number of sewage spill events from Winston Lane CSO. The total duration of spill events from Courtwood Road PSCSO/EO increased substantially in 2008/09 relative to the three previous years.

Table VII.4 Total number of sewage spill events and spill duration from two significant intermittent discharges for the period 2005–2009.

Year	Courtwood Road PSCSO/EO		Winston Lane CSO	
	Total spill events	Total duration (hours)	Total spill events	Total duration (hours)
2005/06	2	0.50	11	19.50
2006/07	5	5.18	37	13.54
2007/08	4	1.00	5	1.65
2008/09	2	9.47	None	n/a

Figure VII.3 represents time series of *E. coli* results in bivalves from classified beds in the Yealm, rainfall and sewage spill events from Winston Lane for 2006. Two *E. coli* results within the range for class C were detected on 27 March 2006 when total rainfall at Watercombe in the preceding 48h exceeded 20mm. There were no spill events on these dates from Courtwood Road PS or Winston Lane CSO. One *E. coli* result (MPN *E. coli* = 5,400 100g-1 FIL) within the range for class C detected in mussels from Fox Cove on 13 June 2006 was coincident with a spill event from Courtwood Road PS. Overall, elevated results seem to be associated to periods of prolonged or high rainfall. No consistent pattern could be detected in relative *E. coli* contamination and sewage spill event/duration at these sites. However, this is not surprising as the vast majority of sampling occasions were not coincident with spill events.

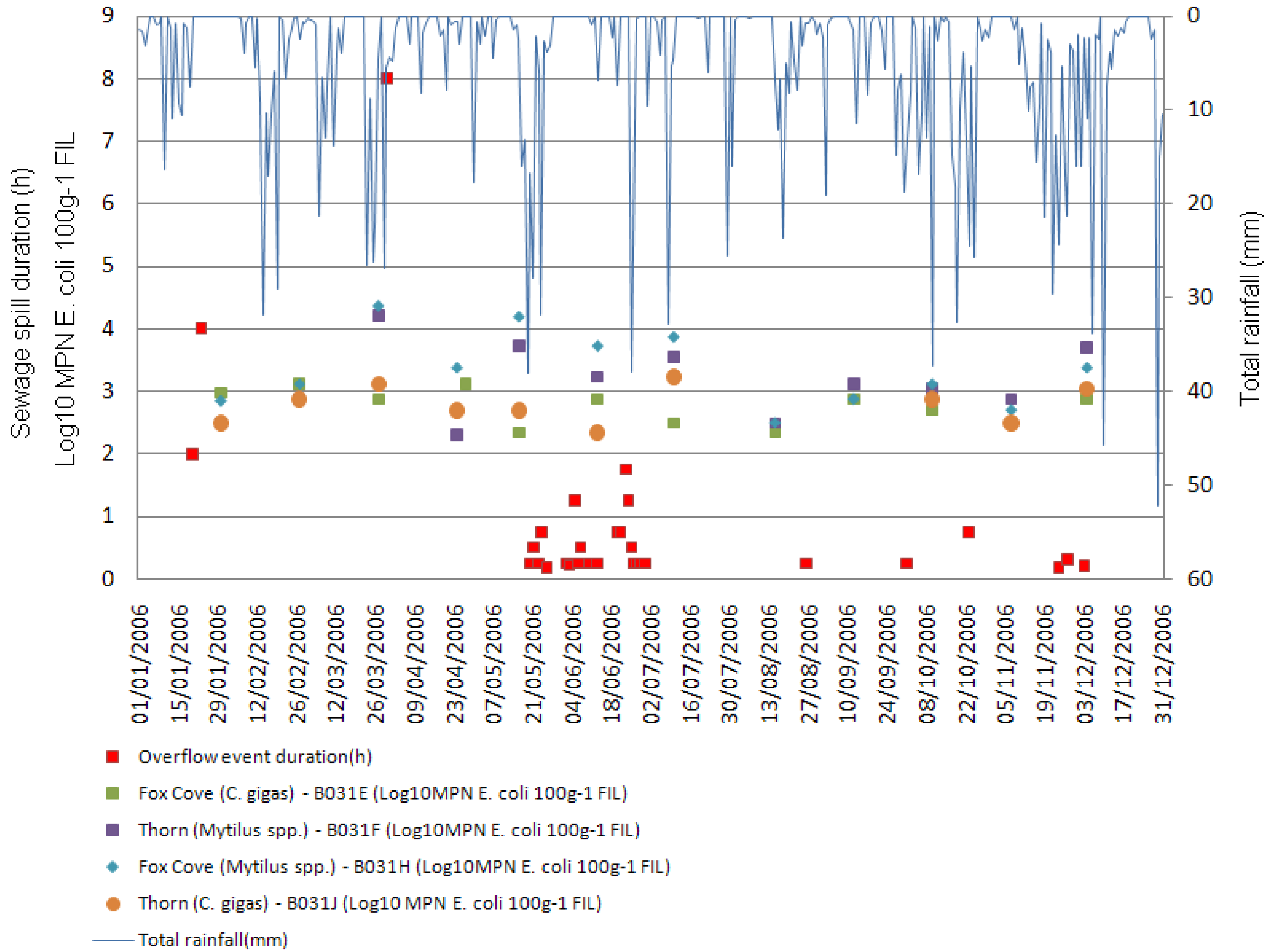

Figure VII.3 Time-series of levels of E. coli in mussels and Pacific oysters from classified beds, rainfall at Watercombe and sewage spill events from Winston Lane CSO in 2006.

APPENDIX VIII
SOURCES AND VARIATION OF MICROBIOLOGICAL POLLUTION: AGRICULTURE

The Yealm catchment is considered to be at risk of diffuse pollution from agricultural land (Environment Agency, 2009). The Environment Agency Pollution Reduction Plan identified the risk of *E. coli* contamination from cattle defecating in watercourses and runoff from arable land and livestock practices (slurry) as problems affecting water quality in the estuary (Environment Agency, 2008).

Farmyards can significantly contribute to loads of faecal indicator microorganisms to watercourses or coastal waters when they have a ready and renewable source of faecal material, a direct hydrological connection with open water channels exists and a sufficient proportion of livestock farms are present in the catchment (Edwards *et al*., 2008).

The catchment contains almost 24,700 farmed animals. Cattle and sheep represent 28% and 54% of the total number, respectively.

Table VIII.1 Numbers of farmed animals in the Yealm catchments.

Catchment	Cattle	Pigs	Sheep	Poultry	Other livestock
Yealm	2,231	124	8,322	593	281
Yealm (tidal)	4,569	55	4,902	3,369	243

Data from June Agricultural Survey supplied by Defra, Farming Statistics.

The concentration of faecal coliforms excreted in the faeces of animal and humans and corresponding loads per day are summarised in Table IX.1.

Table IX.1 Levels of faecal coliforms and corresponding loads excreted in the faeces of warm-blooded animals.

Farm animal	Faecal coliforms (No. g^{-1} wet weight)	Excretion rate (g day^{-1} wet weight)	Faecal coliform load (No. day^{-1})
Human	13,000,000	150	1.9×10^{9}
Pig	3,300,000	2,700	8.9×10^{8}
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).*

Many farms in the southwest UK do not have long-term storage capacity for slurries and manure and, therefore, maintain these as a pile in fields (Roderick and Burke, 2004; Lizbe Pilbeam, Natural England, pers. comm.). For this reason, most farmers frequently apply manure and slurries during the winter, throughout the spring (February–March) for spring growth and some are applied in the autumn for winter cereals. Winter spreading is usually more frequent as farmers try to avoid over-topping their slurry stores. Fewer quantities are retained for the late spring and summer for second and third cut silage applications. Sewage sludge is usually applied to land in February–March and in September (Lizbe Pilbeam, Natural England, pers. comm.).

Younger (2006) reported that sewage sludge spreading occurs at 18 sites across the catchment and that a small number of these tend to be in use at any one time. Younger reported that application of sludge appeared to be concentrated over relatively short periods of time (e.g. one month) with little activity for extended periods outside this time in most cases. In 2006, the industry expressed concerns on the potential effects of sewage sludge applied to land in of shellfisheries in the estuary (Limosa Farms Ltd, pers. comm.). During the desk study of the sanitary survey, Limosa Farms Ltd informed that sewage sludge spreading in the Yealm catchment has been more frequent in recent years.

The agricultural use of sludge (biosolids) is regulated by The Sludge (use in agriculture) Regulations and further control measures are provided in the Code of Practice for the Agricultural Use of Sewage Sludge.

Sewage sludge can be stabilised by a range of treatment methods and is classified as either conventional or enhanced[7], treated depending on the level of pathogen removal (ADAS, 2001). Conventionally treated sludge should achieve a $2Log_{10}$ removal of *E. coli*, and a reduction of $6Log_{10}$ in *E. coli* numbers is necessary for sludge to be designated as enhanced treated (Lang and Smith, 2008). End product standards for treated biosolids also apply and conventionally treated sludge should contain$\leq 5Log_{10}$ *E. coli* g^{-1} dry solids and the number of E. coli present in enhanced treated sludge should be$\leq 3Log_{10}$ *E. coli* g^{-1} dry solids and no *Salmonella* spp. Should be present in 2 g^{-1} (Sweet *et al*., 2001).
Investigations undertaken at a number of South West Water Ltd sites have indicated that poor mixing of the lime with the sludge during the treatment process could result of *E. coli* concentrations exceeding 1,000 g^{-1} and the risk of *Salmonella* sp. being found in the final product (British Lime Association, 2010).

Field level information on limed and digested sewage sludge spreading to agricultural land was obtained from South West Water Ltd. Figure VIII.1–2 shows quantities of sludge spread across the Yealm catchment during the periods January–May and August–October. Overall, the total quantities of sludge spread varied between $31m^3$ and $294m^3$. There is a substantial increase in terms of total quantities spread during the periods January–March and August–October. Therefore, there will be an increased risk of microbial contamination from these sources, in particular during October, when rainfall levels are usually high.

In terms of spatial variation of contamination and despite the variation observed between months, it is apparent that both the upper and lower reaches of the estuary would be vulnerable to microbial loads from these sources.

[7] Liming is an advanced sanitisation treatment for sludge. The process consists of conditioning sludge with lime reaching a homogeneous mixture at a pH of 12 or more and maintaining temperature at least 55°C for 75 minutes or any other time/temperature equivalent. The process contributes significantly to inactivation of microbial pathogens.

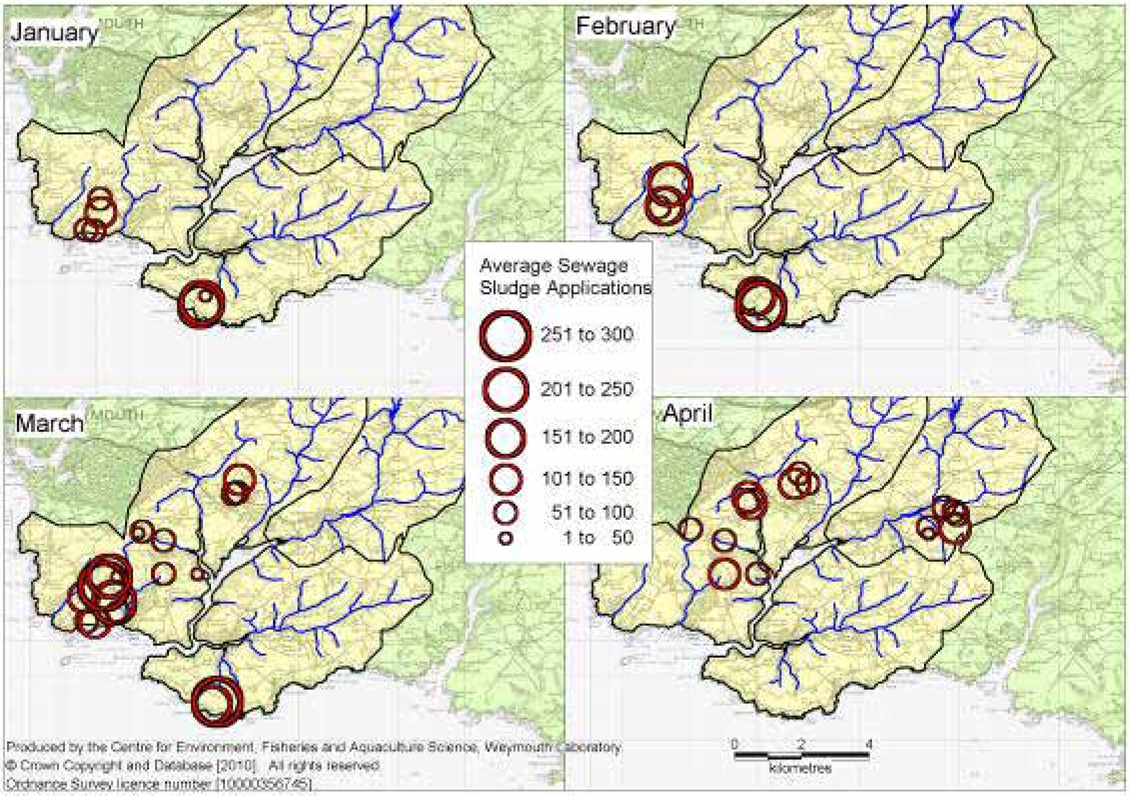

Figure VIII.1 Location and monthly variation of limed and digested sewage sludge spread (m^3) in the Yealm catchment during the period January–April (2007–2010 data).
Data supplied by South West Water Ltd.

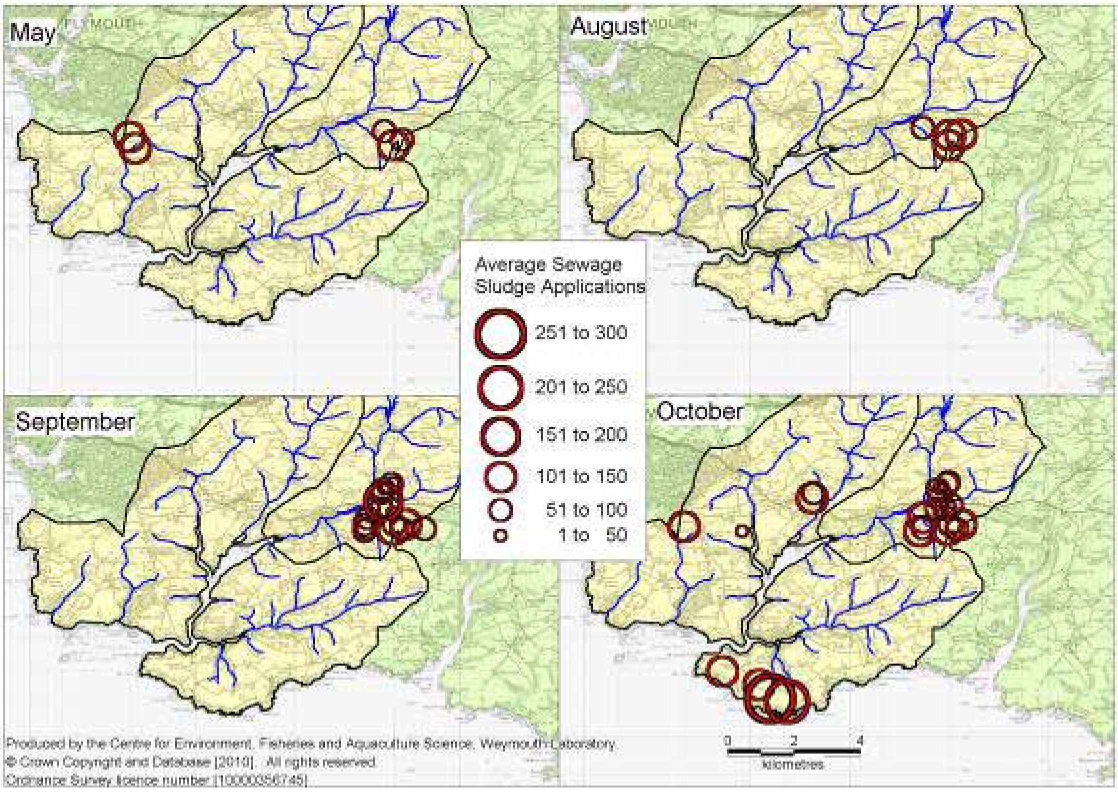

Figure VIII.1 Location and monthly variation of limed and digested sewage sludge spread (m^3) in the Yealm catchment during the period May–October (2007–2010 data).
Data supplied by South West Water Ltd.

A number of initiatives have taken place in the catchment under the Catchment Sensitive Farming Delivery Initiative to minimise the risk of diffuse pollution[8]. These have included soil, manure, nutrient and livestock management, protection of watercourses and crop protection (Defra, 2008).

Table VIII.2 summarises pollution incidents impacting water quality in the Yealm Estuary recorded in the Environment Agency's National Incident Recording System (NIRS) for the period August 2001–September 2008. The location of these incidents is shown in Figure VIII.2.

Table VIII.2 Serious water pollution incidents in the Yealm catchment for the period 2001–2008.

Map ID	Date/time first reported	NGR	Cause	Source	Pollutant	Receiving waters
1	13/11/2002 13:30	SX60649 52812	Accidental spillage	Beef	Diesel (red diesel)	-
2	27/03/2004 05:50	SX58771 60738	Other extreme weather conditions	Sheep	Other contaminated water (water discoloured with clay and ochre from marshland below china clay quarry	Piall – source quick bridge
3	30/03/2004 19:43	SX61459 60917	Other inadequate control or containment	Beef	Solis and clay (runoff from farm track)	Yealm (Hele Cross-Fardel Mill Farm Bridge
4	12/01/2005 13:20	SX59466 59313	Drainage failure	Beef	Silage liquors (silage runoff liquid). Solid manure (liquid from dung heap)	Tributary of the River Piall
5	04/09/2008	SX59171 55898	Other	Dairy	Slurry and dilute slurry (dilute dirty water)	

Data from the Environment Agency.
NB. Only incidents causing damage to water quality and ecosystems are shown. All category 3 (minor damage).

[8] The initial programme runs from April 2006 to March 2008. An extension to the programme will cover the period 1 April 2008 to 31 March 2015.

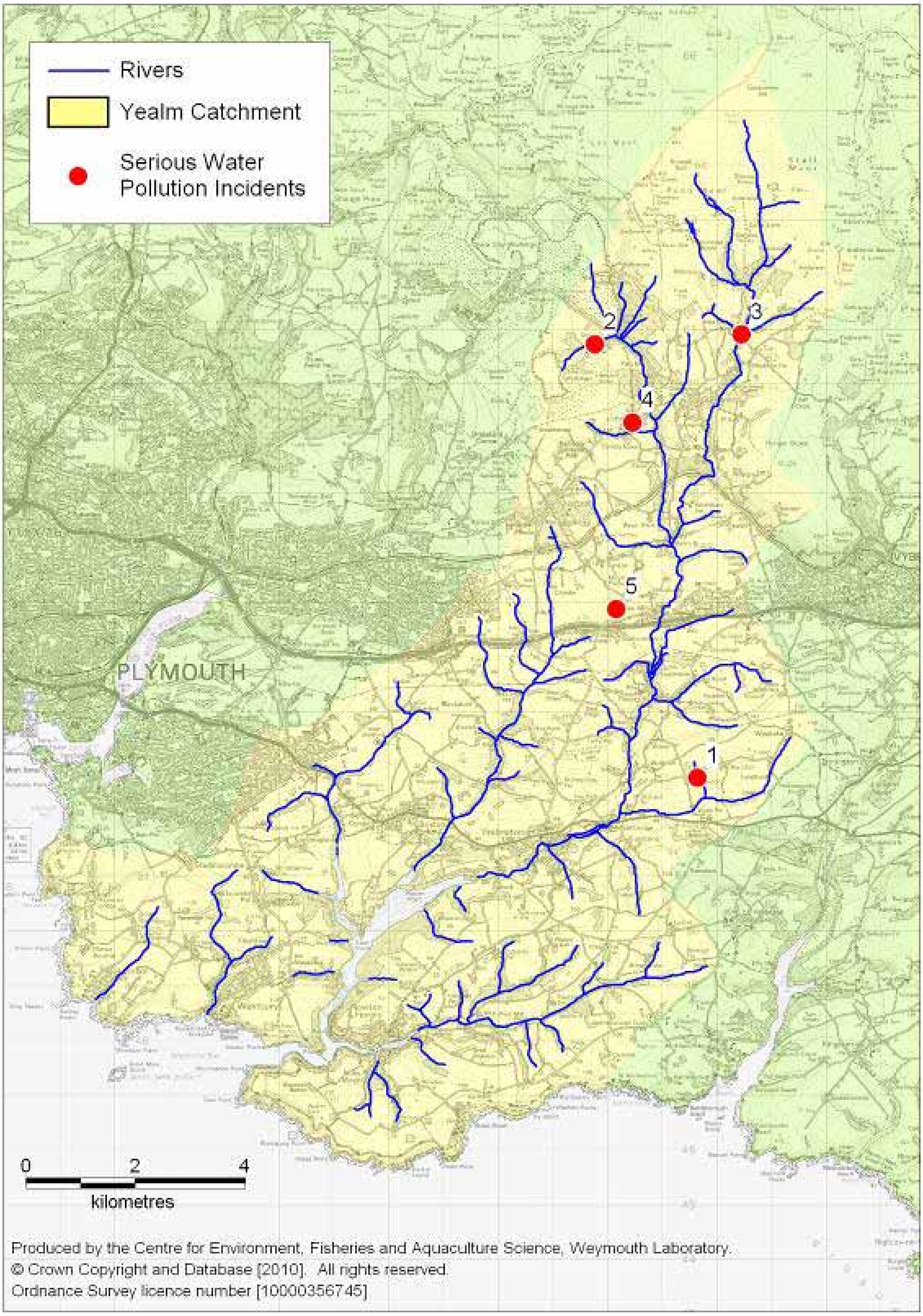

Figure VIII.2 Location of serious pollution incidents impacting on water quality in the Yealm catchment.

Results from the microbial source tracking investigations undertaken by the Environment Agency in the Yealm catchment and tributaries are summarised in Table VIII.3. The locations of sites sampled are shown in Figure VIII.3.

Table VIII.3 Summary of results from microbial source tracking analyses carried out in the Yealm catchment between November 2007–February 2009.

Map ID	Sampling date	Sampling time	Site sampled	Result	Weather conditions
1	26 November 2007	13:00	River Yealm at Wembury House	Ruminant (95%) and human (5%). No other sources suspected.	Dry
1	10 September 2007	13:13	River Yealm at Wembury House	Human and ruminant detected, but other sources suspected.	
1	13 January 2009	12:25	River Yealm at Wembury House	Human (36%) and ruminant (64%). No other sources of contamination suspected.	
2	26 November 2007	13:28	Yealm Estuary (Fox Cove shellfish flesh)	Human (7%); ruminant (93%). No other sources suspected.	Dry
2	10 September 2007	12:43	Yealm Estuary (Fox Cove shellfish flesh)	Ruminant (99.9%) and human (0.1%). No other sources suspected.	
3	26 November 2007	11:05	Newton Stream at Bridgend (upstream tribs)	Human (8.5%); ruminant (91.5%). No other sources suspected.	Wet
4	10 September 2007	11:01	Newton Stream at Bridgend (upstream tribs)	Ruminant (99.9%) and human (0.1%). No other sources suspected.	
4	13 January 2009	10:40	Newton Stream at Bridgend (upstream tribs)	Human (99.5%) and ruminant (0.5%).	
5	26 November 2007	12:05	Cofflete Stream at Combe	Human (58%); ruminant (42%). No other sources suspected.	Dry
5	13 January 2009	12:04	Cofflete Stream at Combe	Human (31%) and ruminant (69%). No other sources of contamination suspected.	
6	26 November 2007	11:50	Silverbridge Lake at Kitley Lake outflow	Ruminant (94.5%); human (5.5%). No other sources suspected.	Dry
6	10 September 2007	11:41	Silverbridge Lake at Kitley Lake outflow	Ruminant (100%). No other sources suspected.	
2	26 November 2007	12:55	Shellfish flesh TUOM	Unexplained source. No human or ruminant detected, therefore suspect other sources.	
2	26 November 2007	13:25	Shellfish flesh Fox Cove	Unexplained source. No human or ruminant detected, therefore suspect other sources.	
7	26 November 2007	11:25	River Yealm at Puslinch gauging station	Human (16.5%); ruminant (83.5%). No other sources suspected.	Misty drizzle
7	13 January 2009	10:55	River Yealm at Puslinch gauging station	Human (76%) and ruminant (24%). No other sources of contamination suspected.	
8	25 February 2009	13:25	Slade Bridge	Human (89%) and ruminant (11%). No other sources suspected.	

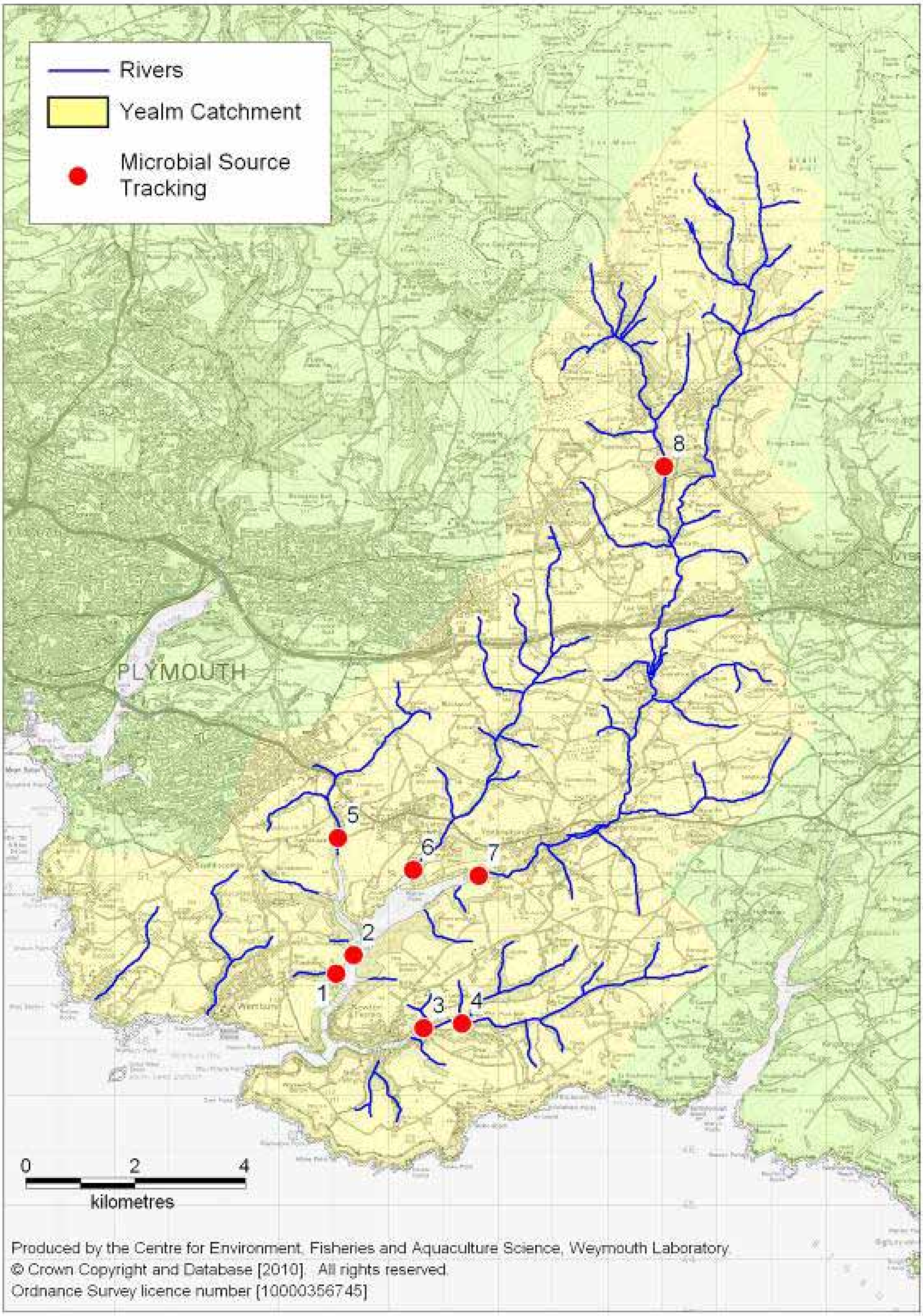

Figure VIII.3 Location of sites sampled for microbial source tracking studies in the Yealm catchment.

The results do not show a clear dominance of human or animal sources across the sampling sites. Despite ruminant sources seem to dominate in sampling sites in the vicinity of bivalve mollusc beds, a significant percentage of results from the River Yealm and Cofflete Stream are attributed to human sources. Therefore, bivalves are likely to be affected by faecal contamination from sewage discharges and dairy washings and surface runoff from agricultural land. This contrasts with previous investigations[9] undertaken by the EA in 2006 showing that agricultural diffuse sources are the primary cause of poor water quality both during dry and wet weather conditions (Nick Smart, pers. comm., 2006).

[9] These included enumeration of faecal coliforms, *Bacteroidetes*, *E. coli* HH2 and F^+ Bacteriophage (Waite *et al*. 2006).

APPENDIX IX
SOURCES AND VARIATION AND MICROBIOLOGICAL POLLUTION: BOATS

Table IX.1 summarises the number of moorings being operated in the Yealm Estuary.

There are 600 moorings within the area of the riverbed leased by the River Yealm Harbour Authority available to residents from parishes of Newton and Noss, Yealmpton, Brixton and Wembury (Yealm Estuary Management Steering Group, 2007). Of these, 156 are for bigger boats (A moorings) and 69 are for smaller boats (B moorings) (Younger, 2006). Another 70 moorings are privately administered by the Kitley Estate (Thorn Pool area) catering for boats from 45ft in length in the lower reaches down to 10–12ft nearer Steer Point. There is room for 70–80 extra visiting boats which are mainly focused around weekends/bank holidays in the summer, although the number of visitors is largely weather dependent (Younger, 2006).

Deep water moorings are established in Yealm Pool and towards the mouth of the estuary; part-drying moorings occur further upstream and entering Newton Creek and shingle and mud drying moorings distributed up Newton Creek, Noss Creek and round the estuary margins (Yealm Estuary Management Plan Steering Group, 2007).

Under the River Yealm Harbour Authority Byelaw 31, no waste may be disposed of within the harbour (River Yealm Harbour Authority, 2007). A pump-out facility is available at the pontoon at Yealm Steps for vessels fitted with holding tanks (Adlard Coles Nautical, 2008).

An assessment of the potential impact of sewage discharges from boats and marinas on the microbiological status of bivalve mollusc beds requires detailed quantitative information on boat movements, occupancy rates and seasonality and accurate knowledge on dilution of contaminants in receiving waters. The high numbers of moorings in parts of the lower estuary suggest that boats can be considered a locally significant source of contamination in the estuary. Although the existence of pump-out facilities will minimise the risk of pollution from boats, bivalves commercially harvested at Thorn and Fox Cove, areas extensively occupied by moorings, may be affected by intermittent discharges from boats. Overall, it can be assumed that summer is the season of highest risk of contamination. In its action programme for 2007–2012, the Yealm Estuary Management Group has identified as priority action continuing to promote the voluntary code of conduct encouraging boat owners to use public conveniences and pump-out facilities near the Harbour Office (Yealm Estuary Management Group, 2007).

APPENDIX X
SOURCES AND VARIATION OF MICROBIOLOGICAL POLLUTION: BIRDS

The ornithological importance of the Yealm Estuary is small. Over-wintering flocks of greenshank, little egrets and water rail, osprey and kingfisher are the most significant features in this estuary. A wide variety of waders and aquatic birds are regular visitors.

Table X.1 Bird sightings in the Yealm Estuary.

Common name	9/08/09	15/09/09	11/01/10	17/01/10	26/01/10	28/01/10	30/01/10	3/02/10
Wigeon	-	-	-	-	-	>60	>100	50
Snipe					-	-	-	20
Greenshank	-	-	-	8	-	-	-	2
Lapwing	-	-						16
Spoonbill	-	-	3	2	+	+	+	+
Little Grebe	-	-	-		-		2	-
Avocet	-	-	-	1	-	+	-	-
Kingfisher	-	-	-	2	-	-	-	-
House Martin	-	Many thousands	-	-	-	-	-	-
Common Sandpiper	+		-	-	-	-	-	-

Data from Wildlife in Devon.

Previous 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). For example, geometric means of *E. coli* detected in faecal samples of Starling (*Sturnus vulgaris*) can be 4.6×10^{7}CFU $100g^{-1}$ (Environment Agency, 2003; Whither *et al*., 2003). Feare (2001) suggests that approximately 10% of the faecal matter could be deposited under a roost, suggesting the potential significant contribution of contamination in these areas. The low numbers of birds in the Yealm Estuary indicate that these are unlikely to be a significant source of faecal contamination to the estuary.

APPENDIX XI
MICROBIOLOGICAL DATA: WATER

BATHING WATERS

Wembury Bay is the only bathing water designated under the Directive 2006/7/EC (European Communities, 2006a)[10] situated at the mouth of the Yealm Estuary (Figure XI.1). This is approximately 4km from shellfish beds at Thorn.

Figure XI.1 Location of bathing water, designated shellfish water and associated monitoring points in the Yealm Estuary.

[10] The bathing season runs from 15 May to 30 September. Water is sampled throughout the season. Levels of bacteria must not exceed the Imperative (I) value (2,000 faecal coliforms $100ml^{-1}$) and the Guideline (G) value (100 faecal coliforms $100ml^{-1}$) represents the ideal maximum value. Bathing waters in England and Wales are classified as:
Poor - fails at least one coliform I standard;
Good - passes coliform I standards but fails at least one coliform G standard;
Excellent - passes coliform G standard and faecal streptococci standards.

The overall quality of this Bathing Water is summarised in Table XI.1.

Table XI.1 Overall quality of Wembury Bay Bathing Water for the period 2004−2008.

Compliance	Bathing season									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Excellent (Guideline Pass)	√	√	√	√	√	√	√	√		√
Good (Mandatory Pass)									√	
Poor (Mandatory Fail)										

Data from the Environment Agency.
NB. The descriptions in this table are based on compliance monitoring and assessment against the current Bathing Water Directive. This will be replaced by assessment against the Directive in 2014.

The Environment Agency used monitoring programme data for the period 2006–2009 to predict that, under the revised BW Directive, Wembury Bay would meet an overall “excellent” classification status.

Figure XI.2 shows a fairly stable distribution of levels of faecal coliforms in surface waters at Wembury Bay over the last years, with an increase in median levels in 2008. Monitoring data for 2009 evidences a left skewed distribution, i.e. larger proportion of results below the median. However, the outlier values represented by asterisks suggest the existence of occasional periods when the microbial quality of the waters had deteriorated in this bathing water.

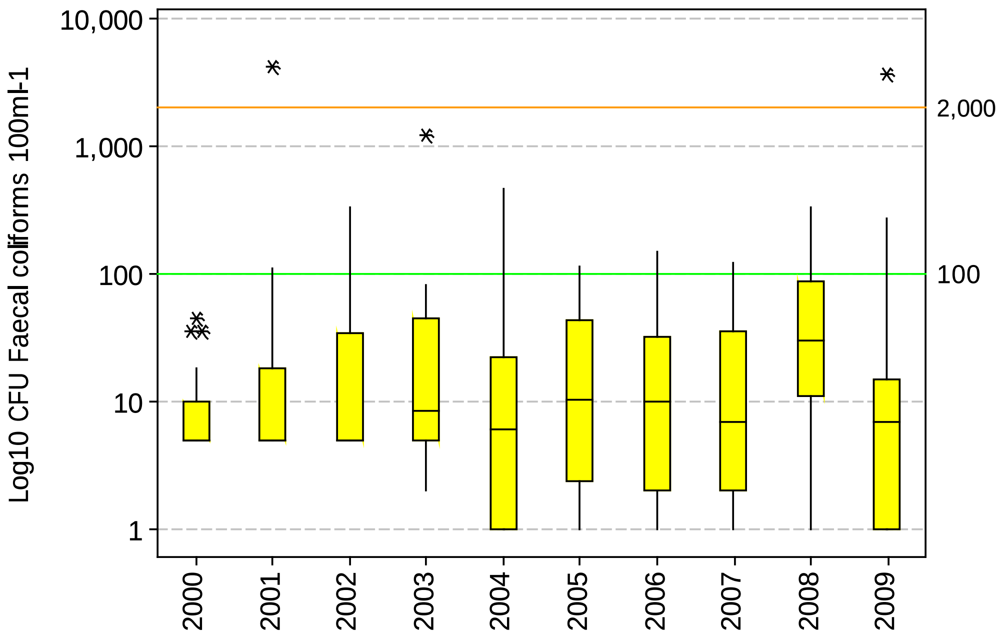

Figure XI.2 Box-and-whisker plots of levels of faecal coliforms in Wembury Bay for the period 2000−2009.
NB. Number of samples per year=20 (22 samples in 2000).

Bradley and Hancock (2003) compared levels of faecal streptococci and total coliforms during the bathing season and outside the bathing season (February–March) during the period 2000–2002. The authors showed that water contamination with total coliforms deteriorated in this bathing water outside the bathing season. This deterioration was more evident with increased wave height (poorer weather conditions).

SHELLFISH WATERS

The upper and middle reaches of the Yealm Estuary from X to Y are designated Shellfish Water under the Directive 2006/113/EC (European Communities, 2006) (Figure XI.1).

The geometric means of faecal coliforms in surface waters decreased during the period 2003–2005 (Table XI.2). The geometric mean for 2005 would be equivalent to class B shellfish.

Table XI.2 Geometric mean of faecal coliforms (CFU 100ml^{-1}) in the Yealm designated Shellfish Water for the period 2001–2005.

Year					
2000	2001	2002	2003	2004	2005*
241	29	85	98	27	42

**Estimated.*

APPENDIX XII

MICROBIOLOGICAL DATA: SHELLFISH FLESH

Table XII.1 shows summary statistics for levels of *E. coli* in bivalves from four current RMPs for the period January 2000–February 2010. Cumulative sum (CUSUM) analysis was computed for Shellfish Hygiene monitoring data summarised in Table XII.1 (not shown). No step changes in the levels of *E. coli* were detected during this period, suggesting that no significant changes have occurred in the overall microbiological quality of bivalves.

Sampling effort has been consistent at all RMPs over the years. Maximum levels of *E. coli* above the class C threshold (MPN≤46,000 *E. coli* $100g^{-1}$ FIL) were detected in mussels from both beds. The higher medians and geometric means indicate that Fox Cove is more contaminated than Thorn for both species. Figure XII.1 shows that differences in contaminating levels are less than 1Log. Furthermore, the existence of outlier results at both sites indicates vulnerability to intermittent episodes of contamination (Figure XII.1).

The positive skewness in the distribution of levels of *E. coli* indicates that most of the results have been below the median and there are relatively few high results. Positive kurtosis of *E. coli* levels in bivalves from all sites indicates a wide and flat distribution of results.

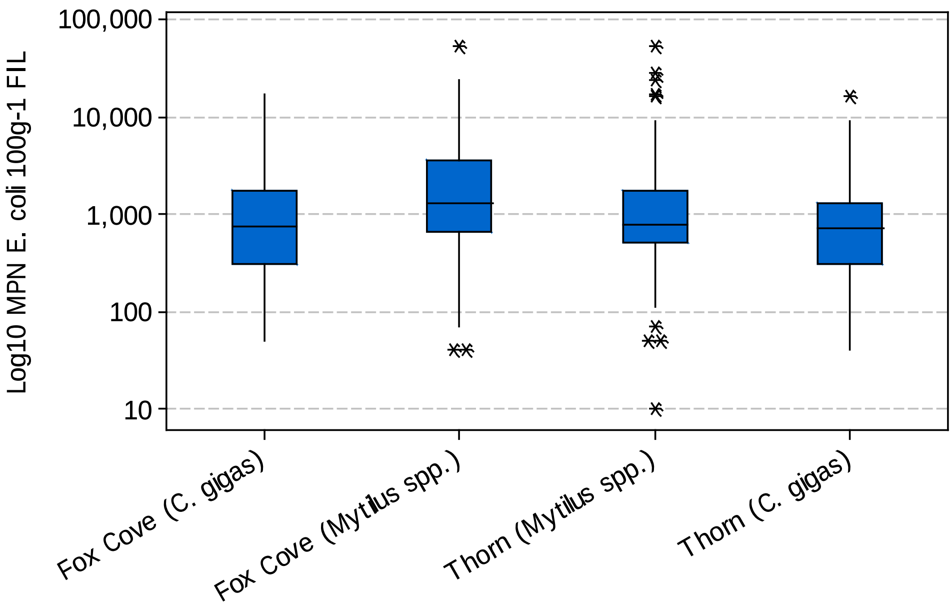

Figure XII.1 Box-and-whisker plots of levels of* E. coli *in four representative monitoring points in the Yealm Estuary.

Table XII.1 Summary statistics of* E. coli *levels in bivalve molluscs from four representative monitoring points in the Yealm Estuary for the period January 2004–August 2009.

						MPN *E. coli* 100g^{-1} FIL								
													95% CI for mean	
RMP	Bed name	Species	n	Date of first sample	Date of last sample	Min.	Max.	Median	Geometric mean	Coefficient of Skewness[11]	Kurtosis[12]	Log_{10} St. Dev.	Lower	Upper
B031J	Thorn	*C. gigas*	117	24 January 2000	2 February 2010	40	16,000	700	659	0.46	0.73	0.448	848	1,607
B031E	Fox Cove	*C. gigas*	121	24 January 2000	2 February 2010	50	17,000	750	833	0.50	0.05	0.497	1,217	2,266
B031F	Thorn	*Mytilus* spp.	114	24 January 2000	2 February 2010	<20	54,000	770	968	0.08	2.05	0.554	1,348	3,700
B031H	Fox Cove	*Mytilus* spp.	118	10 January 2000	2 February 2010	40	54,000	1,300	1,463	0.12	0.13	0.603	2,554	5,136

n - number of samples.
Min. - minimum.
Max. - maximum.
CI - confidence interval.
St. Dev. - standard deviation.
FIL - flesh and intravalvular liquid.

[11] The coefficient of skewness measures the degree of symmetry in the distribution of *E. coli* results. Skewness = 0 gives a perfect normal distribution; skewness <0 distribution is negatively skewed; skewness>0 distribution is positively skewed.

[12] The coefficient of kurtosis relates to the shape of the distribution. Values <0 indicate the distribution is leptokurtic (tall, thin and peaked); values >0 indicate the distribution is platykurtic (wide and flat); values=0 indicates a perfect normality.

SEASONALITY OF *E. COLI* IN SHELLFISH FLESH

The effect of season on the levels of microbiological contamination in bivalve molluscs could be due to biological activity of these animals, variation in the microbiological loading due to factors such as tourism or seasonality in rainfall patterns (Younger *et al.*, 2003). Barry and Younger (2009) have found consistently higher levels of *E. coli* accumulation in mussels than those in Pacific oysters in various commercially harvested beds across England.

Bivalve molluscs in the Yealm Estuary are currently subject to year-round classification. This section presents the results of an investigation to the seasonal variation of levels of *E. coli* in currently classified bivalve mollusc beds using data periods shown in Table XII.1. The aim of this investigation was to evaluate whether any variations in microbiological loads to the estuary result of seasonal variations in the levels of *E. coli* in Pacific oysters and mussels.

Two methods were employed. The first consisted of the analysis of monthly geometric means of *E. coli* together with the number of *E. coli* results >4,600 MPN100g^{-1} FIL in bivalves. The second method consisted of the analysis of seasonal variation of *E. coli* levels. For this purpose, data was amalgamated by season considering spring (March–May), summer (June–August), autumn (September–November) and winter (December–February). Parametric (one-way ANOVA) and non-parametric Kruskall-Wallis[13]) tests using significance level (α) of 0.05 were used to test differences between seasons. Side-by-side box-and-whisker plots[14] were computed to summarise the distribution of these datasets. The analyses were conducted for datasets with more than 100 results[15].

The analyses showed lack of statistically significant differences in seasonal levels of *E. coli* in bivalves from most beds. Levels of the microbiological indicator in Pacific oysters during winter were significantly ($F_{3,113} = 3.43$; $p<0.05$) different from those during the summer–autumn period. Although the geometric mean is generally higher during the period May–December and results are lowest during the period January–April, Younger (2006) noted a prevalence of threshold results occurring in July, August and December. This indicates that the season of higher contamination could be more justified by intermittent episodes of contamination than an underlying higher level of contamination in oysters at this site. Given the lack of consistent seasonal differences in *E. coli* contamination, it is concluded that there is no justification for a modified sampling frequency at currently classified beds in the Yealm.

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[13] All datasets were found to be not normally distributed as indicated by Anderson-Daring test (95% confidence level).

[14] Box-and-whisker plots depict the distribution (central tendency and spread) of a data set. These plots show (a) the centre or median of the data (centre line of the box), (b) the spread or inter-quartile range (box height), (c) quartile skew (relative size of box halves) and (d) the presence of extreme values or outliers (asterisks).

[15] The *European Union Guide to Good Practice on Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* recommends that at least two years' worth of data are necessary to establish a seasonal classification (EU Working Group on the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas, 2007).

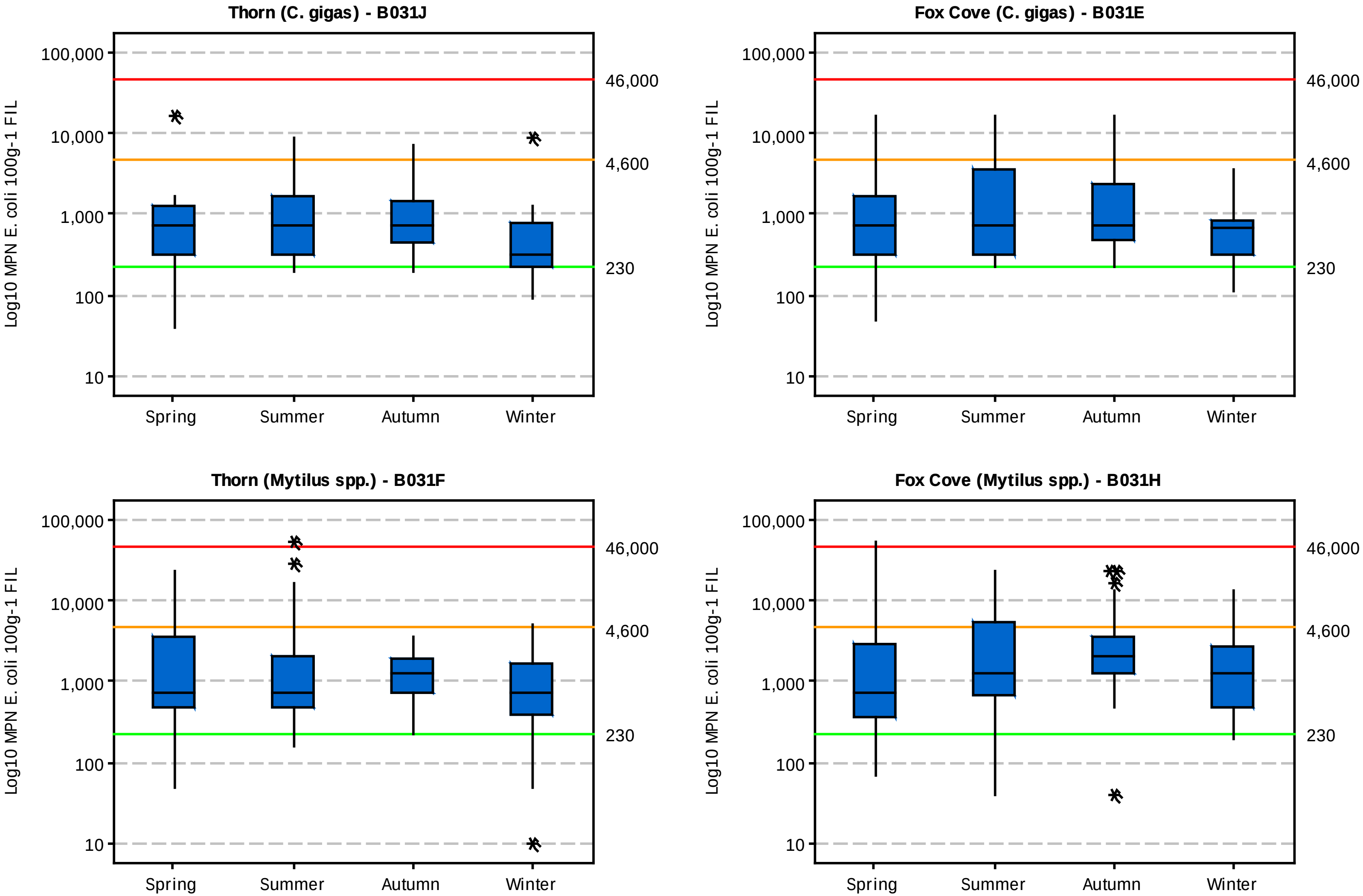

Figure XII.2 Box-and-whisker plots of seasonal variation of* E. coli *levels in bivalves from four representative monitoring points in the Yealm Estuary.

VARIATION OF *ESCHERICHIA COLI* ACCORDING TO RAINFALL

There is historical evidence suggesting that a proportion of high Shellfish Hygiene flesh sampling results are attributable to rainfall associated events, e.g. contamination due to increased runoff and the impact of rainfall-dependent discharges.

The association between levels of *E. coli* in bivalves from four current RMPs in the estuary and rainfall levels in the Yealm catchment was examined for the period 1 January 2000–31 January 2009.

Spearman's rank correlation coefficient (*rho*)[16] was used to estimate correlations between MPN of *E. coli* 100g^{-1} FIL and total daily rainfall monitored at X gauging station (Figure II.1).

Significant positive relationships were detected between rainfall and levels of the indicator in Pacific oysters and mussels from Fox Cove and Thorn (Table XII.2).

Correlation coefficients varied according to the monitoring point and the time of sampling relative to the rainfall event.

Overall, the higher correlation coefficients were detected when the rainfall event happened one/two days before the sampling occasion. When cumulative rainfall is considered, the higher coefficients were detected when rainfall occurred between de 2nd–6th days before sampling.

The fact that positive correlations were consistent for both gauging stations indicate that the levels of contamination in bivalves commercially harvested in the Yealm are likely to increase during and immediately after rainfall events and that this effect could be due to faecal contamination from diffuse sources and/or the effect of rainfall-dependent discharges.

[16] This statistical test is usually defined as the linear correlation coefficient determined on the ranks of the data, in which differences between data values ranked further apart are given more weight (Helsel and Hirsch, 2002).

Table XII.2 Spearman's rho coefficients between rainfall at two gauging stations and MPN of* E. coli *100g^{-1} FIL in bivalves from four monitoring points in the Yealm Estuary during the period January 2000−February 2009.

		Fox Cove (*C. gigas*)	Thorn (*Mytilus* spp.)	Fox Cove (*Mytilus* spp.)	Thorn (*C. gigas*)
Ermington		B031E	B031F	B031H	B031J
	n	107	108	109	108
	95%	0.190	0.189	0.189	0.189
Daily	Day of sampling	0.138	0.185	0.312	0.168
	-1 day	0.290	0.349	0.427	0.321
	-2 days	0.339	0.385	0.450	0.226
	-3 days	0.278	0.353	0.383	0.211
	-4 days	0.274	0.125	0.267	0.061
	-5 days	0.333	0.248	0.222	0.223
	-6 days	-0.078	-0.001	-0.098	0.012
	-7 days	0.049	0.105	0.049	0.088
Cumulative	-2 days	0.261	0.329	0.415	0.336
	-3 days	0.291	0.393	0.465	0.391
	-4 days	0.333	0.445	0.491	0.382
	-5 days	0.356	0.414	0.486	0.343
	-6 days	0.380	0.439	0.461	0.346
	-7 days	0.318	0.374	0.373	0.298
Watercombe		B031E	B031F	B031H	B031J
	n	110	112	112	112
	95%	0.188	0.186	0.186	0.186
	Day of sampling	0.249	0.181	0.329	0.163
	-1 day	0.253	0.386	0.457	0.305
	-2 days	0.313	0.354	0.546	0.204
	-3 days	0.243	0.279	0.255	0.124
	-4 days	0.297	0.196	0.310	0.086
	-5 days	0.264	0.236	0.188	0.201
	-6 days	-0.033	0.030	-0.047	0.001
	-7 days	-0.010	0.068	0.069	0.034
	-2 days	0.294	0.337	0.442	0.301
	-3 days	0.307	0.391	0.512	0.346
	-4 days	0.335	0.405	0.503	0.316
	-5 days	0.337	0.383	0.492	0.277
	-6 days	0.343	0.400	0.460	0.282
	-7 days	0.292	0.362	0.396	0.252

VARIATION OF *ESCHERICHIA COLI* ACCORDING TO RIVER FLOWS

The association between levels of *E. coli* in bivalves and water levels in the River Yealm at Puslinch was examined for the period 1 January 2000–31 January 2009 using Spearman's rank correlation coefficient (*rho*).

No positive associations were found between flows in the River Yealm and levels of *E. coli* in bivalves. Levels of *E. coli* in Pacific oysters at Thorn were found to be negatively associated with river flows between the 5th and 7th days before sampling. This could be due to dilution effects caused by the influence of seawater at this site.

Table XII.2 Spearman's rho coefficients between riverflow and MPN of* E. coli *100g^{-1} FIL in bivalves from four monitoring points in the Yealm Estuary during the period January 2000−February 2009.

Puslinch		Fox Cove (*C. gigas*) B031E	Thorn (*Mytilus* spp.) B031F	Fox Cove (*Mytilus* spp.) B031H	Thorn (*C. gigas*) B031J
	n	94	98	96	97
	95%	0.203	0.199	0.201	0.200
Daily	Day of sampling	0.111	0.140	0.177	0.001
	-1 day	0.063	0.161	0.178	0.009
	-2 days	0.049	0.159	0.150	0.023
	-3 days	0.039	0.090	0.048	-0.057
	-4 days	0.008	0.081	0.010	-0.092
	-5 days	-0.050	0.012	-0.075	-0.200
	-6 days	-0.131	-0.058	-0.113	-0.242
	-7 days	-0.137	-0.017	-0.091	-0.210
Cumulative	-2 days	0.096	0.158	0.199	0.023
	-3 days	0.084	0.168	0.189	0.034
	-4 days	0.075	0.153	0.165	0.006
	-5 days	0.063	0.141	0.142	-0.017
	-6 days	0.053	0.132	0.114	-0.049
	-7 days	0.039	0.117	0.093	-0.057

APPENDIX XIII
MICROBIOLOGICAL DATA: BACTERIOLOGICAL SURVEYS

Table XIII.1 summarises results from a bacteriological survey undertaken by the Local Enforcement Authority following a cause for concern for mussels at Thorn.

Table XIII.1 Levels of faecal indicator microorganisms, salinity and water temperature in six sampling sites in the Yealm Estuary.

Site	Collection date	Faecal coliforms (CFU 100ml^{-1})	*E. coli* (CFU 100ml^{-1})	Water temp. (°C)	Salinity (ppt)
Shortaflete Creek	31/05/2007	1600	350	15.4	22
	04/06/2007	20	4	16.3	29
	13/06/2007	130	75	18.6	27
	19/06/2007	350	50	17.2	29
	02/07/2007	3500	1100	17.5	12
	17/07/2007	240	240	17.2	28
Opposite Thorn	31/05/2007	910	70	15.4	24
	04/06/2007	75	31	16.2	29
	13/06/2007	75	50	18.8	27
	19/06/2007	540	110	17.2	30
	02/07/2007	1700	350	17.7	18
	17/07/2007	1100	70	16.9	28
Brixton STW outfall	31/05/2007	350	250	17	0
	04/06/2007	240	240	20.3	0
	13/06/2007	540	170	21	0
	19/06/2007	1700	240	18.8	0
	02/07/2007	5400	2400	18	0
	17/07/2007	5400	2200	18.3	0
Cofflette stream (tidal)	31/05/2007	35000	7500	14.4	0
	04/06/2007	35000	17000	16.3	0
	13/06/2007	24000	13000	15.2	0
	19/06/2007	160000	1600000	17.2	0
	02/07/2007	9100	5400	16.7	0
	17/07/2007	7000	1400	16.8	0
Fox Cove	31/05/2007	540	170	16.4	26
	04/06/2007	1300	70	18.2	29
	13/06/2007	540	500	18.9	26
	19/06/2007	910	280	17.2	31
	02/07/2007	17000	3500	18	8
	17/07/2007	3500	500	19	15
Thorn	31/05/2007	350	75	16.4	26
	04/06/2007	1700	35	18.2	17
	13/06/2007	350	170	18.6	29
	19/06/2007	350	130	17.6	31
	02/07/2007	2400	170	17.9	11
	17/07/2007	3500	1100	19	19

The results indicate that Cofflete Stream could be considered as a very significant route of faecal contamination to the estuary in comparison with all other sites sampled. During a shoreline survey on 1 February 2006, Younger (2006) noted high levels of turbidity in this creek in the absence of previous rainfall events. The author also noted that the main points of contamination of faecal origin (as given by *E. coli* and faecal streptococci) were Newton Creek, Cofflete Creek and the River Yealm upstream of Puslinch, although water contamination with streptococci was considerable higher than that with *E. coli*.

Shoreline Survey

General

Date of survey	10th and 11th March 2009	
Production Area	Yealm Estuary	
Area(s) surveyed	see Figure A.2	
Commercial Species	Farmed	Mussels (*Mytilus* spp.) Pacific oysters (*Crassostrea gigas*)
Harvester(s)	Martyn Oates and Steve Allen	
Local Authority	Plymouth Port Health Authority	

On the 10th and 11th of March 2009, staff from the Cefas Weymouth Laboratory and Plymouth Port Health Authority performed a shoreline survey in the Yealm Estuary. The aim of the survey was to confirm the presence of potential sources of microbiological pollution previously identified as part of a desk study and to identify any additional potential sources of contamination in the area surveyed. Surveys on both days were undertaken by foot. Observations and results apply to the time of the survey. Observations relate to the location and field-of-view of the observer at the time they were made.

Tidal conditions
The survey took place between 09.30 and 14.00 on 10th March 2009 and between 09.50 and 15.00 on 11th March 2009. The tidal curve for the two days is shown in Figure A1.

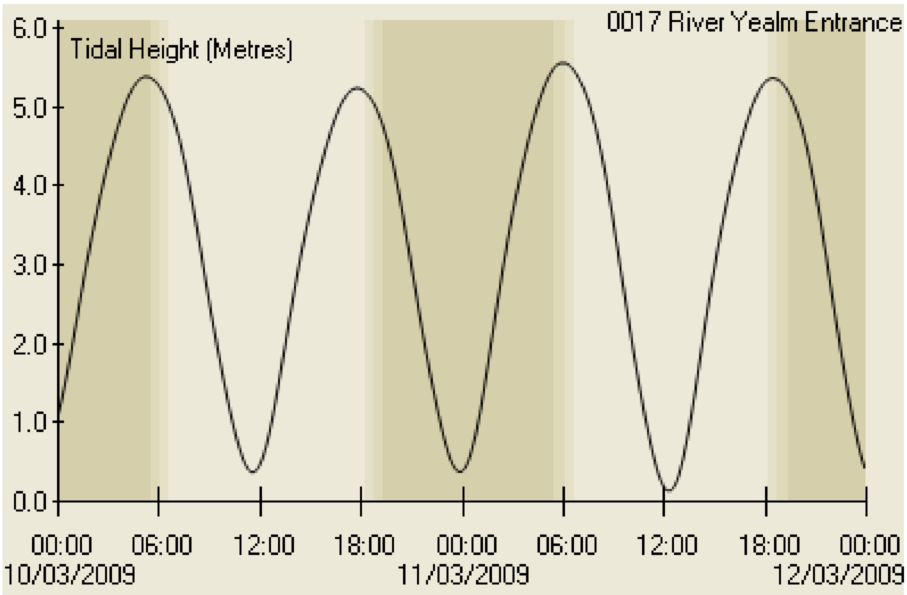

Figure A1. Tidal curve at River Yealm Entrance for the 10th and 11th March 2009.
Prediction based on Plymouth (Devonport). Admiralty TotalTide (UKHO, 2009).

Area surveyed

The principal focus of the survey was to record the location of the mussel and oyster fisheries, to record potential sources of pollution in the near vicinity, and upstream, of these, and to take associated freshwater, seawater and mussel samples. The survey tracks by foot and boat are shown in Figure A2.

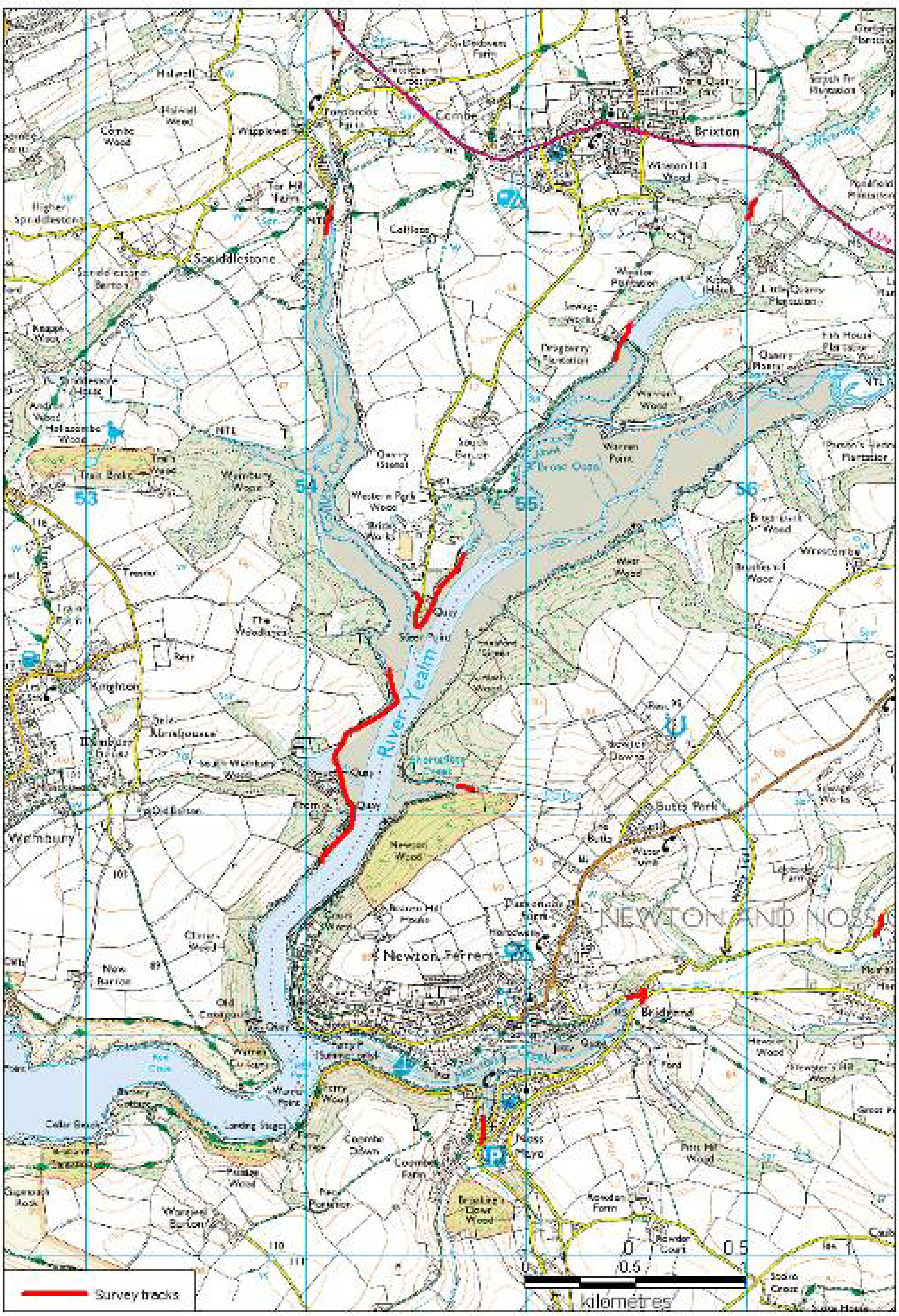

Figure A2. Area surveyed (red lines).

Weather

The weather was light cloud but dry with a moderate wind on 11th February and overcast with occasional drizzle and a light breeze on the 12th February. The maximum temperature during the survey period on each day was 11ºC.

3.2 RESULTS

Shellfish Farming Operations

There were three areas of trestles with poches of Pacific oysters on the west side of the main estuary. One was at the site known as Fox Cove (Figures A.6 and A.7). The other two were in two separate parts of the site known as Thorn (Figures A.8 and A.9). No mussels for cultivation were on site due to the difficulty in obtaining seed and the classification status of the area. One bag of mussels had been placed at the Fox Cove site, and one at the Thorn South site, for the purposes of sampling only. The Pacific oysters are harvested year-round.

The location of the farmed shellfisheries is shown in Figure A3.

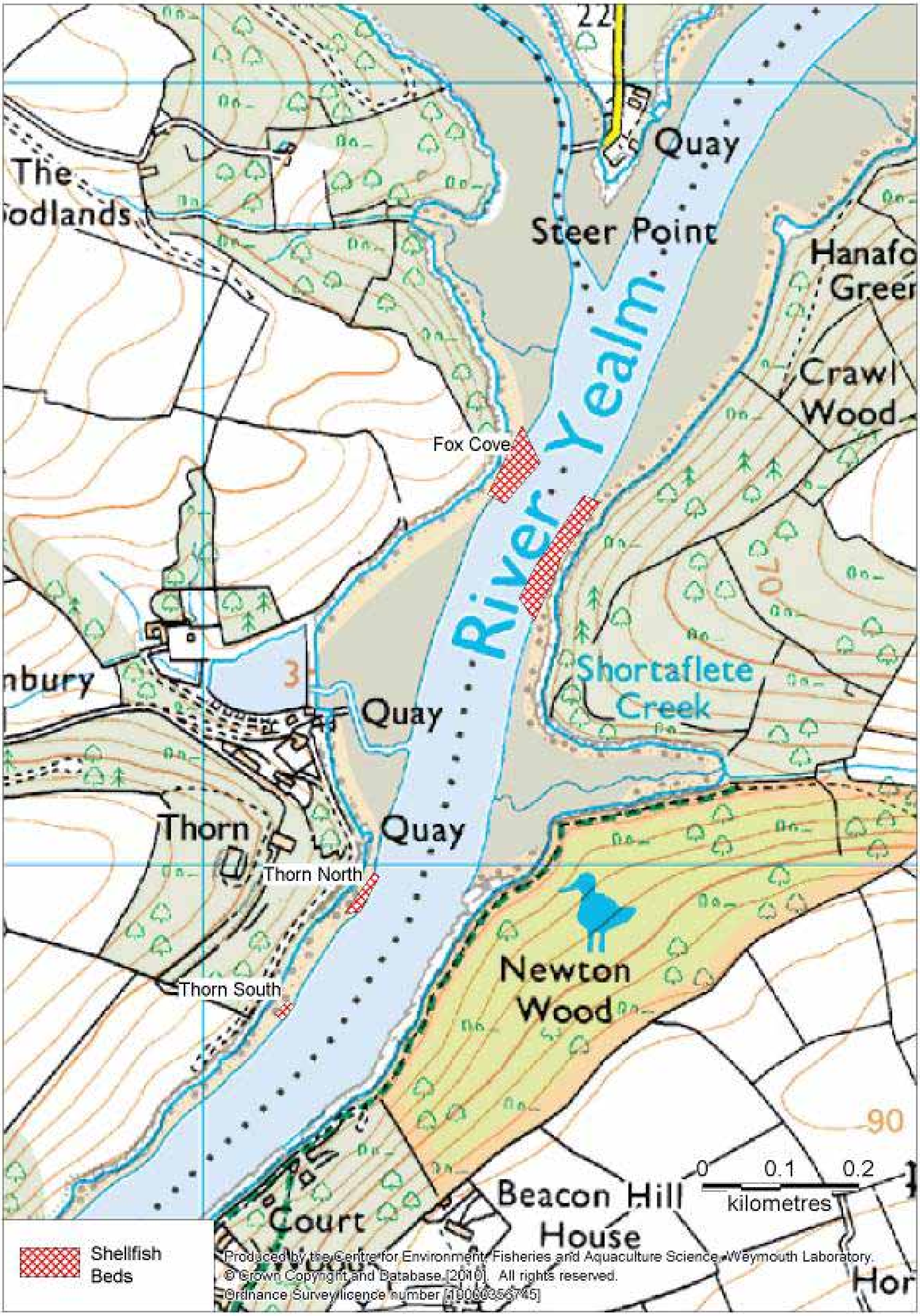

Figure A3. Shellfish farming operations in the Yealm estuary.

Sewage Treatment Works

The locations of the following sewage treatment works and pumping stations were recorded during the survey:

Name	Location *	Figure
Yealmpton STW	SX 57663 51483	A.10
Yealmpton PS	SX 57740 51488	A.11
Newton Ferrers STW	SX 56601 48507	A.12
Brixton STW	SX 55395 51182	A.13

*The locations of sewage treatment works were recorded at the entrances.

Sewage related debris

Plastic debris was seen in the vicinity of the Thorn trestles. Some of this could have been sewage related.

Boats

Moored boats were mainly located in the main estuary in the vicinity of Newton Ferrers (Figures A.14 and A.15) and in Newton Creek. However, a significant number of boats were also moored in the stretch of estuary between Newton Ferrers and Steer Point. There were also a number of unoccupied moorings which may be used during the summer months. This stretch of estuary is in the immediate vicinity of the shellfisheries (see Figures A.6 to A.9).

Land use and animals

Much of the estuary is steep sided with deciduous woodland and fields above this. Developed areas are located at Newton Ferrers and Noss Mayo on the estuary itself with the communities of Yealmpton and Brixton being located on rivers feeding into the north of the estuary. Other small collections of houses and individual dwellings occur around the estuary. Approximately 40 sheep were observed in fields near Kitley House (Figure A.16). Wild birds were predominantly seen around the pond by Kitley House and on the pond at South Wembury (approximately 30 ducks and geese). Two ponies were observed in a field by the pumping station on the south bank of the river at Yealmpton.

Other observations

A pipe of approximately 11cm diameter was observed going out into the river at one end of the trestles at Fox Cove. The end was under water and so it could not be determined whether any flow was associated with it. A seawater sample (YW09) was taken in the immediate vicinity. The pipe may be associated with the scout camp located above the slopes – if so, an impact would only be expected when this was being used (which was not the case at the time of the survey).

Water samples

Sampling principally took place under dry weather conditions although there was light drizzle on the second day. Nine samples of river or streamwater and five samples of seawater were taken and submitted to Plymouth HPA laboratory for *E. coli* analysis. Seawater samples were tested on site for salinity (parts per thousand; ppt) using a refractometer. No piped flows were observed and thus no samples were taken of these (where possible, river or stream samples were taken downstream of sewage treatment works). The sampling locations are shown in Figure A.4 and the results given in Table A1.

Shellfish samples

Shellfish were sampled at the trestles at Fox Cove (samples YM1 and YO1), Thorn South (YM2 and YO2) and Thorn North (YO3). The sampling locations are shown on the map in Figure A.5 and the results are given in Table A.2.

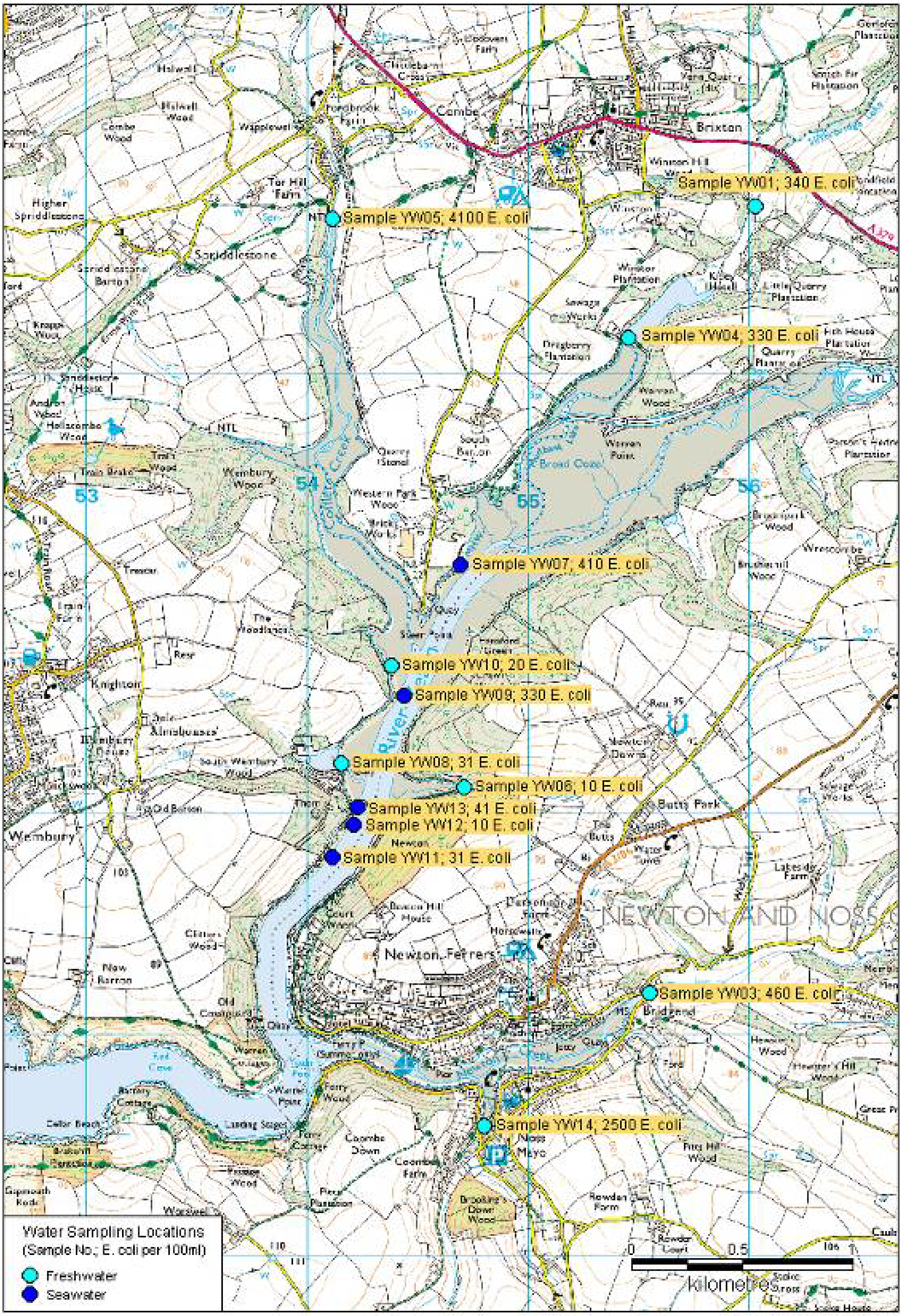

Figure A4. Water sampling locations

Table A1. E. coli in samples of water collected at the time of the shoreline survey.

Sample no.	NGR	Sample type	Description	Salinity ppt	Flow m^3 day^{-1}	MPN *E. coli* 100 ml^{-1}	Loading *E. coli* day^{-1}
YW01	SX 56026 51757	Fresh	Stream near Kitley House	-	28100	340	9.6×10^{10}
YW02	SX 57608 51278	Fresh	River Yealm below Yealmpton (Figure A.17)	-	142000	2900	4.1×10^{12}
YW03	SX 55545 48188	Fresh	Stream at head of Newton Creek (Figure A.18)	-	27800	460	1.3×10^{11}
YW04	SX 55451 51156	Fresh	Stream at head of Mudbank Lake (Figure A.19)	-	-	330	1.4×10^{11}
YW05	SX 54105 51701	Fresh	Stream at head of Cofflete Creek (Figure A.20)	-	19300	4100	7.9×10^{11}
YW06	SX 54703 49122	Fresh	Stream at head of Shortaflete Creek	-	1690	10	1.7×10^{8}
YW07	SX 54689 50129	Sea	North of Steer Point	9	-	410	-
YW08	SX 54147 49228	Fresh	Stream from sluice below pond at South Wembury	-	2130	31	6.6×10^{8}
YW09	SX 54432 49535	Sea	Fox Cove shellfish site	9	-	330	-
YW10	SX 54375 49674	Fresh	Stream north of Fox Cove shellfish site	-	288	20	5.8×10^{7}
YW11	SX 54107 48804	Sea	Thorn South shellfish site	30	-	31	-
YW12	SX 54206 48950	Sea	Thorn North shellfish site	30	-	10	-
YW13	SX 54220 49027	Sea	Off quay above Thorn North shellfish site	30	-	41	-
YW14	SX 54796 47584	Fresh	Noss Mayo Stream	-	3670	2500	9.2×10^{10}

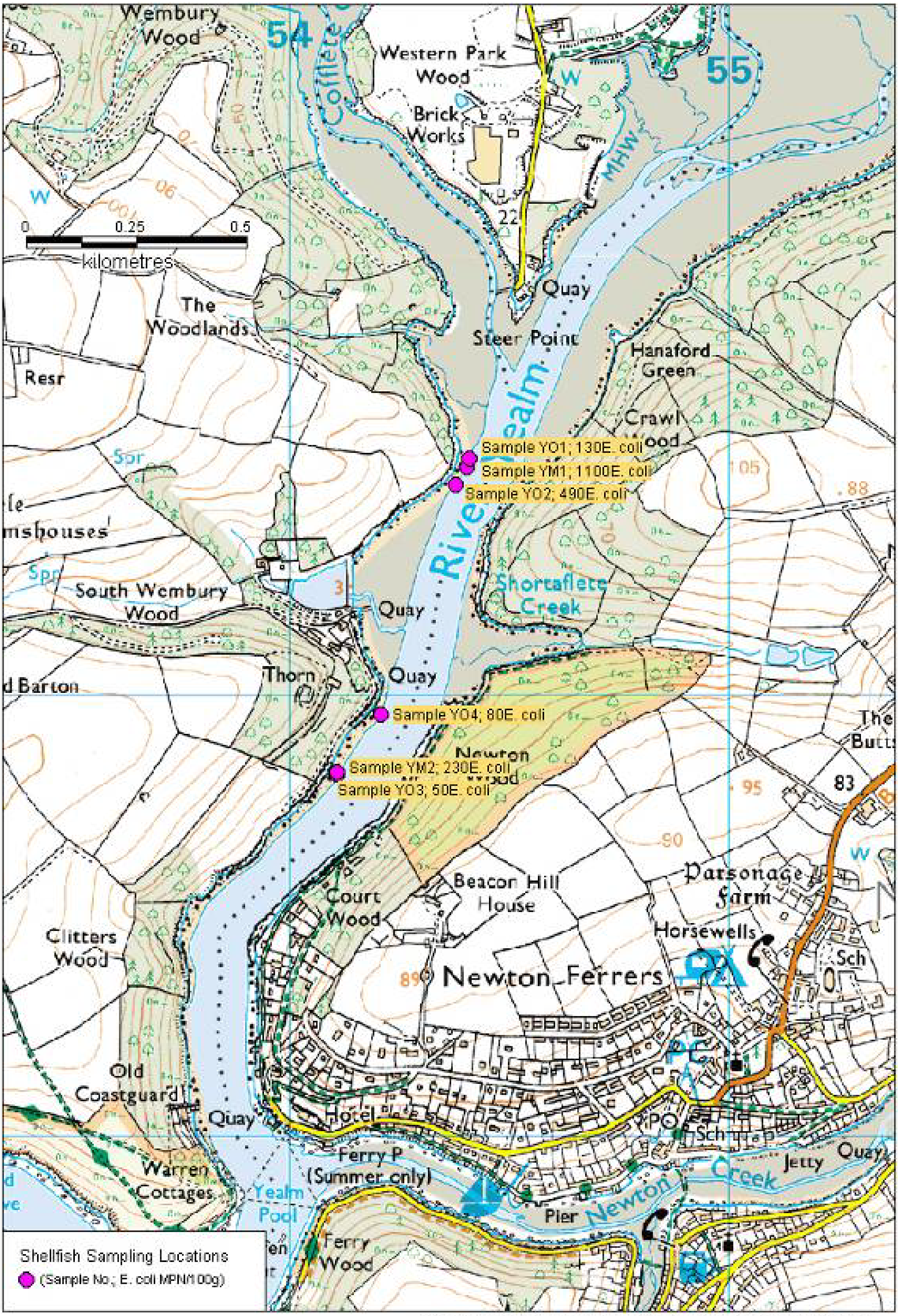

Figure A5. Shellfish sampling locations.

Table A2. E. coli in samples of mussels collected at the time of the shoreline survey.

NGR	Sample no.	Species	Depth	MPN E. coli 100 g^{-1}
SX 54402 49518	YM1	Mussels	N/A*	1100
SX 54408 49538	YO1	Oysters	N/A	130
SX 54375 49480	YO2	Mussels	N/A	490
SX 54105 48821	YO3	Oysters	N/A	50
SX 54106 48827	YM2	Mussels	N/A	230

*N/A = not applicable; all samples were taken from trestles above the level of the seawater at the time of sampling.

Figure A.6. Fox Cove shellfish trestles – 1.

Figure A.7. Fox Cove shellfish trestles – 2.

Figure A.8. Thorn South shellfish trestles.

Figure A.9. Thorn North shellfish trestles.

Figure A.10. Yealmpton STW.

Figure A.11. Yealmpton PS.

Figure A.12. Newton Ferrers STW.

Figure A.13. Brixton STW.

Figure A.14. Boats at Newton Ferrers - 1

Figure A.15. Boats at Newton Ferrers – 2.

Figure A.16. Sheep and stream near Kitley House.

Figure A.17. River Yealm below Yealmpton.

Figure A.18. Stream at head of Newton Creek.

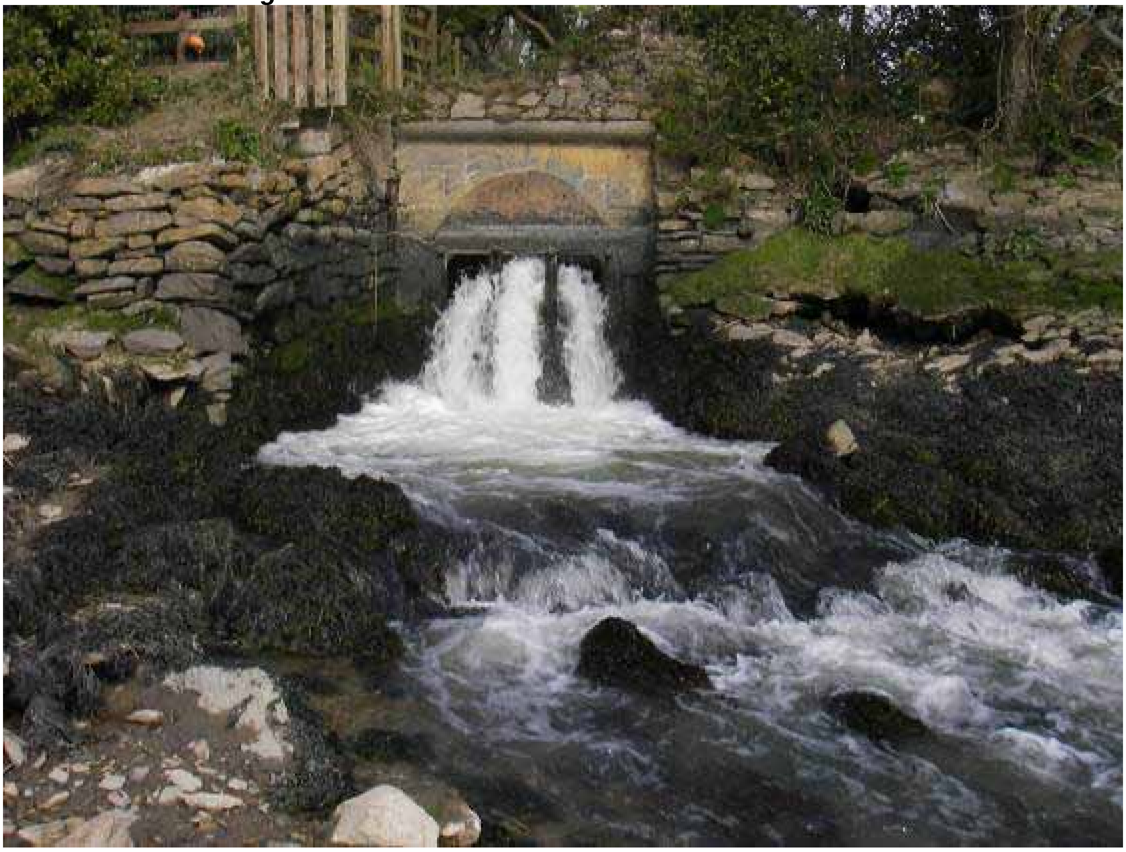

Figure A.19. Stream at head of Mudbank Lake.

Figure A.20 Stream at head of Cofflete Creek.

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List of Abbreviations

AONB	Area of Outstanding Natural Beauty
BMPA	Bivalve Mollusc Production Area
CD	Chart Datum
Cefas	Centre for Environment Fisheries & Aquaculture Science
CFU	Colony Forming Units
CSO	Combined Sewer Overflow
CZ	Classification Zone
Defra	Department for Environment, Food and Rural Affairs
DWF	Dry Weather Flow
EA	Environment Agency
E. coli	*Escherichia coli*
EC	European Community
EEC	European Economic Community
EO	Emergency Overflow
FIL	Fluid and Intravalvular Liquid
FSA	Food Standards Agency
GM	Geometric Mean
ISO	International Organization for Standardization
km	Kilometre
LEA (LFA)	Local Enforcement Authority formerly Local Food Authority
M	Million
m	Metres
ml	Millilitres
mm	Millimetres
MPN	Most Probable Number
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
OSGB36	Ordnance Survey Great Britain 1936
PS	Pumping Station
RMP	Representative Monitoring Point
SAC	Special Area of Conservation
SSSI	Site of Special Scientific Interest
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. Ebb-dominant estuaries have asymmetric tidal currents with a shorter ebb phase with higher speeds and a longer flood phase with lower speeds. In general, ebb-dominant estuaries have an amplitude of tidal range to mean depth ratio of less than 0.2.
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 N^{th} 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 a skewed data such as one 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 data set, 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.
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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