Water Quality & Aquaculture REPORT

Wholescape Assessment of Water Quality Status, drivers and impacts in the Exe Estuary Catchment and implications for ecosystem health and services, including Shellfish Aquaculture.

FULL REPORT excluding Appendices

http://hdl.handle.net/10871/131804

Published 2022

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1 Report outline

This 'wholescape' assessment of water quality in the Exe Estuary catchment has been completed as part of the South West Environmental and Economic Prosperity (SWEEP) aquaculture project https://sweep.ac.uk/portfolios/aquaculture/, which has the aim of supporting the sustainable expansion of aquaculture in SW England through integrated understanding and management of water quality issues at a whole catchment scale. The investigation focuses on the Exe Estuary catchment,extending from the sources of its rivers down to the Exe Estuary and into Lyme Bay (**Figure 1**).

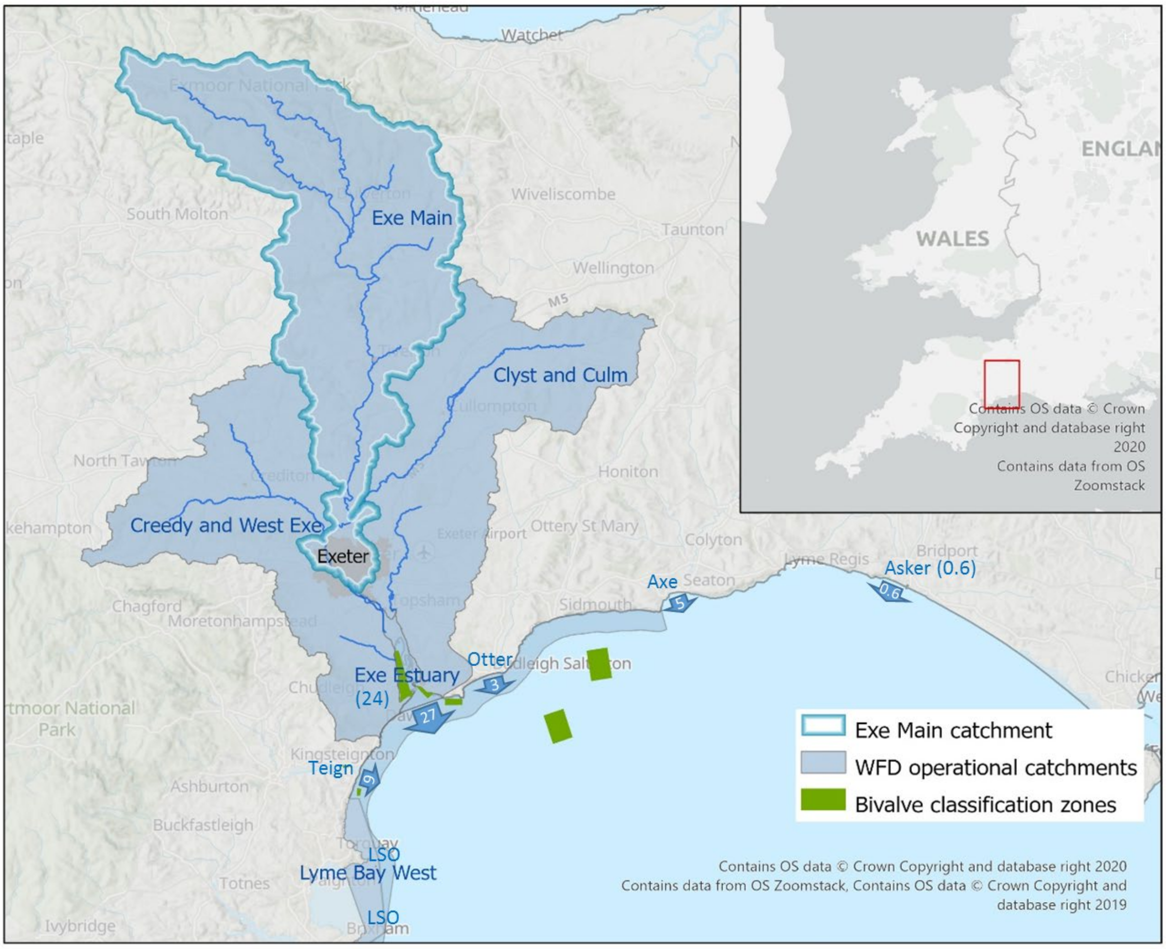
The report tracks the ecological, microbiological and chemical pollution status of these water courses and evaluates their impacts on estuarine and coastal shellfish, which are sensitive receptors, indicators (sentinels) and regulators (bio-remediators) of water quality, as well as highly sustainable food sources. We follow a similar (but finer grain) investigative approach to that undertaken in the Rivers Trusts' "State of our Rivers Report" for England (Rivers Trusts, 2021). As such we envisage that the following report will serve to inform a wide range of stakeholders in addition to the shellfish industry and regulatory authorities (e.g. bathing water users, water and tourism industries, and the general public).

The specific aims of this investigation are to provide an assessment of the current water quality of the Exe Estuary catchment, including tributaries of the Exe Estuary (**Figure 1**), assessing the drivers for water quality impairment, and impacts of this on estuarine and coastal bivalve shellfish aquaculture (farming of mussels, oysters and clams). This was done through a detailed evaluation of publicly available data and information. The investigation follows a receptor-pathway-source approach to back-track from designated shellfish waters in Lyme Bay and the Exe Estuary to potential upstream sources of contaminants in the Exe Estuary catchment. When reviewing information on potential sources and drivers of water quality issues, we highlight where there are significant data gaps. This report also provides a summary of activities and actions already underway within the wider catchment designed to achieve water quality improvements and discusses potential future catchment management interventions.

By taking a wholescape approach this assessment also attempts to address linkages between freshwater waters, estuarine and coastal waters in terms of their water quality status, the key pressures they face both locally and from up-stream, and the impacts that arise from these pressures. To date knowledge concerning these linkages has been limited by a lack of integrated assessments across the land-sea interface https://catchmentbasedapproach.org/learn/wamm/. A wholescape approach for joining up decision-making on land and at sea is now laid out in Marine Planning Policy and Integrated Coastal Zone Management, addressing the importance of land-sea interactions (HM Government, 2018a). This catchment investigation is one of the first case examples of a 'wholescape approach' being implemented in the UK.

Figure 1: The Exe Estuary catchment and tributaries feeding into the Exe Estuary and Lyme Bay

Water Framework Directive (WFD) operational catchments are highlighted in blue. Classification zones for bivalve shellfish production are shown in green. River discharges are labelled with their historical mean flow rates in m^3 per second https://nrfa.ceh.ac.uk/data/search and two long-sea sewage outfalls (LSO) are also shown.



The process of the investigation involved collating and evaluating available water quality monitoring data in association with geospatial data on land uses and specific activities, including agriculture and aquaculture production, urban wastewater treatment and storm water management. This enabled information on water quality status, pressures and impacts to be compiled from various disparate data sources.

Available data and reports referred to in this investigation are listed in Bibliography. The investigation drew on various digital data sources in spreadsheet and Geographical Information System (GIS) formats, including from the following data hub websites:

- UK Centre for Ecology and Hydrology https://eip.ceh.ac.uk/hydrology/water-resources/
- Connecting the Culm https://connectingtheculm.com/; https://connectingtheculm.com/wp-content/uploads/2021/02/CtC-Evidence-Review-1stEdition-Feb2021_logos.pdf
- DEFRA MAGIC database https://magic.defra.gov.uk/
- Devon Local Nature Partnership https://www.devonlnp.org.uk/devons-environment/
- Dorset and East Devon Aquaculture https://www.dorsetaquaculture.co.uk/
- East Devon Catchment Partnership https://data.catchmentbasedapproach.org/pages/working-groups
- Environment Agency Catchment Data Explorer https://environment.data.gov.uk/catchment-planning/
- Environment Agency Water Quality Archive https://environment.data.gov.uk/water-quality/view/landing

- Exe Estuary Management Partnership https://www.exe-estuary.org/publications/state-of-the-exe-estuary/
- FSA Shellfish Classification https://www.food.gov.uk/business-guidance/shellfish-classification
- HM Government https://www.data.gov.uk/
- Lyme Bay Fisheries and Conservation Reserve https://www.lymebayreserve.co.uk/download-centre/
- Riverfly Partnership Data Explorer https://www.riverflies.org/content/DataExplorer
- SWW (data concerning metals, pesticides and pharmaceuticals in municipal wastewater
- The Rivers Trust https://www.theriverstrust.org/key-issues/sewage-in-rivers
- UK Water Industry Research - Chemicals Investigation Programme https://ukwir.org/my-ukwir-homepage
- Westcountry Rivers Trust https://www.theriverstrust.org/key-issues/state-of-our-rivers#main-content

2 Background and Context

2.1 Status of UK aquaculture and dependence of shellfish quality on water quality

Aquaculture is the fastest growing food production sector globally and, due to declining capture fisheries, it is expected to underpin sustainable economic growth in rural and coastal communities, including in the UK (DEFRA, 2015; FAO, 2020). Over the last 40 years in the UK the Aquaculture industry (shellfish and finfish) has seen considerable growth and is now a significant contributor to the UK economy with an annual value of £1.1 billion, equalling that of capture fisheries (OECD, 2021), with huge potential for future sustainable growth (DEFRA, 2015; Highlands and Islands Enterprise, 2017; Huntington and Cappell, 2020). The growth of UK aquaculture brings a number of socio-economic and environmental benefits, including the provision of sustainable long-term growth; employment opportunities; niche markets (e.g. for exotic species grown in bio-secure systems); additional ecosystem services beyond food production (e.g. nutrient regulation, habitat provisioning) (Huntington and Cappell, 2020; Pinn et al., 2021).

Growth in UK aquaculture to £1.1 billion per year (at point of first sale - OECD, 2021) has been dominated by Scotland, which holds 85% of the UK share, while the industry has stagnated in other UK countries (Hambrey and Evans 2016; Black and Hughes, 2017; Huntington and Cappell, 2020). For example, aquaculture has declined by 5.6% in England in the last decade due to a number of factors, including complex regulation and planning, low social acceptance and domestic consumption, lack of economic investment, growing climate and environmental challenges (Huntington and Cappell, 2020). Nevertheless SW England remains a major centre for aquaculture, containing over a third of production areas for shellfish in England and Wales (111 out of 331 areas, Food Standards Agency, 2022) and has considerable scope to diversify/expand (Maritime UK, 2020). The Exe estuary and neighbouring coastal waters produce some of the highest volumes of shellfish in the SW region (**Section 3**).

Some of the main environmental challenges faced by the industry are associated with impairment of water quality by various forms of pollution. As bivalve shellfish (e.g. mussels and oysters) process large volumes of water when filter feeding on plankton (3.4 and 34 litres per hour, respectively) (Newell, 2004), they can accumulate and retain in their flesh water-borne contaminants, including potentially harmful chemicals and pathogenic microorganisms (Campos et al., 2013; Cefas, 2013) (Brown et al., 2020; Webber et al., 2021). Furthermore, while planktonic primary production, fuelled by nutrients (nitrogen and phosphorus) underpins shellfish production, excessive nutrient inputs from land can lead to eutrophication and asphyxiation of shellfish, as shown historically in the Exe Estuary (Langstone et al., 2003). Thus bivalve shellfish are sensitive indicators of a wide range of pollutants (**Section 4**).

Maximum threshold concentrations for a range of organic and inorganic chemical contaminants in shellfish meat, for human consumption, are stipulated by EU Hygiene Regulations (EC, 2004a, b and c). Other priority substances listed in Annex II of Directive 2008/105/EC4; and synthetic compounds (biocides, pesticides, antifoulants, flame retardants and pharmaceuticals) are also monitored in shellfish under the Water Framework Directive (WFD: 2000/60/EC) and Oslo Paris Commission (Beyer et al., 2017). Priority substances regulated under the WFD, may impact on shellfish health and productivity, but these impacts are difficult to discern under current assessment regimes (**Section 4**). Land-derived faecal microbial contaminants can also accumulate in shellfish. While this may have limited direct impact on shellfish health and growth, some accumulated faecal bacteria (e.g. enterococci) and viruses (e.g. norovirus) can impact on the health of human consumers, if faecal indicator organisms (FIOs – *Escherichia coli* or *E. coli*) exceed statutory limits of 230 colony forming units per 100 g of shellfish flesh and intervalvular fluid) (EC, 2004c). This in turn can impact on the National Health Service, and on the shellfish industry, through loss of sales, product recalls and loss of consumer confidence (Campos and Lees, 2014; Hassard et al., 2017).

The loading/presence of chemical and faecal contaminants in estuarine and coastal waters may be related to multiple sources within the catchment and their relative importance may change depending on seasonal agricultural practices, climatic factors such as rainfall, in combination with catchment topography/geology and also hydrological factors, including tidal movements. According to Kay et al., (2010), urban (sewerage-related) sources are generally the dominant drivers of FIOs in UK rivers during base flow conditions e.g. in the summer, when there is little or no runoff from agricultural land, whereas during high river flows - improved grassland and associated livestock are the significant source of FIOs. Nevertheless, Combined Sewer Overflows (CSOs), Sanitary Sewer Overflows (SSOs) and Storm Tank Overflows (STOs) can also be significant contributors of FIOs and bacterially contaminated water during wet weather and high river flows (Crowther et al., 2016). The importance of agricultural and municipal sewage sources of contaminants in the Exe Estuary catchment are investigated in **Section 5**.

Flood events exacerbate water pollution, not only through increased land runoff, but also through the resuspension of sediments bearing chemical and microbial contaminants and nutrients (Gooday et al., 2014). Metals and some organic pollutants can persist in sediments for decades (Everaert et al., 2017). Faecal contaminants including *E.coli* can persist in freshwater and estuarine sediments for periods of several weeks (Davies et al., 1995; Perkins et al., 2016), thus obscuring FIO source tracking (Kay et al., 2010; Hassard et al., 2016). Other sources of animal-derived FIOs include terrestrial and aquatic wildlife populations, which may be significant in some cases, particularly for estuarine and coastal waters (Crowther et al., 2016; 2018). For example, some northern hemisphere estuaries, such as the Exe estuary regularly accommodate large populations of several thousand overwintering wildfowl and waders (WeBS, 2017) and cumulative inputs of FIOs can reach $x10^{11}$-10^{12} colony forming units every 24 hours (Davies et al., 1995; Perkins et al., 2016). Faecal contamination of shellfish (and bathing) waters in the Exe estuary and neighbouring coastal waters is related to multiple rural and urban land uses and sources in the catchment, which are examined in **Section 6**. Subsequent sections (**Sections 7-11**) of this report focus on range of chemical contaminants with the potential to impact on shellfish and environmental and human health more generally.

2.2 Legal framework for the protection of water quality in the UK

The protection of water quality in the UK has multiple strands, which relate to specific designated uses of water bodies, including nature conservation, drinking water abstraction, bathing, fisheries and shellfish production (**Appendix 1**). The protective legal framework for freshwaters, transitional waters (estuaries) and inshore coastal waters (up to 1 nautical mile offshore) is defined by the Water Framework Directive (WFD - 2000/60/EC), enacted in England and Wales by Environment (Water Framework Directive) (England and Wales) Regulations 2017 (Section 1.2.1). Protection of marine waters is afforded by the Marine Strategy Framework Directive (MSFD - 2008/56/EC) enacted in the UK by the Marine and Coastal Access Act (2009). These legal instruments are key components of the UK Environment Act (2021).

3 Overview of the Exe Estuary catchment draining into the Exe Estuary and Lyme Bay

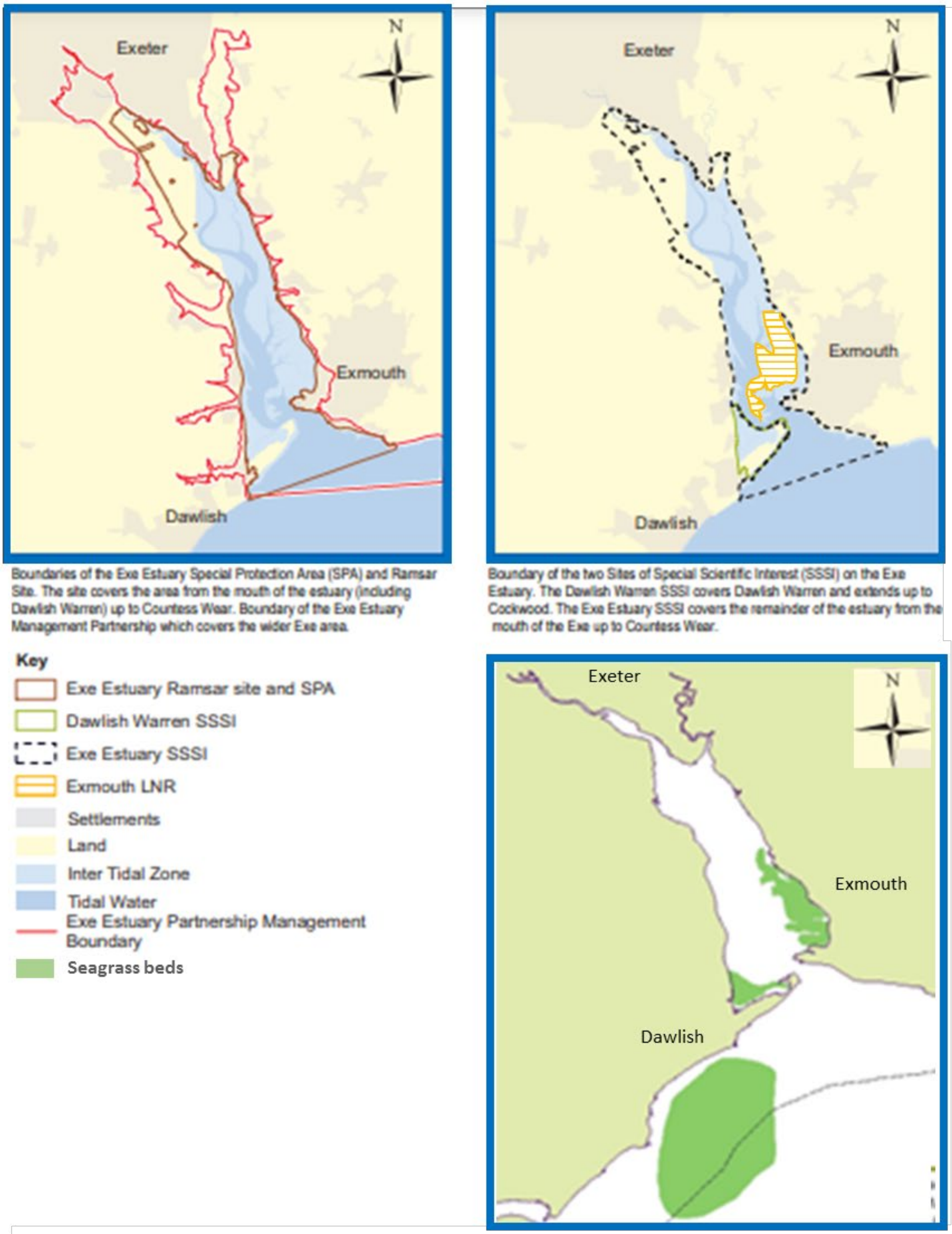
The following section of the report presents an overview of the location and character of protected shellfish waters in Lyme Bay and the Exe Estuary, briefly describes other protected areas (requiring water quality regulation), and looks back upstream to identify the various riverine inputs and anthropogenic discharges that influence water quality within the Exe Estuary catchment.

3.1 Lyme Bay

Lyme Bay extends eastwards for 65 km (35 nautical miles) from Start Point Lighthouse in Devon to Portland Bill Lighthouse in Dorset. The Bay contains a number of internationally important Marine Protected Areas, including the Lyme Bay and Torbay Special Area of Conservation and the East of Start Point Marine Conservation Zone. The coastline from the mouth of the Exe Estuary to Beer represents the East Devon Heritage Coast and is part of the wider Dorset and East Devon World Heritage Site ('Jurassic Coast'). Two WFD coastal waterbodies extend 1 nautical mile out to sea https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3086 from the mean high spring tide water mark: Lyme Bay West (Dartmouth to Beer) and Lyme Bay East (Beer to Portland Bill). Broader coastal areas i.e. Marine Character Areas MCA 1 - Lyme Bay West and MCA 2 - Lyme Bay East extend from mean high water to 12 nautical miles offshore, to a water depth of 60 m (Marine Management Organisation, 2013). The Environmental Status of these marine areas is assessed and managed under the Marine Strategy Framework Directive – MSFD (2008/56/EC) and has attained 'Good' status (**Section 4.2**).

Lyme Bay West is typically less ecologically diverse compared to Lyme Bay East. Nevertheless, possibly the largest single seagrass site in England (~1,000 ha) is located here, comprising of a subtidal seagrass (*Zostera marina/angustifolia*) bed to the south of the Exe estuary (Devon Biodiversity Records Centre, 2005; Marine Management Organisation, 2016) (**Figure 2**). During the scoping of the Marine Management Organisation's South Marine Plan, covering Folkestone to the river Dart (HM Government, 2018a), sea grass (*Zostera spp.*) was found to occupy an area of 1,657 ha, i.e. 34% of the total UK seagrass coverage (4,887 ha; Luisetti et al., 2013). Using the same baseline calculation, the seagrass site in Lyme Bay may have historically (in 2005) supported ~20% of the total UK seagrass coverage, however more data are needed to corroborate this. Elsewhere in Lyme Bay West the seabed typically consists of fine sand and mud sediments, derived principally from rapidly eroding sandstone formations and from the rivers Teign and Exe (Munro, 2012). There are several nearshore and offshore sand banks, which are part of a dynamic, wave driven (predominantly east to west) long-shore sediment transport system (SCOPAC, 2013).

Figure 2. Marine Protected Areas and key habitat features in the Exe Estuary and Lyme Bay West



Boundaries of the Exe Estuary Special Protection Area (SPA) and Ramsar Site. The site covers the area from the mouth of the estuary (including Dawlish Warren) up to Countess Wear. Boundary of the Exe Estuary Management Partnership which covers the wider Exe area.

Boundary of the two Sites of Special Scientific Interest (SSSI) on the Exe Estuary. The Dawlish Warren SSSI covers Dawlish Warren and extends up to Cockwood. The Exe Estuary SSSI covers the remainder of the estuary from the mouth of the Exe up to Countess Wear.

In Lyme Bay East river discharges are much smaller and tidal streams are markedly stronger. Consequently, the seabed is much rockier and sediments much coarser, which results in richer assemblages of filter feeding animals such as larger erect sponges, gorgonians, soft corals (Munro, 2012). Lyme Bay East MCA contains high-biodiversity reefs formed of mudstone, limestone, chalk and granite outcrops, pebbles, cobbles and boulders, listed under Annex I of the Habitats Directive (92/43/EEC). These reefs are home to protected species, including cold water corals such as the pink sea fan (*Eunicella verrucosa*) (listed under Schedule 5 of the UK Wildlife and Countryside Act 1981) and Ross coral (*Pentapora fascialis*). The exclusion of scallop (*Pecten maximus*) dredging and bottom trawling from the Lyme Bay Marine Protected Area (part of the Lyme Bay and Torbay SAC designated in 2008) has resulted in substantial recovery of listed species and broader benthic communities, which reached a peak from 2011-13 (Sheehan et al., 2013; 2021). The recovery was reversed temporarily by storms in the North Atlantic, which hit the southwest of the UK during the winter of 2013–2014 (Kendon, 2015) and some key commercial species (including *P. maximus*) remain in low abundance within the SAC and surrounding areas (Sheehan et al., 2021). Lyme Bay nevertheless supports a range of sediment and reef dwelling invertebrates including bristle worms, razor clams and mussels and provides important spawning/nursery grounds for number of fish species such as lemon sole (*Microstomus kitt*), sand eels (*Ammodytes tobianus*), mackerel (*Scombre scombrus*), thornback ray (*Raja clavata*) and spotted ray (*Raja montagui*) (Marine Management Organisation, 2020; Natural England, 2020a).

3.2 Exe Estuary

The Exe estuary is a bar-built ria estuary (flooded river valley), covering an area of 18 km^2 between its upper and lower tidal limits at Countess Wear and Exmouth, respectively. The estuary is surrounded by an additional area of 5.45 km^2 of wetlands (**Figure 2; Appendix 2**) giving a total area of 23.45 km^2 internationally protected wetlands under the Ramsar Convention (JNCC, 2008). The seaward end of the estuary is bounded by Dawlish Warren, a large, south-west to north-east orientated sand spit, 2.5 km long, 500 m wide and 1.4 to 6.0 m above Ordnance Datum (SCOPAC, 2013). Dawlish Warren has been protected by various sea defences incorporating sand, rock armour and groynes. The estuary is dredged regularly to maintain a navigable channel for private and commercial vessels and estuary margins include reclaimed land and additional tidal defences, as well as transport, commercial and recreational infrastructure. The estuary system is classified under the WFD as 'highly modified', (Environment Agency, 2013). Given the international conservation importance of the estuary, the WFD target is for the estuary to achieve 'Maximum Ecological Potential', taking into account its heavily modified status (2000/60/EC). The Estuary is currently classified as achieving Moderate Ecological Potential **(Section 4.1**).

Tidal currents funnel in and out of the narrow inlet between the end of Dawlish Warren spit and Exmouth. The estimated flushing time for the estuary is 6 days (Uncles, 2002). Ebb tides are considerably faster than corresponding, longer duration flood tides, with flows reaching 3 ms^{-1} during spring tides and 1 ms^{-1} during neap cycles (SCOPAC, 2013). These high velocities are capable of moving large quantities of sediment, up to medium sized sand. Sediments drifting into the inlet are flushed several kilometres seaward and wave action drives material back landward (Posford Duvivier, 1998a).

Sediment inputs to the estuary are dominated by marine sources, with both tidal currents and waves moving ~18,000 m^3 yr^{-1} of fine sand (in suspension) and coarse sand and gravel (as bedload) towards the estuary entrance (Posford Duvivier, 1998a and b). Fluvially derived sediment input is relatively low, with the main supply of river sediment (1900 m^3 yr^{-1}) coming from the River Exe (Posford Duvivier, 1999). The estuary is consequently highly turbid (with up to 25 g L-1 suspended solids in the upper estuary around Turf locks), leading to low levels of light penetration in the water column (Langstone, et al., 2003). Despite this primary production is exceptionally high, with chlorophyll concentrations generally exceeding 10 μg L^{-1}, and therefore indicating eutrophic conditions, which are symptomatic of excess nutrient inputs (**Section 7.1**). Nevertheless, dissolved oxygen levels often exceed 100% and the estuary contains diverse habitats for fauna and flora, including shallow intertidal flats, saltmarsh, seagrass and shellfish beds Langstone et al., 2003).

The estuary is an internationally important nature conservation area with multiple designations (**Figure 2**). The entire estuary and bordering marsh land (including Exminster and Bowling Green marshes) is a Ramsar protected wetland area and a European Marine Site/ Natura 2000 Site - Special Protection Area (SPA), owing to the presence of internationally important resident protected bird species and >20,000 migratory (over-wintering) wildfowl and waders (WeBS, 2017; Natural England, 2020b). The estuary is also a Site of Special Scientific Interest by virtue of its bird populations and rare plant species (mostly on Exminster Marshes), as well as nationally significant populations of invertebrates inhabiting the intertidal flats. The mudflats between Lympstone and Bull Hill bank, which support eel grass beds and invertebrates, including mussels and cockle beds are also designated as a Local Nature Reserve (EEMP, 2021).

3.3 The Exe Estuary catchment (non-tidal, freshwater)

The Exe Estuary catchment (1520 km^2) includes three operational catchments: the Exe main (655 km^2), the Clyst & Culm (460 km^2) to the east and the Creedy & West Exe (405 km^2) to the west. (Environment Agency, 2021b). **Appendix 3** contains a full list of water bodies in each of the three operational catchments. The River Exe rises on Exmoor at 450m above sea level and descends 82.7 km to Exmouth (JNCC, 2008). The River Creedy and River Culm drain into the River Exe, which subsequently drains into the Exe estuary at Countess Wear, while the River Clyst joins the estuary at Topsham and two other significant tributaries, the River Kenn and Polly Brook enter at Starcross and Exton, respectively. Mean river flow rates entering the Exe Estuary are substantially higher for the River Exe at Trews Weir (25 m^3/s) compared to the River Clyst (1.4 m^3/s), River Kenn (0.5 m^3/s) and Polly Brook (0.4 m^3/s) (Langstone et al., 2003; UK Centre for Ecology and Hydrology, 2021). All water courses draining into the Exe Estuary and into Lyme Bay West, with the potential to impact on the quality of shellfish (and bathing) waters therein, are listed in **Appendix 4**.

The Exe Estuary catchment falls within the Environment Agency's South West River Basin District and more specifically the East Devon Management Catchment. The East Devon management catchment (also including the Sid & Otter and Axe & Lim – which discharge directly to Lyme Bay) is primarily located in the county of Devon, although small areas in the North and East of the catchment are located in Somerset and Dorset respectively. The Exe catchment stretches from Exmoor and the Brendon Hills, to Exmouth in the south. The Blackdown Hills form the eastern boundary with the Haldon Ridge to the west.

The Exe Main catchment is largely rural and agricultural (**Table 1; Figure 3**) with significant population centres in Exeter and Tiverton. The main river system within the catchment is the River Exe (Source to River Creedy) and its tributaries the Rivers Barle, Quarme, Haddeo, Batherm and Lowman. The Exe, Barle and Quarme rise on Exmoor, within the Exmoor National Park, an area of moorland and wooded valleys before flowing in roughly a southerly direction before being joined by the Haddeo, Batherm and Lowman. In the upper catchment of the Exe the geology is predominantly Devonian siltstones and sandstones, with soils characterised by low permeability peaty soils. The more central areas of the catchment are dominated by improved grassland pasture for dairy and beef cows and sheep with some pigs and poultry and also arable land (cereals) in more fertile lowland areas. The soils consist of loamy subsoils over clay subsoils, which are generally slowly permeable (Westcountry Rivers Trust, 2014; East Devon Catchment Partnership, 2016).

The Creedy and West Exe catchment lies to the west of the Exe Main and is predominantly improved grassland pasture, with arable land (cereals) mainly in the lower catchment. Soils are relatively freely draining acid loamy soils over Permian mudstone siltstone or sandstone (Westcountry Rivers Trust, 2014). The main tributaries are the River Yeo which merges with the River Creedy near Crediton and meets the River Exe at Cowley Bridge near Exeter. The southern part of the catchment is coastal with a number of tidally influenced streams flowing into the Exe Estuary (East Devon Catchment Partnership, 2016). The most significant of these streams is the River Kenn, which rises in the Haldon Hills and flows for 14.2 km through Haldon Forest and agricultural land and receiving treated effluent from Kenton and Starcross sewage treatment works (STW), before entering the estuary between Starcross and Powderham.

The Clyst and Culm catchment lies to the east of the Exe Main catchment and is also mostly agricultural, but with a higher proportion of pigs and poultry and some light industry (building, energy generation, computer software and hardware) around Cullompton. The soils are slightly acid loam interspersed with poorly draining clay soils over Gault mudstone, sandstone and limestone (Westcountry Rivers Trust, 2014). The eastern part of this catchment falls within the Blackdown Hills area of outstanding natural beauty (AONB). The River Culm joins the main River Exe just north of Exeter, whilst the River Clyst rises near the village of Clyst William, near Cullompton and enters the Exe Estuary south of Topsham. Polly Brook is a smaller, but nevertheless significant tributary, rising east of Woodbury, then receiving treated sewage from Woodbury STW before flowing into the Exe Estuary at Exton.

Table 1: Agricultural land use classification in the Exe Estuary catchment based on UK CEH Land cover plus (incl. crops) – based on satellite imagery

Crop	Land area (km^2)
Grass	650.48
Winter wheat	52.02
Maize	46.95
Winter barley	27.30
Spring barley	14.27
Oilseed rape	10.24
Winter oats	7.74
Field beans	2.82
Spring wheat	2.49
Potatoes	1.53
Peas	0.39
Other crops	14.55

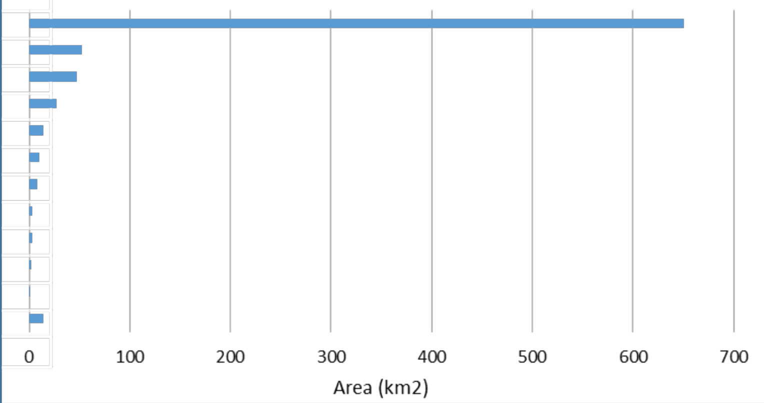
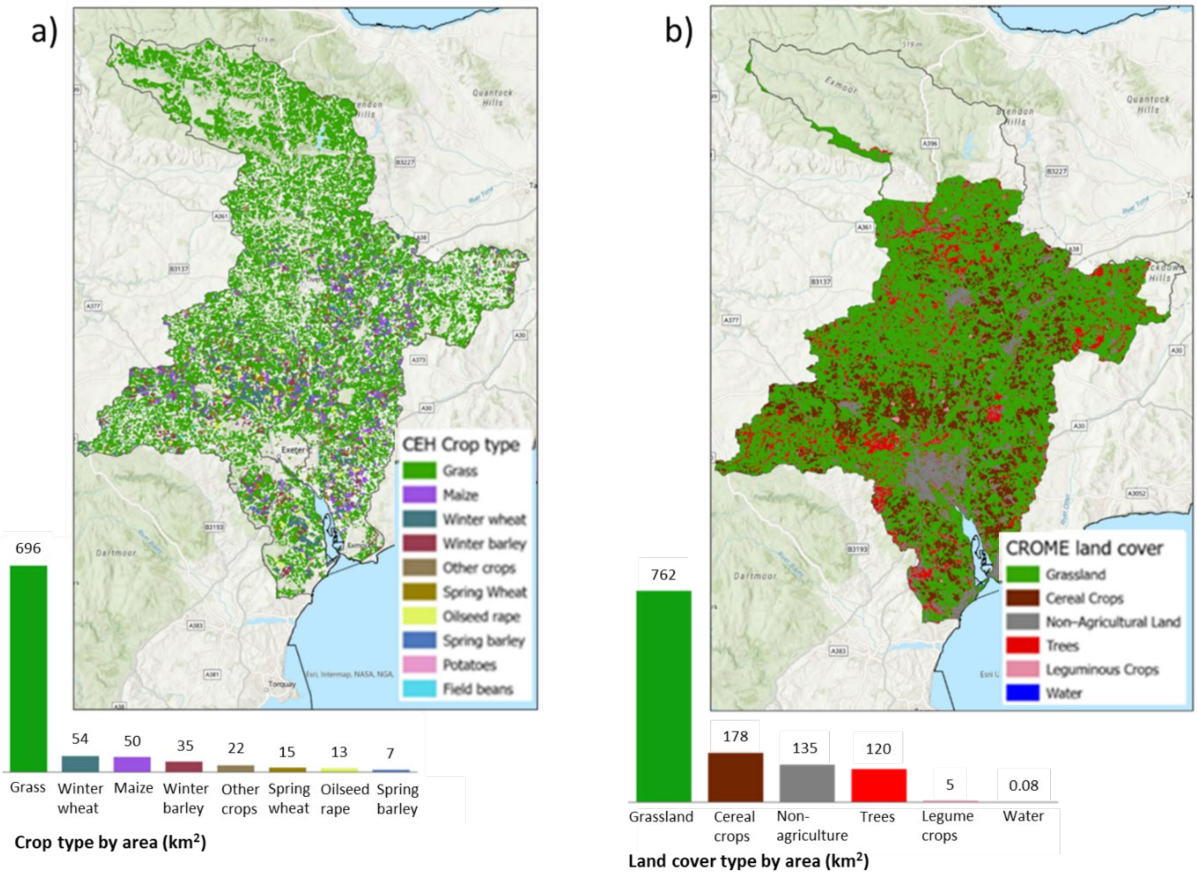


Figure 3: a) UK CEH Land Cover Plus and b) Crop Map of England (CROME) 2019 showing land use classification by crop type for the Exe Estuary catchment
https://www.ceh.ac.uk/services/ceh-land-cover-plus-crops-2015 https://data.gov.uk/dataset/8c5b635f-9b23-4f32-b12a-c080e3f455d0/crop-map-of-england-crome-2019



There are a number of sensitive ecological receptors in the Exe Estuary catchment, which are potentially susceptible to impaired water quality. These include the Exmoor Heaths Special Area of Conservation (SAC) and Exmoor and Quantock Oaks SAC, both located towards the north of the management catchment along with the Exmoor National Park. The East Devon and Blackdown Hills Areas of Outstanding Natural Beauty (AONB) are located in the South and East of the catchment. A number of SSSI designations are also distributed across the catchment. For example the South Exmoor SSSI containing the River Barle and its tributaries with submerged plants such as alternate watermilfoil (*Myriophyllum alterniflorum*). The North Exmoor SSSI is nationally important for its south-western lowland heath communities and for transitions from ancient semi-natural woodland through upland heath to blanket mire, which regulates water entering the upper catchment. The upper Exe also supports salmon and fishing is permitted in the Exe and the Barle.

4 Classification of water quality and shellfish quality

4.1 Water Framework Directive classifications

Water quality classification under the WFD is based on ecological status, chemical status and hydro-morphological status. Overall water quality classification follows a 'one out, all out' approach in which the lowest scoring biological and/or chemical element determines whether a water body passes or fails to achieve its desired water quality objective. In general the objective is to achieve 'Good' status or potential overall, while water bodies containing conservation features of international importance (Natura 2000 sites) are required to achieve 'High' ecological status, or in the case of the heavily hydro-morphologically modified Exe Estuary, they must achieve 'Maximum ecological potential'. To have an overall high status (or reference condition), a water body needs to comply with all the criteria monitored: biological, physical and chemical.

According to the most recent data for the South West River Basin District (latest data to 14 September 2021) - 206 out 697 (29.5%) of water bodies in the District have achieved 'Good' ecological status or higher to date (tranches 1 and 2 combined) (**Appendix 5.1**). This compares with 14% of all water bodies across England achieving the same objective (Environment Agency, 2021b) (**Figure 4**).

WFD assessment data specifically for the Exe Estuary catchment, including each of the operational catchments within it (Clyst & Culm; Creedy & West Exe; Exe main; Exe Estuary; Lyme Bay (West) show that only 12 out of 64 (18.75%) of water bodies (from the Creedy and West Exe and Exe main catchments) currently achieve 'Good' ecological status or higher (**Appendix 5.2; Figure 5**). Predominant reasons for not achieving good (RNAG) ecological status/potential include agriculture and rural land management - pollution; urban and transport - pollution; water industry – pollution from waste water.
https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3033/rnags

Figure 4: Proportion of water bodies with Good ecological status or higher in England, SW England and the Exe Estuary catchment (2019)

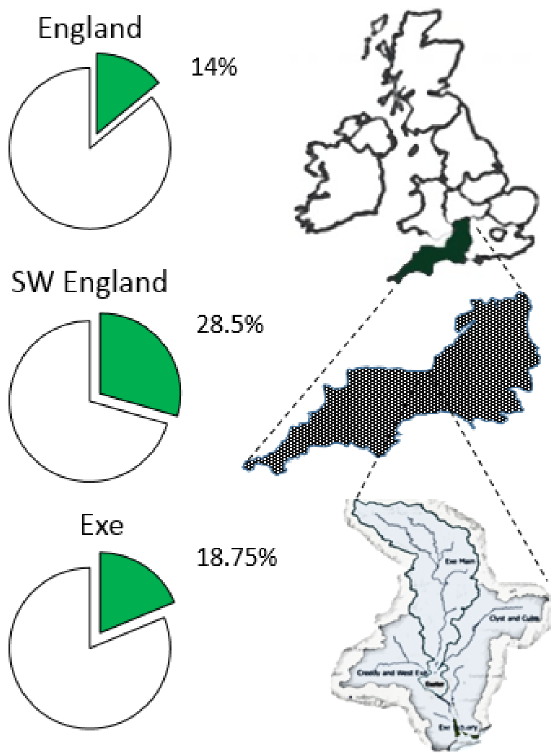
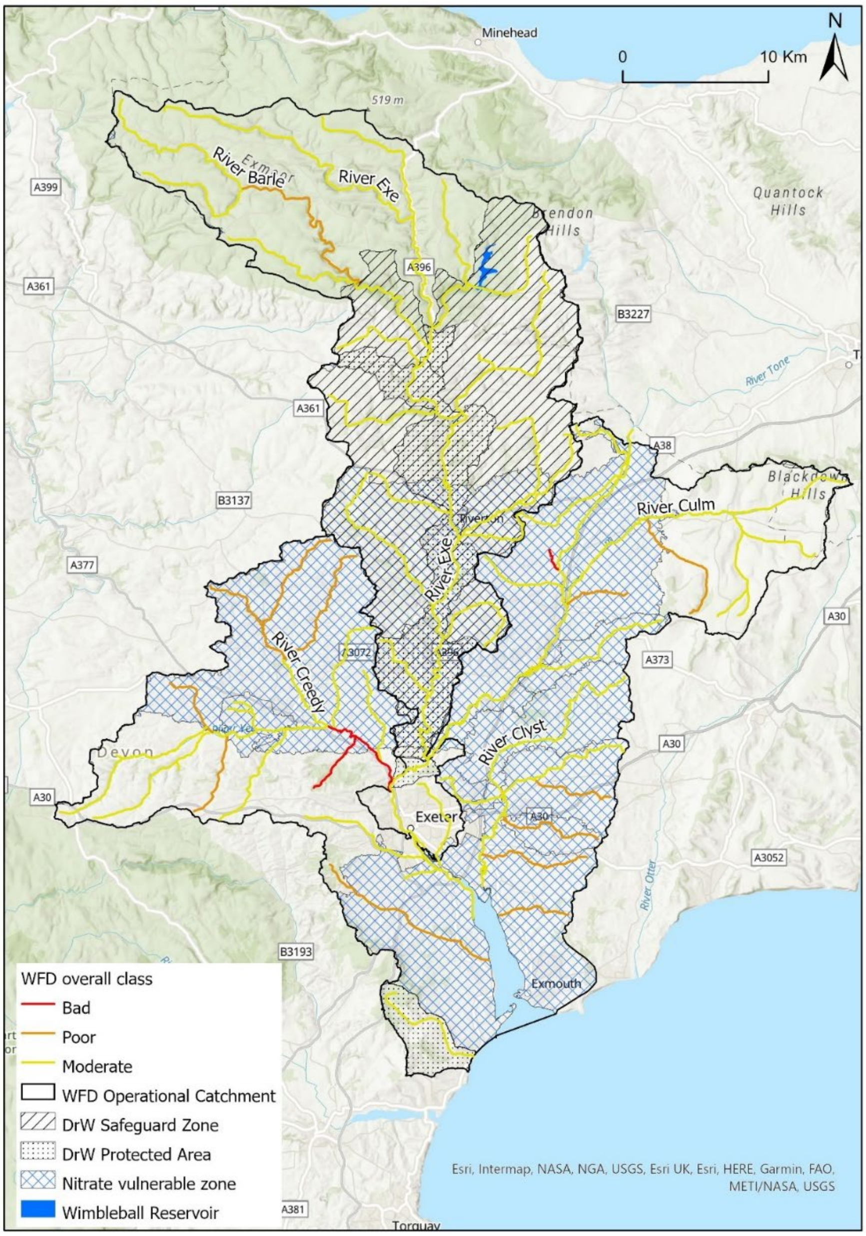


Figure 5: Water Framework Directive (WFD) classification of Ecological Status of rivers in the Exe Estuary catchment in 2019



All water bodies in the Exe Estuary catchment (and all others in the UK) currently fail to meet 'Good' chemical status (**Appendix 5.3**). Reasons for not achieving good (RNAG) chemical status include: exceedance of Environmental Quality Standards (EQS_{biota}) for: a) poly-brominated diphenyl ethers (PBDEs) EQS_{biota} = 0.0085 μg/kg; b) mercury and its compounds EQS_{biota} = 20 μg/kg. Chemicals a) and b) have recently been detected up to 2500× the EQS_{biota} for PBDEs and up to 10× the EQS_{biota} for mercury in signal crayfish (*Pacifastacus leniusculus*) in freshwaters and/or blue mussels (*Mytilus edulis*) in transitional and coastal waters in the UK (Environment Agency, 2019a; 2019b; 2021a). Sources of these chemicals are largely atmospheric pollution. Additional reasons for not achieving good (RNAG) chemical status, for named water bodies in the Exe Estuary catchment include: c) benzo[ghi]perylene (in Lower Batherm in Exe Main catchment and Exe Estuary). These chemicals a, b and c are priority hazardous substances listed under the WFD (Environment Agency, 2021b).

4.2 Marine Strategy Framework Directive classifications (relating to nutrient and chemical pollution)

The South Marine Plan states that "Much of the economic and cultural prosperity of the South Marine Plan areas is reliant on water quality". Marine Plan Policies S-WQ-1 and S-WQ-2 seek to manage impacts on water quality, and the habitats and species which benefit water quality through the ecosystem services they provide (**Section 5.1**).

According to the UK updated assessment and Good Environmental Status under the Marine Strategy water quality-related GES descriptors (**Appendix 6**) indicate that Good status has been achieved in the majority of areas (DEFRA, 2019). Some estuarine and coastal waters continue to exhibit eutrophication problems (21 problem areas, and 11 potential problem areas, rewspectively). These areas represent a small proportion of the total area of UK waters (0.03%) and of 0.41% of estuarine and coastal waters. Concentrations of hazardous substances and their biological effects in the Celtic Regional Sea Area (including Lyme Bay) are generally lower than thresholds that cause harm to sea life, and are not increasing (89% compliance for contaminant concentrations and 96% compliance for biological effects). The few failures are caused by highly persistent legacy chemicals such as PCBs in biota and marine sediments mainly in coastal waters and often close to polluted sources.

Oslo Paris Commission (OSPAR) criteria for contaminants in biota, including mussels (**Appendix 7**) are used to assess progress against the targets for Good Environmental Status (GES) set out in the UK's Marine Strategy (DEFRA, 2019), which requires that concentrations of substances identified within relevant legislation and international obligations are below levels at which adverse effects are likely to occur to sea life. OSPAR Environmental Assessment Criteria (EACs) represent contaminant concentrations in bivalve shellfish below which adverse environmental effects are avoided, including secondary poisoning in organisms that consume bivalve shellfish i.e. fish, birds and marine mammals (OSPAR, 2021).

Shellfish monitoring results for blue mussels at Exmouth (Beacon Point) in 2016 showed mercury concentrations (27 μg/L) to be marginally above the EAC (22 μg/L). More recent shellfish monitoring results gathered by the Environment Agency for blue mussels from Exmouth (Cockwood Harbour) in 2019 showed that mercury (26 μg/L) was again marginally above the EAC and may therefore present an environmental risk. From the 2019 data it is not clear whether Tri-butyl tin may also pose an environmental risk, since the detection limit (<20 μg/L) was above the EAC (15.2 μg/L) (**Table 2**). All other measured contaminants were below EAC values (OSPAR, 2021).

4.3 EU Food hygiene regulations relating to chemical contaminants

EU hygiene Regulation (EC) No 1881/2006) administered by the Food Standards Agency also sets maximum permitted levels of contaminants in bivalve shellfish to safeguard human consumers. Concentrations of specified contaminants in fish and other seafood caught or harvested for human consumption in UK seas generally do not exceed agreed safety levels. The most recent shellfish monitoring results gathered by the Food Standards Agency for blue mussels from Exmouth (Beacon Point) in 2015 indicate that heavy metals (including mercury) and PAHs are below maximum permitted levels (MPLs). Total concentrations of poly brominated diphenyl ethers (SBDE6 = 0.203 μg/L) exceeded the human health EAC (0.0085 μg/L) set by OSPAR by a factor of more than 20 (**Table 2**).

Table 2: Chemical contaminants in mussels sampled from Exmouth in 2015 and 2019

***Site S1**: Exe Approaches - Beacon Point, NGR: SX99698050, Date: 12/01/2015; Source: FSA, 2015*
***Site S2**: Exe West - Sandy Bay, NGR: SY02247907, Date: 18/02/2019; Source: EA, 2019*
***Site S3**: Starcross - Cockwood Harbour, NGR SX99698050, Date: 21/02/2019, Source: EA, 2019*
Standards:

- *Maximum permitted levels (MPLs) in bivalve shellfish according to Contaminants in foodstuffs Regulation (EC) 1881/2006. PBDE human health standard [d] corresponds to the EQS (2013/39/EU)*
- *Environmental Assessment Criteria (EACs) according to OSPAR (2021).*

EACs correspond with the following standards (depending on the chemical):
[a] EQS_{biota} (bivalve shellfish) (2008/105/EC), [b] OSPAR Quality Standard based on secondary poisoning;
[c] OSPAR Quality Standard for fish muscle; Measured values above EACs highlighted in RED.

Chemical group	**Chemical**	**Concentration in mussels (µg/kg wet weight)**				
		Measured S1 - 2015	**Measured S2 - 2019**	**Measured S3 - 2019**	**MPL**	**EAC**
Poly aromatic hydrocarbons	Benzo[a]pyrene	1.42	3.50	1.02	10	5[a]
	Benzo[a]anthracene	2.51	1.41	1.04	10	-
	Chrysene	2.4	1.80	1.36	10	-
	Benzo[b]fluoranthene	4.65	3.37	3.41	10	-
	Benzo(g,h,i)perylene	-	26.7	0.635	-	-
	Benzo(k)fluoranthene	-	1.42	1.35	-	
	Fluoranthene	-	3.54	4.23	-	-
	Phenanthrene	-	1.30	4.64	-	-
	Naphthalene	-	<1	<1	-	-
	Anthracene	-	<0.5	<0.5	-	-
	Pyrene	-	4.18	<0.5	-	-
	Indeno(1,2,3-cd)pyrene	-	2.90	4.33	-	-
Metals	Cadmium (Cd)	137	90	179	1000	160[b]
	Mercury (Hg)	**27**	**26**	**31.1**	500	**22[b]**
	Lead (Pb)	499	314	391	1500	1000[b]
Dioxins	Sum of dioxins	-	-	-	4	0.0012[b]
	Sum of dioxins & PCBs	-	-	-	8	0.0012[b]
	Sum of ICES 7 PCBs	-	-	-	-	0.075[c]
Poly chlorinated biphenyls	PCB - 028	-	<0.5	<0.1	-	67
	PCB - 052	-	0.117	<0.1	-	108
	PCB - 101	-	0.234	<0.1	-	121
	PCB - 118	-	0.299	0.119	-	25
	PCB - 138	-	0.459	0.205	-	317
	PCB - 153	-	0.651	0.282	-	1585
	PCB - 180	-	<0.1	<0.1	-	469
Organo chlorines	DDT -pp	-	0.103	<0.1	-	-
	DDE -pp	-	0.515	0.243	-	-
	TDE -pp	-	0.103	<0.1	-	-
	Hexachlorobenzene	-	0.133	<0.1	-	10
Poly brominated diphenyl ethers	BDE28	-	<0.006	0.007	-	120
	BDE47	-	0.093	0.041	-	44
	BDE99	-	0.060	0.029	-	1
	BDE100	-	0.031	0.015	-	1
	BDE153	-	<0.02	<0.02	-	4
	BDE154	-	0.019	<0.01	-	4
	SBDE6 (sum of 6 BDEs)	-	**0.203**	**0.85**	**0.0085[d]**	44
Tri butyl tin	TBT	-	**<20**	**<20**	-	**15.2[b]**

4.4 Classification of shellfish waters (relating to faecal pollution)

The shellfish waters of the Exe Estuary (and the majority i.e. ~90% of shellfish waters in England and Wales) are classified under the EU Hygiene Regulations (EC) No. 854/2004 as being Class B (≤ 4600 *E. coli* / 100 g of shellfish flesh and intravalvular fluid), requiring shellfish depuration. This classification and the lack of purification facilities currently prevents the export of shellfish to EU countries, which is the largest single market for these food products produced in the UK (Food Standards Agency, 2021). Designated shellfish waters located 3-10 km offshore in Lyme Bay have also been reported to be impacted occasionally by elevated *E. coli* concentrations in shellfish, leading to seasonal downgrading from Class A to Class B (**Table 3**). The sources of this faecal contamination remain unknown (Land et al., 2022).

Table 3: Classification of shellfish waters based on faecal indicator organism (FIO) counts in bivalve shellfish (minimum of 10 samples required per year for Class A; 8 samples for Class B & C)

Class	*E. coli* mean probable number /100g shellfish flesh	Treatment required
A	≤ 230 (80% of sample results) < 700 (100% of sample results)	May go direct for human consumption
B	≤ 4600 (90% of sample results) < 46000 (100% of sample results)	Must be depurated, heat treated or relaid to meet Class A
C	≤ 46000 (100% of sample results)	Must be laid for at least 2 months, followed where necessary by treatment in a Purification Centre to meet Class A requirements
P	> 46000	Prohibited from production or collection

Under the EU Hygiene Regulations (EC) No. 854/2004, Official Control Measures require that all shellfish harvesting areas undergo sanitary surveys to provide the best available information and evidence for hygiene classification zoning and monitoring (based on *E. coli* counts in shellfish) to ensure public health protection (CEFAS, 2013; FSA, 2021). The findings of recent sanitary surveys for shellfish waters in Lyme Bay (West) and the Exe Estuary are summarised below.

4.4.1 Lyme Bay (West)

There are four coastal shellfish production sites located in Lyme Bay (West) (**Figure 2**), each employing long lines for farming blue mussels (*Mytilus edulis*). Two sites lie inshore, one in Tor Bay and one in Labrador Bay, and both hold long-term B classifications based on *E. coli* counts in the shellfish flesh (**Table 4**). The remaining two sites are Lyme Bay Site 1 (10 km offshore) and Lyme Bay Site 2 (3 km offshore), which hold seasonal A/B and long-term A classifications, respectively. Seasonal downgrading of Site 1 (during the winter) is due to occasional elevated FIO counts (>230 *E. coli*/100 g of shellfish flesh). This has prevented the export of mussels from this site during the winter to the farm's principal market in the European Union (EU). The offshore sites are only partially developed. According to the Marine Management Organisation planning consent, the offshore sites will merge, extending over 15 km^2 and production is expected to increase from 3,000 up to 10,000 tonnes of mussels each year, making it the highest production shellfish site in the UK.

The existing offshore mussel farms in Lyme Bay (Sites 1 and 2) been shown to attract a high diversity of other flora and fauna. In particular these include large shoals of Atlantic horse mackerel (*Trachurus trachurus*), European bass (*Dicentrarchus labrax*) and grey mullet (*Chelon labrosus*). Commercially important brown crab (*Cancer pagurus*) and lobster (*Homarus gammarus*) are also present in high abundance and feed on the mussels, which fall to the sea bed below the suspended mussel farm (Sheehan et al., 2019). The offshore mussel farms regularly attracts numerous fishing boats that deploy static and towed fishing gear around its perimeter. The development of the farm has also been anecdotally reported to coincide with increased spat settlement and juvenile mussel recruitment in Lyme Bay (Holmyard pers. comm.).

Table 4: Location and classification status of shellfish production sites in Lyme Bay West (W) and the Exe estuary (FSA, 2021; Carcinus, 2021)
E. coli counts are per 100 g of shellfish flesh and intervalvular fluid.

Classification follows EU Hygiene Regulations (EC) No. 854/2004 (see ***Table 3****)*

Location	Representative Monitoring Point	FSA Ref	National Grid Reference	Distance offshore (km)	*E. coli* count (min-max)	*E. coli* count (mean)	Class
Lyme Bay W	Site 1	B090M	SY13687543	9	18-35000	54	A/B
Lyme Bay W	Site 2	B090P		3	18-3300	42	A
Lyme Bay W	Labrador Bay	B27AI	SX94087054	0.5	18-24000	125	B
Tor Bay	Fishcombe	B082B	SX90965741	0.2	18-35000	129	B
Exe Estuary – Exe Approaches	Beacon Point	B26AT	SX99698050	-	18-7900	218	B
Exe Estuary – Dawlish to Starcross	Cockwood Harbour	B26BH	SX97948072	-	18-24000	346	B
Exe Estuary – Sandy Bay	Sandy Bay	B26BJ	SY02247907	-	18-13000	836	B
Exe Estuary - Lympstone	Lympstone	J0591	SX98818314	-	N/A	N/A	B
Exe Estuary – Starcross to Powderham	River Kenn	B26BC	SX97638313	-	330-24000	1489	P
Exe Estuary – Public beds	N/A	N/A	N/A	-	N/A	N/A	P

4.4.2 Exe Estuary

The Exe estuary contains six shellfish areas (**Table 4**), including naturally occuring shellfish beds, relayed/bottom grown and trestle grown shellfish (Kershaw and Acornley, 2009; Carcinus, 2021; Food Standards Agency, 2022).

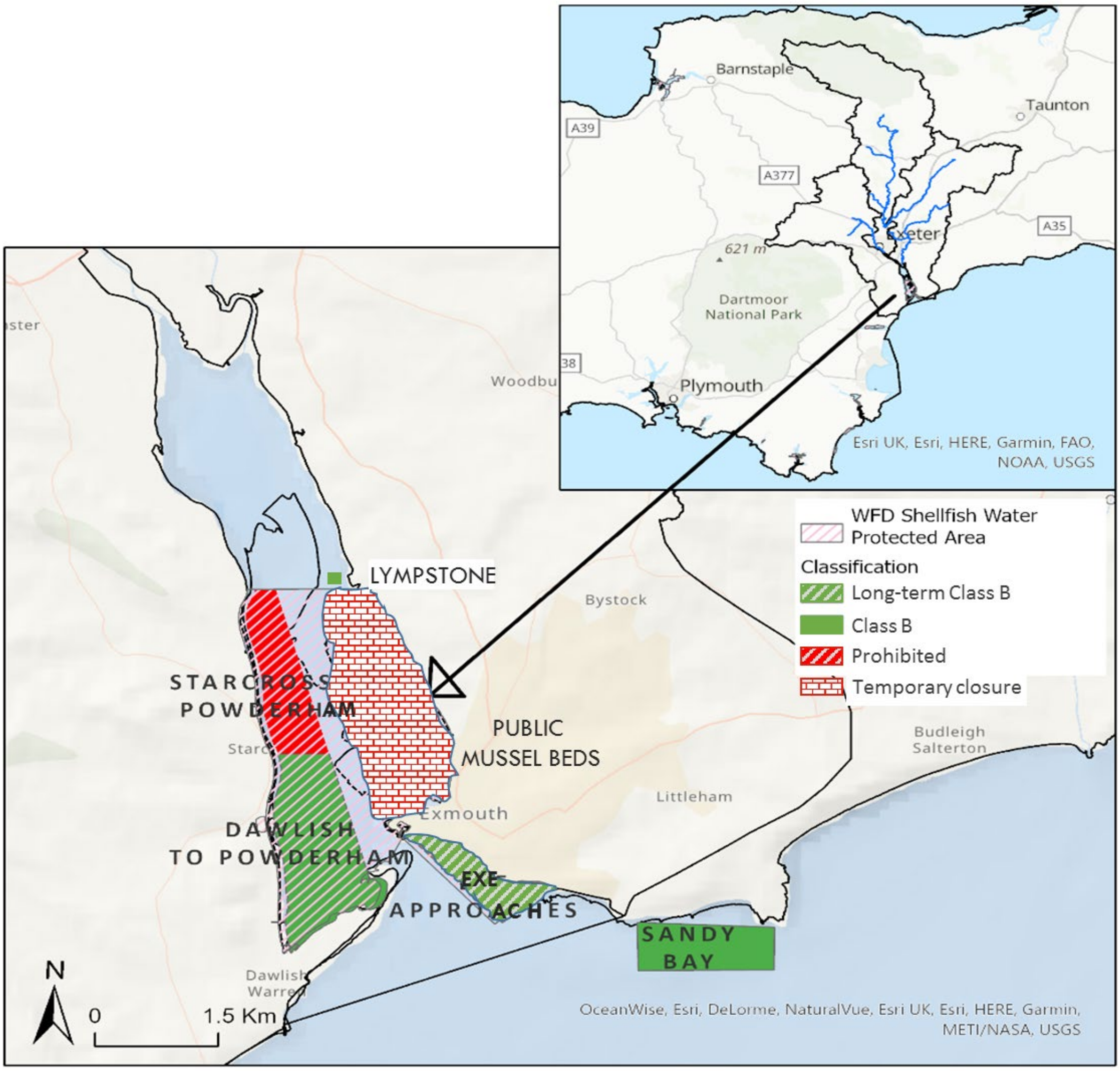
Three shellfish areas are currently closed for food production: i) Powderham to Starcross is prohibited following the recording of high *E. coli* levels in shellfish at the representative monitoring point (River Kenn - B36BC) in 2015, but is now being developed as a native oyster (*Ostrea edulis*) culture site (Aquafish Solutions, 2021); ii) Sandy Bay has recently been declassified (wild surf clams - *Spisula solida*); iii) Public mussel beds (*Mytilus edulis*) in the centre of the estuary remain closed following severe scouring of the beds by storms in the winter of 2013/2014 – reducing them from 20 ha equivalent to 2000 tonnes in 2013 to approximately 2.5 ha and <1 tonne in June 2019 - Devon & Severn IFCA, 2019)

Three shellfish areas are currently classified for food production: iv) Exe Approaches at the estuary mouth containing wild mussels - *Mytilus edulis*); v) Dawlish Warren to Starcross with relayed/ranched mussels and vi) Lympstone with farmed Pacific oyster (*Magallana gigas*) and Atlantic oyster (*Ostrea* *edulis*). These three areas are classified as Class B or long-term Class B (>5 years compliance), based on Official Control monitoring of FIO concentrations in shellfish samples (**Table 3**) obtained each month from representative monitoring points (RMPs) (**Table 4; Figure 3**).

Cockwood Harbour, located between Dawlish Warren and Starcross, is the main shellfish aquaculture area and has been classified since 2013 for relaying and growing 150-170 tonnes of mussels per year, with potential to increase this to 2,500 tonnes (CEFAS, 2013). Mussels are relaid and harvested on a two year rotation by Exmouth Mussels Ltd. using fluidised suction dredging. The area is also classified for growing and harvesting of Pacific oysters (Carcinus, 2021). Recent increases in sedimentation in this area has impacted on shellfish survival and growth, particularly affecting recently laid mussels and causing Exmouth Mussels Ltd. to reduce production substantially. Exmouth Mussels Ltd. have intimated this may have been due to the flood defence work at Dawlish Warren in 2016/17, which was followed by the errosion of Bull Hill sand bank. Annual mussel stock assessments are being conducted by Devon and Severn IFCA to see if the sedimentation and/or the reduction in relaying are impacting mussel populations and biodiversity in general throughout the estuary.

Stock assessments have demonstrated the ecological importance of bivalve shellfish in the Exe Estuary. The decline of natural and farmed mussel beds (following 2013/14 winter storms) appears to have led to increasing levels of suspended sediment and smothering of the bed of the estuary at Exmouth and Cockwood Harbour (Devon and Severn IFCA, 2021). In turn the loss of mussel reef habitat has impacted other invertebrates and reduced valuable food sources for fish and protected water birds (Devon and Severn IFCA, 2021). Exmouth Mussels Ltd. have previously relayed a proportion of their stock intertidally to increase food availability for the over-wintering bird species, for which the estuary is designated as a SPA. The ecological impacts of reduced relaying operations by Exmouth Mussels Ltd. around Cockwood Harbour (as a result of increased sedimentation) have not been assessed fully (Devon and Severn IFCA, 2021).

Figure 3. Shellfish protection zone and shellfish classification zones



4.5 Bathing water classification (relating to faecal pollution)

Bathing water protected areas are those in which a large number of people (100 or more people) are expected to bathe at any one time. There are 29 bathing water areas in Lyme Bay West (between Dartmouth and Beer); 18 are located between Hope's Nose (Torquay) and Beer and 2 of these are located at the mouth of the Exe Estuary. Under the UK Bathing Water Regulations 2013 (SI:1675, enacting the EU Bathing Water Directive 2006/7/EC), waters must be tested for faecal indicator organisms (FIOs – *E. coli* and/or intestinal enterococci) at weekly intervals between 1 May and 30 September, with a minimum of 20 samples tested annually. There are three measurement criteria for each FIO, including a minimum standard, which is sufficient for a bathing area to pass and standards of Good and Excellent water quality (**Table 5**).

The designated bathing waters at Exmouth and Dawlish Warren have historically (up to 2019) been awarded a Blue Flag for excellent bathing water quality. There was a pause in water quality sampling and classification in 2020 (due to the COVID pandemic). Sampling has subsequently resumed on a weekly basis during the bathing season (most recently between May 1st 2021 and Sep 30th 2021) and regularly achieve Excellent bathing water quality with respect to faecal indicator organisms (*E. coli* and intestinal enterococci) (**Table 5**). However, water quality testing has shown that the bathing waters occasionally experience short-term faecal pollution (HM Government, 2021a). The Environment Agency provides a daily pollution risk forecast for bathing waters based on the effects of rain and seasonality on bathing water quality. These factors affect the levels of bacteria that get washed into the sea from livestock, sewage overflows and urban drainage via rivers and streams. When these factors combine to make short term pollution likely, a pollution risk warning is issued via the following website (https://environment.data.gov.uk/bwq/profiles/help-understanding-data.html) and beach managers will display a sign advising against bathing. For beaches in Devon and Cornwall, pollution risk forecasts provided by the Environment Agency (and Surfers Against Sewage), come from South West Water, who also publicise the forecasts via BeachLive https://www.beachwise.org.uk/beachlive/. Given that more people are now swimming outside the normal bathing season, South West Water are considering year round alerts via BeachLive in the near future.

Table 5: Standards for coastal and transitional waters

(A)Based upon a 95-percentile evaluation; (B)Based upon a 90-percentile evaluation.

Faecal Indicator Organism	Classifications based on number of colony forming units per 100 mL of water		
	"Excellent"	"Good"	"Sufficient"
Intestinal enterococci	100(A)	200(A)	185(B)
Escherichia coli	250(A)	500(A)	500(B)

4.6 Drinking water classification (relating to chemical pollution)

1.6: Drinking water protected areas

Drinking Water Protected Areas (Surface Water) are areas in which raw water is abstracted for drinking water supplies from rivers and reservoirs. There are three Drinking Water Protected Areas (DrWPAs) in the Exe Estuary catchment, which cover a total area of 113.6 km^2 (17.3% of the Exe Estuary catchment – 655 km^2): Exe (Barle to Culm - GB108045015050) 103.2 km^2; Exe (Haddeo to Barle - GB108045015060) 3.7 km^2 ha; Exe (Culm to Creedy - GB108045009060) 6.9 km^2; plus Budleigh Brook, Dawlish Water, West Lyn River and the Bray. Drinking water from these areas is abstracted from the River Exe and treated at two water treatment works; Allers WTW located upstream of Tiverton and Pynes WTW located upstream of Exeter (SWW, 2019). Potential drinking water pollutants requiring monitoring, management/treatment are listed in **Appendix 1** and include a wide range of agents including faecal bacteria (*E. coli* and Enterococci), nitrate, heavy metals, pesticides and aromatic hydrocarbons.

According to recent Environment Agency monitoring data (Environment Agency, 2021b), Drinking Water Protected areas in the Exe (Barle to Culm - GB108045015050) and Creedy and West Exe (YEO

US Over Compton - GB108052015681) are at risk from a range of contaminants, which sometimes exceed the Drinking Water Directive standard of 0.1 µg/L (**Table 6**).

Table 6: Pesticides highlighted as presenting risk to drinking water protected areas in the Exe main catchment (Ian Townsend WRT, pers. comm.; Environment Agency, 2021b)

Chemical	Status	Action
Area - Exe (Barle to Culm)		
Atrazine	Banned in 2004	Not detected in Exe in 25+ yrs
Chlorotoluron	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Diazinon	Still approved for use as an acaricide in sheep dipping	Monitor concentrations
Dicamba	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Isoproturon	Banned, to be withdrawn from use	Monitor declining concentrations
MCPA	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Mecoprop-P	Active optical isomer of mecoprop is still registered for use.	Monitor concentrations
Area - YEO US Over Compton		
Atrazine	Banned in 2004	Not detected Exe catchment in 25+ yrs
Simazine	Banned in 2004	Not detected Exe catchment in 25+ yrs
MCPA	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Bentazone	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Chlortoluron	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Isoproturon	Banned, withdrawn from use	Not detected in Exe catchment since 2016
Diuron	Banned, withdrawn from use	Not detected in Exe catchment since 2013

An additional area of 402 km^2 (61.4%) of the Exe Estuary catchment constitutes a Surface Water Safeguard Zone (SWSGZ5012), which surrounds the above Drinking Water Protected areas, and is also highlighted to be at risk from pesticides (in particular: Chlorotoluron, MCPA, Mecoprop, Metaldehyde and Triclopyr) (Environment Agency, 2021c). The physical-chemical properties underlying the mobility (leachability) of these chemicals in soil are summarised in **Appendix 8**. Although the Granular Activated Carbon (GAC) treatment installed at Pynes Water Treatment Works and Allers Water Treatment Works in 2006 was initially extremely effective in removing pesticides from the raw water, after about 12 to 18 months South West Water began to find low levels of pesticides coming through into the treated water (**Appendix 9**). Pesticides, including metaldehyde, are confidently attributed to ongoing human activity (mainly agricultural use) in the catchment of the River Exe. The only pesticide to regularly appear in treated water from Allers/Pynes WTWs has been metaldehyde (generally <20ng/l). This pesticide is well known to not be efficiently removed by GAC (Townsend pers. comm.).

4.7 Classification of Nitrate Vulnerable Zones

There are four Nitrate Vulnerable Zones (NVZs) in the Exe main catchment, which are highlighted as being at risk from agricultural nitrate pollution:

S535	Aylesbeare Stream	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/9e38eec537ec47dcbc0875e7122d206b/data
S536	Clyst	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/a07bcb1ef5304e239c81bbb794ef09e3/data
S537	River Weaver	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/e51d26fec9384380a6f1d3926b5831fb/data
S538	Yeo (Creedy)	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/b2f0ce62c14646a7a4edf813035cce83/data

The 2019 WFD classification for the Exe Estuary based on dissolved inorganic nitrogen concentrations was 'Moderate' (Environment Agency, 2021b). Reasons for not achieving the WFD objective of 'Good' for this chemical quality element include nitrogen inputs from agricultural land, including arable land and grassland holding livestock, and also from municipal waste water discharges. The corresponding 2019 WFD classification for biological quality elements was 'Moderate', due to sea grass beds at the entrance to the Estuary (**Figure 2**) not being in favourable condition (which may be partly due to excess nitrogen and eutrophication). At the same time, phytoplankton and macroalgae (seaweeds) were classified at achieving 'Good' ecological status, which may be due to rapid flushing of nutrients out to sea and/or high levels of turbidity which reduce light availability for photosynthesis in the water column.

Additional Ground Water Safeguard Zones in the Exe catchment, which are at risk from nitrate fertilzers (and possibly pesticides) include the following:

GWSGZ 0063	Colaton Raleigh 2 & 4	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/ccb2ef54792f419690c5b84026965d9b/data
GWSGZ 0064	Dotton Boreholes 1-5,7	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/27f42f1c454740e4bae4586acd084d31/data
GWSGZ 0066	Starcross	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/83a4e5b53208425b9b6e19367a5154c5/data
GWSGZ 0069	Greatwell Borehole 1, 2 , 3, 4b, 6p	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/363ec486fe444376afc10b646dab970c/data
GWSGZ 0070	Harpford	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/cf22d6c611664f77812ed533257424bc/data
GWSGZ 0071	Otterton Bh4	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/c5ba3cc908674d41a691e7f047959484/data
GWSGZ 0072	Starcross	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/0ce89a7f5c4b4f80b46b42f483b8773b/data

5 Water quality pressures and solutions (remedial measures)

Principal sources of water pollution in the Exe Estuary catchment include agricultural discharges (largely diffuse agricultural runoff from farm land), point source municipal waste water discharges, and industrial discharges, which may be point source or diffuse, e.g. in the case of abandoned copper and silver mines on Exmoor. The scale and likely influence of each of these sources on water quality in the Exe Estuary catchment are investigated in detail below.

As an overview, Environment Agency investigations into reasons for not achieving 'Good' ecological status under the Water Framework Directive found that diffuse pollution from agricultural sources accounted for 54% of failures for water bodies in the East Devon catchment (including the Exe Estuary catchment). East Devon Catchment Partnership also report that water quality problems are more often related to manure and slurry runoff from farming compared to municipal sewage inputs and runoff from urban areas (East Devon Catchment Partnership, 2021).

The proportional contribution of different sources of pollution vary depending on location and the pollutant concerned. For this reason, the sources and solutions for different pollutant classes in the Exe Estuary catchment are investigated and discussed separately below.

Under flood conditions pollution sources can merge and therefore integrated solutions involving wider catchment planning e.g. combining land and sewer system management are often called for. These integrated pressures and solutions for managing water quality are discussed first.

5.1 Integrated pressures and solutions for managing water quality

The Government's 25 Year Environment Plan (25 YEP) identifies the need for a joined up approach, i.e. to integrate agricultural development, under the new UK Agriculture Bill, with the environmental management of land, air and water to enhance biodiversity and ecosystem functioning. Most importantly the 25 YEP aims to maximise the delivery of multiple ecosystem services from agricultural landscapes through implementation of holistic catchment-based approaches and natural capital-based Environmental Land Management Schemes (HM Government, 2018a; 2018b).

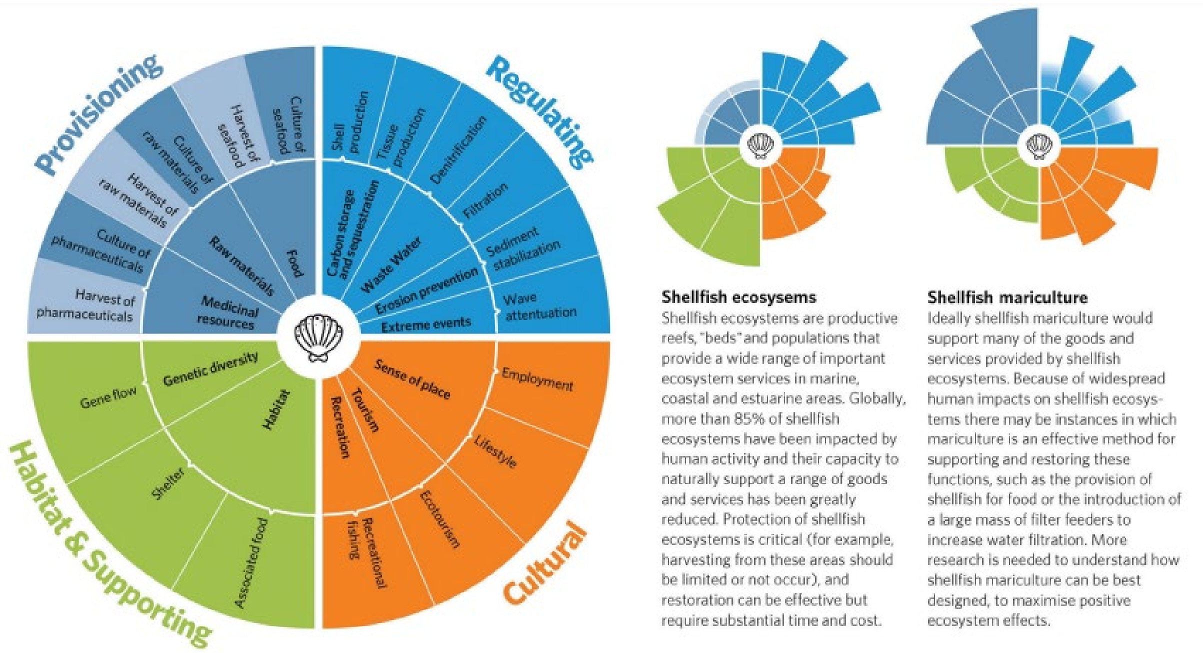
The East Devon Catchment Partnership advocate an ecosystem services approach in catchment management planning (West Country Rivers Trust, 2014). An integrated ecosystem services approach has been developed by Westcountry Rivers Trust to enable opportunity mapping in East Devon, including water quality (and quantity) regulation through natural flood management and Catchment Sensitive Farming. Management options include: i) restoring/maintaining good soil condition; ii) restoring/creating wetland habitats including Culm grasslands; iii) tree planting to increase rainfall interception and soil infiltration (Westcountry Rivers Trust, 2014). Examples of integrated catchment management in action include South West Water's Upstream Thinking Programme covering the Exe main and Creedy and West Exe catchments (SWW, 2021b), East Devon County Council's Clyst Valley Regional Park and Devon County Council's Connecting the Culm project (2019-2022).

The South Marine Planning policy S-WQ-1 also refers to the importance of ecosystem services in helping to regulate water quality. Habitats such as coastal saltmarsh, intertidal mudflats, seagrass, reed beds and natural blue mussel beds provide ecosystem services which maintain and can improve water quality. Policy S-WQ-2 encourages activities improving water quality including habitat restoration and bioremediation.

5.1.1 The role of shellfish and shellfish aquaculture in maintaining ecosystem functioning, including regulating water quality

Bivalve shellfish such as mussels and oysters play an important role in the healthy functioning of estuarine and marine ecosystems and the provision of ecosystem services (ES) that contribute to human wellbeing (**Figure 4**) (Theuerkauf et al., 2021). As filter feeders these shellfish help maintain water quality, by removing microbial and chemical contaminants (Smaal et al., 2019). By forming biological reefs, shellfish also help regulate coastal wave action and sediment dynamics and provide biodiverse habitats in an otherwise sediment-dominated environment (Seed and Suchanek, 1992; Andrews et al., 2011; Theuerkauf et al. 2021). For example "blue mussel beds on sediment" are listed as a UK Biodiversity Action Plan (BAP) Priority Habitat (JNCC, 2011). Bivalve shellfish also constitute an important food source for predatory invertebrates (crabs and lobsters) and vertebrates (fish, mammals and birds), as well as for humans (JNCC, 2011).

Figure 4: Ecosystem service provisioning by natural shellfish ecosystems and farmed shellfish (mariculture) – Figure by Alleway et al. (2018)



Delivery of ecosystem services is often highly variable, both spatially and temporally, depending on the condition of the ecosystems providing them (Maes et al., 2020), on hydrodynamic conditions which vary greatly along estuaries and coasts, and also on service accessibility/perceptibility by humans (Grabowski et al., 2012; La Peyre et al., 2014; Theuerkauf et al., 2021). Additionally, interactions occur between the different ecosystem services, which in turn influence the goods and benefits derived. These interactions can operate through trade-offs, i.e. one ecosystem service or benefit can have a negative impact on another.

The use of bivalve shellfish to bio-remediate water quality (microbial, chemical, nutrient and turbidity related water quality) in the Exe Estuary has been examined by the Marine Management Organisation - Project No: 1105 on Environmental remediation in South Marine Plan Areas (**Appendix 10**). The 'bottom cultivation' (on the estuary bed) of native oysters (*Ostrea edulis*) and blue mussels (*Mytilus* *edulis*) was rated as most cost-effective, with native oyster cultivation scoring highest for sustainability, and equal with mussels for additional environmental and societal benefits (e.g. provision of reef-forming habitat, fish nursery function and waste removal) (Marine Management Organisation, 2016). Bivalve shellfish could reduce nitrogen in water bodies by between 1 – 15 % of annual loads and occasionally up to 25 % of daily loads (Marine Management Organisation, 2016).

6 Faecal pollution

Environment Agency bathing waters investigations using a DNA tracing technique suggest the majority of faecal indicator bacteria are of ruminant origin at Exmouth Town Beach (CEFAS, 2013). Exmouth bathing water is affected by the catchment surrounding the Littleham Brook (600 ha), and by the Exe Estuary catchment (~150,000 ha), which contain over 50 dairy and other livestock farms (HM Government 2021a). Faecal matter from grazing livestock is either deposited directly on pastures, or collected from livestock sheds, if animals are housed indoors during the colder months, and then applied to agricultural lands as a fertilizer. Significant numbers of poultry and some pigs are also farmed in the catchment. Manure from pigs and poultry is typically stored without containment and applied tactically to nearby farmland.

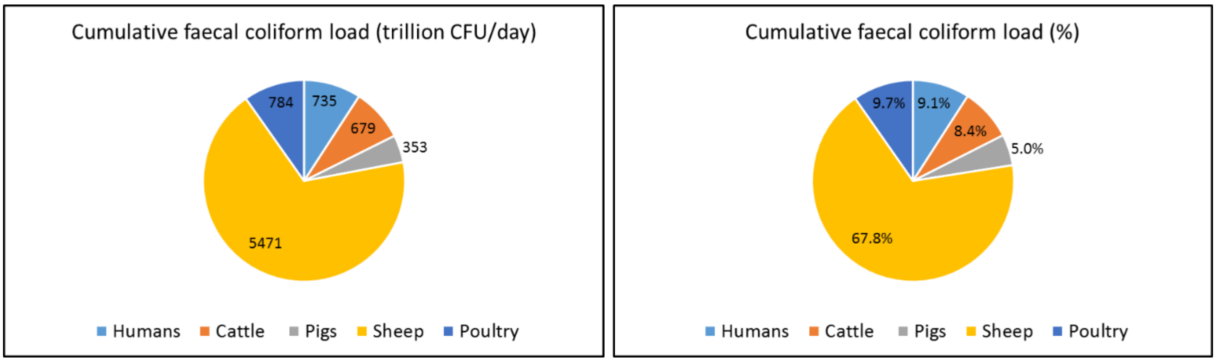
Simple calculations based on livestock numbers and human population numbers in the Exe Estuary catchment support these water quality monitoring investigations i.e. confirming that faecal production is likely to be dominated by livestock. Sheep carry the highest faecal coliform load per gram of faeces and multiplying this value by the total amount of faeces per individual and the number of individuals yields the highest contribution to the total faecal coliform load (68%) (**Table 9; Figure 5**).

Table 9: Calculated daily faeces and faecal coliform production from humans and livestock in the Exe Estuary catchment

CFU is colony forming unit for faecal coliform bacteria. Data: a) CEFAS (2013); b) AgCensus (2010).

Source	a) Faeces per individual per day (g [wet weight])	a) Faecal coliforms (million CFU/g faeces [wet wt])	Faecal coliforms per individual per day (million CFU/indiv/day)	a), b) Population number in Exe Estuary catchment	Cumulative faecal coliform load (trillion CFU/day)	Cumulative faecal coliform load (%)
Humans	150	13.0	1950	377000	735	9.1
Cattle	23600	0.23	5428	125045	679	8.4
Pigs	2700	3.3	8910	45166.7	353	5.0
Sheep	1130	16.0	18080	302595	5471	67.8
Poultry	182	1.3	236.6	3315432	784	9.7

Figure 5: Calculated daily faeces and faecal coliform production from humans and livestock in the Exe Estuary catchment



Investigations concerning faecal pollution highlight increasing trends throughout the UK (House of Commons Environmental Audit Committee, 2022), including SW England and the Exe Estuary catchment (River Trusts, 2021). These investigations also highlight the importance of flood events in increasing sewer overflows and land run-off. Climate change is bringing increasingly wet winters to the UK (Kendon et al., 2021). For example February 2020 was the UK's wettest February since records began in 1862; mean total rainfall was 209 mm (237% of the long-term average).

Potential sources and hotspots concerning faecal pollution in the Exe Estuary's and Lyme Bay's shellfish waters have been investigated via systematic sanitary surveys comprising walk-over surveys and desktop studies (CEFAS, 2013; CEFAS, 2015; Carcinus, 2021). **A key conclusion from these sanitary surveys is that shellfish production areas, which are most at risk from faecal contamination lie in the upper Exe Estuary around the confluence of the Exe at Countess Wear and the confluence of the Clyst at Topsham, and also in the mid estuary, at the confluence of the River Kenn** (Carcinus, 2021).

6.1 Municipal sewage inputs

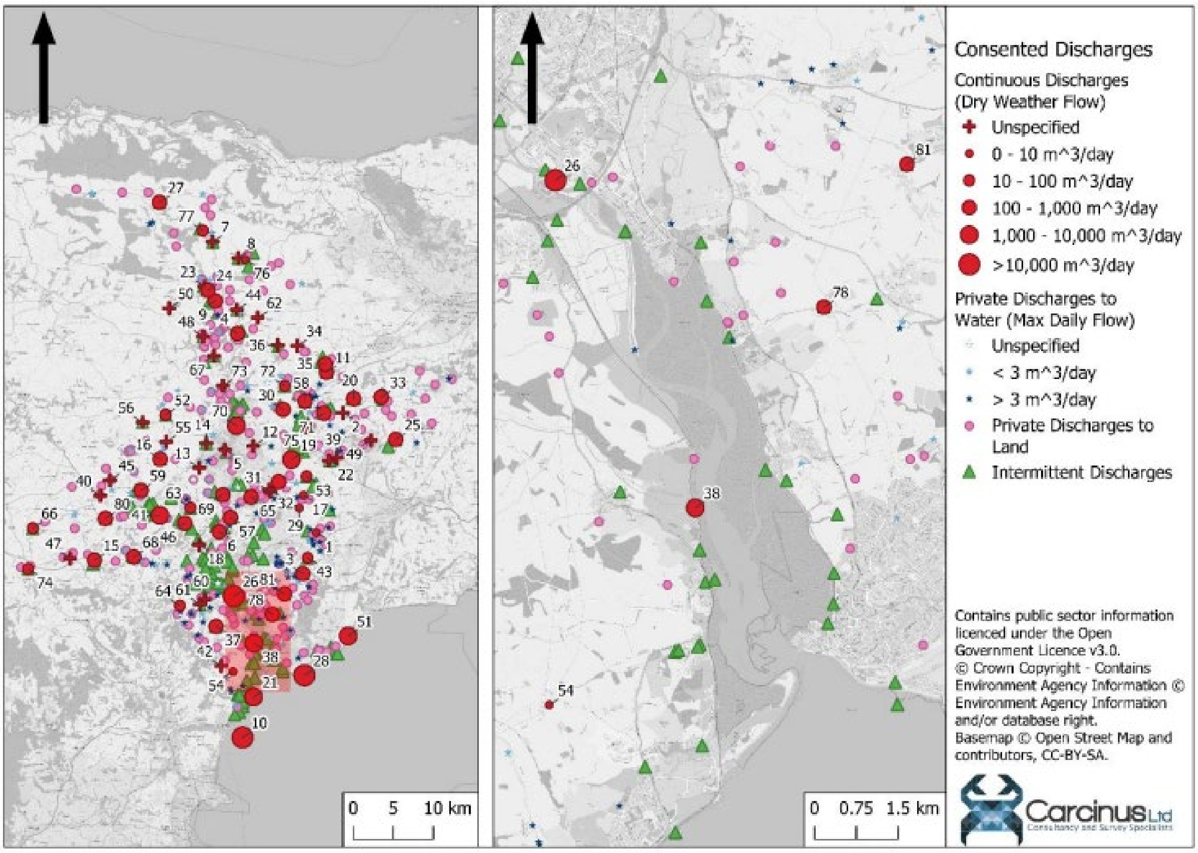
There are 82 consented continuous sewage discharges within the Exe Estuary catchment and Exe Estuary, which receive various physical, chemical and biological treatments (**Figure 6; Appendix 11**). Total waste water treatment works (WWTW) discharges amount to ~70,000 m^3/day, which is equivalent to 0.8 m^3/sec (3.2% of mean river flow, i.e. 25 m^3/sec for the River Exe at Trews Weir) (SWW; UK CEH, 2021). Exeter's Countess Wear WWTW has the highest permitted dry weather flow of 40,486 m^3/day (UV treated), making up over half the total of all continuous discharges in the Exe main catchment. The second and third highest continuous sewage discharges in the Exe Estuary catchment are from Exmouth (11,825 m^3/day) and Dawlish sewage treatment works (4,856 m^3/day), respectively – both are UV treated and discharge into Lyme West via long sea outfalls to protect coastal bathing waters. Other significant continuous discharges to Lyme Bay West include Teignmouth's Buckland STW (21,818 m^3/day), which is not UV treated, but discharges via a long sea outfall. Other significant continuous discharges to the shellfish waters of the Exe Estuary include Kenton and Starcross (1,750 m^3/day; UV treated) and Woodbury sewage treatment works (408 m^3/day; not UV treated) (**Appendix 11**).

There are 251 consented intermittent discharges within the Exe Estuary catchment, of which 50 are within 2 km of the Exe estuary. Intermittent discharges comprise Combined Sewer Overflows (CSOs), Storm Tank Overflows (STOs), Sanitary Sewer Overflows (SSOs) and pumping station emergency overflows, all of which can result in the release of untreated sewage into surface waters (Carcinus, 2020) (Figure 6; Appendix 12). Exeter's Countess Wear SSO is the single largest intermittent discharge, which, before the installation of UV treatment in 2018, contributed 42.6% (2.6 $x10^{11}$ *E. coli* CFU) of the total bacterial load (6.1 $x10^{11}$ *E. coli* CFU) from all intermittent discharges into the Exe

Estuary (Pateman et al., 2018). Spill frequencies and durations of intermittent discharges into the Exe Estuary and Lyme Bay West for 2020 are taken from The Rivers Trust https://www.theriverstrust.org/key-issues/sewage-in-rivers and are summarised in **Appendix 13**. Among the 36 intermittent discharges identified, 26 exceeded their spill frequency trigger permit in 2020 (spills per year as 10 year averages: 40 spills for water bodies; 14 spills for shellfish waters; 5 spills for bathing waters - per bathing season) (SWW, 2021a). Of these 15 have been highlighted for further investigation and improvement. The most frequent and longest duration intermittent discharges are Maer Road CSO entering Lyme Bay at Exmouth (65 overflows, 858 hrs), Warren Road CSO entering Shutterton Brook and the Exe Estuary at Dawlish; Cofton CSO entering Cofton Stream and Cockwood Harbour (45 overflows, 384 hrs); Bonhay Road CSO, entering Exe Estuary at Starcross (20 overflows, 129 hrs); Exton North entering the River Clyst and Exe the Estuary (146 overflows, 2003 hrs).

In addition to the water company owned discharges, there are a number of privately owned (STW and septic tank) discharges within the catchment. Few of these discharge directly to water bodies near the shellfish classification zones; the most significant include private STWs serving Haldon Forest Holiday Park (45 m^3 day^{-1}) and the Lord Haldon Country Hotel and Haldon House at Dunchideock (27 m^3 day^{-1}), both of which discharge into the River Kenn (Environment Agency, 2018a, 2018b; Carcinus, 2021).

Figure 6: Consented continuous and intermittent sewage discharges contained within the Exe Estuary catchment, Exe Estuary and Lyme Bay West – See Appendix 11 and 12 for further details.



6.2 Faecal pollution from agriculture

Faecal pollution from agriculture potentially originates from two main sources, the application of sewage sludge (biosolids) and the application of livestock manure/slurry to fertilise arable land for crops and improved grassland for livestock grazing.

6.2.1 Sewage sludge

Sewage sludge is a by-product of the treatment of sewage. In 2020/21 South West Water produced 42.85 thousand tonnes of dry solids (from sewage sludge) and of this 42.72 were recycled or disposed via their bioresources service, with the majority being subjected to anaerobic digestion and lime stabilisation techniques to create a biosolid product for agricultural use (SWW, 2022). Anaerobic digestion (AD) is being used increasingly in developed countries for treating sewage sludge, with the principle aims of volume reduction and biogas production, the latter being used for energy generation. Pathogen removal is also a key aim, if the biosolids produced by AD are to be used to fertilise pasture or arable land, so as to safeguard agricultural crops, livestock and human consumers. Once optimised AD has been shown to deactivate a wide range of pathogens, including bacteria, parasites, viruses and other microbes harbouring antibiotic resistant genes (ARGs). Monitoring is needed to establish quantitative relationships between commonly used faecal indicators such as *E. coli* and AD resistant-pathogens and to track ARGs in AD resistant microbial hosts (Zhao and Liu, 2019). The presence and sources of antibiotics and ARGs in the Exe Estuary catchment are discussed in **Section 11**.

6.2.2 Farmyard manure and slurry

Manure applied to agricultural land is produced by livestock as farmyard manure (FYM), diluted slurries, and poultry manures, which all largely remain in their natural form. Manures are by far the largest components of organic fertilisers used in agriculture in England; others include anaerobically digested (AD) sewage sludge (bio-solids) and some industrial 'wastes' such as compost, paper waste or brewery effluent (**Table 10**) (DEFRA, 2021c).

Since farmyard manures and slurries are untreated, they are also the primary source of pathogens in 'farm to fork' microbial risk assessments. Recent research has shown that the prevalence of a range of pathogens in farmyard manure and slurry varies substantially between countries, depending on temperature, storage, livestock sources and levels of livestock vaccination (**Appendix 14**). Nevertheless, even in developed countries such as Ireland, the prevalence of *Cryptosporidium* spp. in cattle may be as high as 26% (Nag et al., 2021).

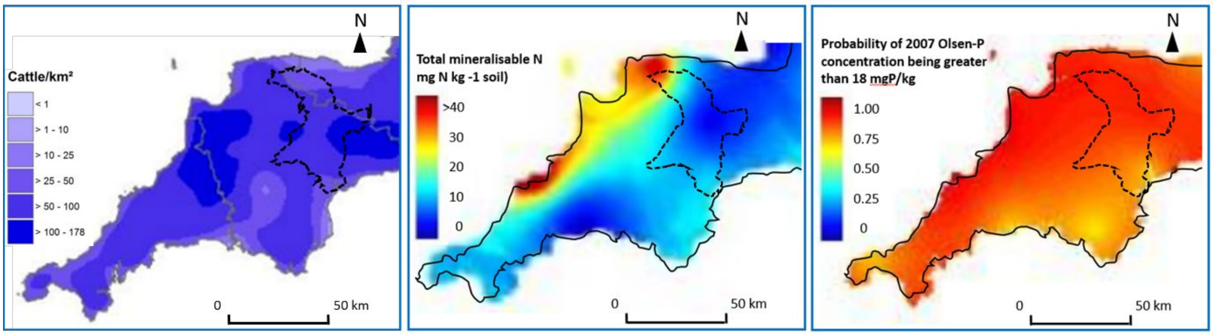
Table 10: Proportion of overall organic application rates per hectare of farmed area (excluding rough grazing) by nutrient type, England 2019/20

(a) Includes home produce, imported and purchased FYM and Slurry

Source of organic fertiliser	Nutrient provision		
	Nitrogen	Phosphate	Potash
Farmyard manure (FYM) & slurry[(a)]	89%	84%	95%
Digestate from on-farm anaerobic digestion	<1%	<1%	<1%
Digestate from off-farm anaerobic digestion	7%	2%	2%
Other organic products	4%	14%	3%

No spatial data were found to be available for faecal inputs from manure and slurry. Inputs can potentially be inferred from the density of livestock grazing and variation in soil fertility with respect to total mineralisable nitrogen and Olsen-P as a measure of the fertility of agricultural soils across the Exe Estuary catchment is shown in **Figure 7**. Cattle grazing density distributions (dairy and beef cattle) were obtained from the Animal and Plant Health Agency (APHA, 2020). Total mineralisable-N and Olsen-P distributions were obtained from the Countryside Survey Soils report (UK CEH, 2010). The plotted data indicate that manure and slurry inputs are more likely the mid to lower Exe Estuary catchment, particularly in the Culm. Traditionally the Culm area has been grazed extensively by cattle and sheep. Since the outbreak of Foot and Mouth disease in 2001 livestock are less evenly distributed across the Culm and livestock now graze in more concentrated groups (Devon Wildlife Trust, 2014).

Figure 7: Variation in livestock grazing and in soil fertility (as indicators of manure and ferliser spreading) across the Exe Estuary catchment



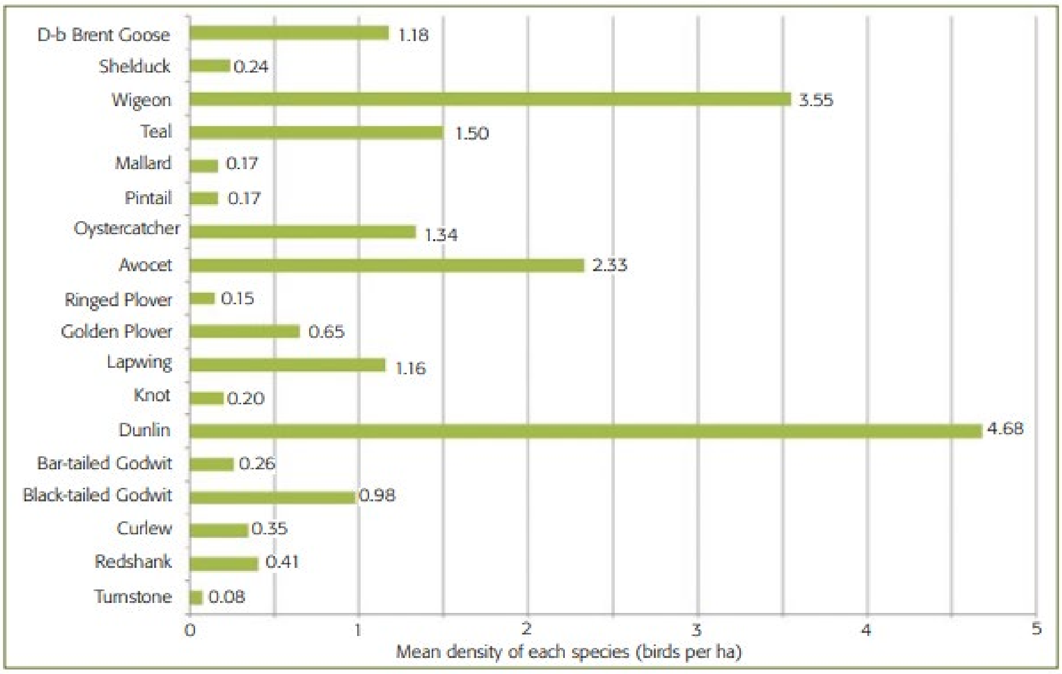
6.3 Faecal pollution from boats and shipping

A variety of boats navigate Lyme Bay and the Exe Estuary and potentially make overboard sewage discharges in the designated shellfish and bathing waters. There are around 1,800 moorings in the Exe estuary alone (CEFAS, 2013). Significant fishing fleets of <100 boats operate from Exmouth and Brixham; an additional 20 fishing vessels are listed as having their home port at Beer, Sidmouth or Axmouth (Carcinus, 2021). Fishing vessels have been observed to operate in areas adjacent to the offshore mussel farm (Lyme Bay Sites 1 and 2), and vessels using static gear may well operate within the lease boundaries. Theses fishing vessels potentially make overboard discharges in close proximity to the mussel lines from time to time, and their presence is likely to be evenly distributed throughout the year. Larger vessels, such as tankers and container ships also regularly pass through Lyme Bay, although the main shipping routes are located in the central English Channel and ships are not permitted to make overboard discharges within 5.5 km of land (Carcinus, 2021).

6.4 Faecal pollution from wildlife

Marine wildlife populations including water birds and marine mammals are a potential source of faecal contamination to shellfish and bathing waters. There are no major seal colonies in Lyme Bay or the Exe Estuary, however, they are spotted frequently in coastal waters, as are harbour porpoises and several dolphin species (Carcinus, 2021). Water birds, including wading birds and waterfowl are abundant in the Exe estuary, and populations regularly swell with the arrival of overwintering migrants. Annual water bird numbers averaged over the period 2015-2020 are 22,533 birds according to the BTO Wetland Bird Survey (WeBS) (Frost et al., 2021). The relative densities of different species of water birds in the Exe Estuary in 2016 are presented in **Figure 8**. These various water birds roost mainly in marginal wetlands, including Exminster and Bowling Green marshes and also on Dawlish Warren (Knot, 2021). Water birds may in the winter contribute to the loadings of faecal indicator organisms to estuarine and coastal shellfish waters (and bathing waters) on ebbing spring tides, following tidal inundation of the marshes. This represents a moderate risk (CEFAS, 2013; Carcinus, 2021). It is important to note that microbial communities, including faecal coliforms and pathogens (e.g. *Clostridium, Campylobacter* and *Helicobacter*) can vary substantially between wading bird species (Keeler and Huff, 2009) and these microbial communities also differ substantially to those associated with human and agricultural livestock faeces (Boukerb et al., 2021). Further work is required to better understand these variations in order to improve the tracking of faecal pollution sources in catchments.

Figure 8: Relative densities of different species of water birds in the Exe Estuary in 2016



▲ **Mean densities of waterbirds at low tide on Exe Estuary in 2016/17.**

Simple calculations based on water bird numbers in the Exe Estuary indicate that faecal coliform production is likely to be dominated by wildfowl, including Brent goose, Shelduck, Widgeon, Teal, and Mallard ducks (62%). Wading birds, including Bar-tailed and Black-tailed godwit, Oystercatcher, Avocet, Knot, Dunlin and Lapwing are also substantial contributors to faecal coliform production by waterbirds (37.9%), while gulls are likely to be minor contributors (0.1%) (**Table 11; Figure 9**).

Table 11: Calculated faecal coliform production from wading and water birds in the Exe Estuary in 2016/17

Data sources: a) Jones and Obiri-Danso (1999); b) Meerburg et al. (2011); c) Scherer *et al. (1995); d) Frost (2018). Less abundant water bird species are not accounted for in this table (e.g. egrets, rails).*

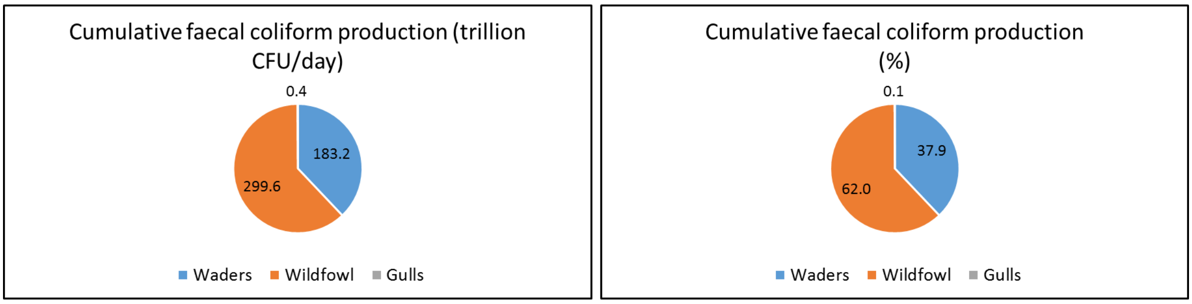
CFU is colony forming unit for faecal coliform bacteria.

Table 11: Calculated faecal coliform production from wading and water birds in the Exe Estuary in 2016/17

Data sources: a) Jones and Obiri-Danso (1999); b) Meerburg et al. (2011); c) Scherer *et al. (1995); d) Frost (2018). Less abundant water bird species are not accounted for in this table (e.g. egrets, rails). CFU is colony forming unit for faecal coliform bacteria.*

Water bird	a), b) Average abundance of faecal coliforms (million CFU/g of faeces wet weight)	c) Estimated faecal production (g/ bird/ day)	Estimated production of faecal coliforms (million CFU /24h /bird)	d) Mean annual total birds	Cumulative faecal coliform production (trillion CFU/day)
Bar-tailed and Black-tailed godwit	7080	10	7080000	873	61.8
Oystercatcher and Avocet	4700	10	4700000	2584	121.4
Knot	0.529	5	2.645	141	0.0004
Dunlin	0.529	5	2.645	3295	0.0087
Lapwing	0.255	8	2.040	817	0.0016
Waders				7709	183.2
Shelduck and Widgeon	736	18	13248	2668	35.3
Mallard	78300	27	2114100	120	253.0
Teal	736	13	9568	1056	10.1
Brent Goose	8.8	160	1408	831	1.2
Wildfowl				4675	299.6
Gulls	17.5	15	262.5	1408	0.3696

Figure 9: Calculated faecal coliform production from water birds in the Exe Estuary in 2016/17



6.5 Solutions addressing faecal pollution

6.5.1 Reduction and treatment of raw sewage discharges

Under the freedom of information act, data showing frequent spills of raw sewage from UK water company-owned intermittent discharges to watercourses in the UK in 2019 and 2020 (reaching ~400,000 spills in 2020) are now publically available https://www.theriverstrust.org/key-issues/sewage-in-rivers. These data, and pressure from the Environmental Audit Committee and the House of Lords prompted HM Government to make provisions in the Environment Act (2021) to set long-term statutory targets for the improvement of the natural environment, including for water companies in England to secure progressive reduction in the adverse impacts on the environment and on public health of discharges from storm overflows. Ministers are also required to publish, by September 2022, a plan to reduce sewage discharges from sewer overflows and their adverse impacts, including on public health https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted.

Improvements in sewage systems are currently made through the Water Industry National Environment Programme (WINEP), the programme of work water companies in England (and Wales) are required to do to meet their obligations from environmental legislation and UK government policy (HM Government, 2021b). WINEP is delivered through implementation of Asset Management Plans (AMPs) agreed between each of the regional water companies and the Environment Agency.

With regard to continuous discharges, South West Water (under AMP6: 2015-2020) invested in construction of new sewage treatment works (STWs) (£2.532 million) and expansion of existing STWs (£3.723 million), with additional investment in nutrient (phosphate) removal by activated bed STWs (£4.255 million) and filter bed STWs (£4.144 million) (Expenditure for 2020 – SWW, 2020). Recent, notable upgrades in 2021 to continuous discharges in the vicinity of the Exe Estuary include the deployment of UV disinfection at the Kenn and Kennford STW (Carcinus, 2021).

With regard to intermittent discharges, a systematic approach is used by water companies (including SWW) to prioritise infrastructure improvements, which will improve the quality of protected shellfish waters and bathing waters – the approach taken follows Urban Pollution Management (Foundation for Water Research, 2019) and employs the Storm Overflow Assessment Framework (SOAF) (**Appendix 14**). Overflows are counted using Event Duration Monitoring (EDM) and targeted for investigation if they exceed a spill frequency trigger permit (spills per year as 10 year averages: 40 spills for water bodies; 14 spills for shellfish waters; 5 spills for bathing waters - per bathing season) (SWW, 2021a). After checking rainfall data for exceptional rainfall events, for which overflows are permitted, investigations are made into possible sewer blockages or leaks and whether the hydraulic capacity of the system is adequate. Then the environmental and aesthetic impacts of the intermittent discharge are determined and used to identify the most cost beneficial solution to reduce the impact and/or frequency of discharges.

To protect shellfish water quality in the Exe Estuary, South West Water made improvements to eleven CSOs within the Countess Wear STW (Exeter) sewerage catchment by March 2018. Based on SOAF cost-benefit assessments and investments under AMP6 (2015-2020), improvements were prioritised for the Countess Wear sanitary sewer overflow (SSO). This SSO was considered the single largest intermittent discharge impacting on the quality of shellfish waters and bathing waters of the Exe Estuary and adjoining coast (Pateman et al., 2018). Improvements introduced UV disinfection, which was predicted to remove 42.6% of the total average annual bacterial load from all intermittent discharges in the catchment (including STOs, SSOs and CSOs) (**Table 12**). The aim was to achieve ≤ 300 *E. coli* /100 mL in shellfish flesh and intravalvular fluid, in compliance with the Shellfish Water Protected Areas (England and Wales) Directions 2016 (HM Government, 2016) (Pateman et al., 2018). However, no *E. coli* monitoring data are currently available for Countess Wier SSO, so its impact on shellfish waters in the Exe Estuary cannot be assessed directly. Currently the closest representative monitoring point for shellfish (Cockwood Harbour) is approximately 9.5 km downstream. Another notable AMP6 improvement project benefiting the Exe Estuary targeted Lympstone outfall pumping station. The project incorporated infiltration removal and storm water storage to achieve a reduction in CSO spills (to less than 10 significant spills per annum) and screening to improve spill quality (Steer et al., 2018).

A further nine CSOs were scheduled for improvements by SWW by June 2021. Information on these improvement projects was not available for this report.

Table 12: Summary of bacterial loads (*E. coli* cfu – colony forming units) and estimated reductions due to Countess Wear SSO disinfection

Intermittent discharges in the Exe Estuary catchment entering the Exe Estuary	Estimated load m^3 x *E. coli* cfu/100ml	Estimated load (%)
Total contribution from CW storm tank discharges	2.6 $x10^{11}$	42.6
Total contributions from other intermittent discharges	3.5 $x10^{11}$	57.4
Total estimated load from intermittent discharges	6.1 $x10^{11}$	100

6.5.2 Sustainable Urban Drainage Systems

As part of its "Downstream Thinking" Programme, South West Water is running an on-going WaterShed Project in Exmouth to store water in tanks, to manage/recycle rainwater for domestic use, and to build Sustainable Urban Drainage Systems (SUDs) including rain gardens that will hold water during storms before slowly soaking into the ground or feeding gradually back into the sewerage network. The WaterShed project is expected to reduce combined sewer overflows into the Exe Estuary (SWW, 2021c).

6.5.3 Management of farmyard manures and slurries

Given the potentially high pathogen load in farmyard manures and slurries (**Appendix 14**), managing their storage and agricultural use as organic fertilisers is highly important for food safety, particularly in the case of ready to eat crops (salads, fruits and vegetables). Guidelines provided by the Food Standards Agency (2009) should be followed to minimise the risk of microbial pathogen contamination. These guidelines include:

- You should NOT apply fresh solid manure or slurry (i.e. manure that has not been batch stored or treated e.g. with lime) within 12 months of harvesting a ready-to-eat crop, including a minimum period of 6 months between the manure application and drilling/planting of the crop.
- You should also ensure that there is a 12 months gap between livestock last grazing in the field and harvesting of a ready-to-eat crop, including a minimum period of 6 months between the last grazing and drilling/planting of the crop.
- Spreading of treated or batch stored solid manure or slurry (stored for at least 6 months) should take place before drilling/planting of the crop.

Additional prioritised interventions highlighted in the DEFRA funded Demonstration Test Catchment project (WQ0203) in the Tamar SW England by Crowther et al. (2018) and Kay et al. (2018) for reducing diffuse faecal/microbial pollution from agricultural sources to coastal waters include:

- Containing manures and slurries before application to land and minimising yard runoff from farm steadings
- Managing intensively grazed (particularly streamside) pastures by installing stream bank fencing and water troughs can reduce mean *E. coli* and intestinal enterococci inputs to water courses by $\log_{10}$ 0.842 and 2.206, respectively
- Creating Free Water Surface Constructed Wetlands can reduce *E. coli* inputs by $\log_{10}$ 1.88, while dirty water treatment systems can reduce *E. coli* inputs by $\log_{10}$ 1.34-2.92
- Minimising runoff and slowing water flows by constructing riparian vegetated buffer strips and creating grass swales along ditches.

- Modelling FIO attenuation along watercourses e.g. $\log_{10}$ 1.0 die-off for *E. coli* may occur within 3 – 50 hrs depending on sunlight intensity and water turbidity (Figure
- Prioritising pollutant sources located closest to the coast.

6.5.4 Catchment management

Schemes benefiting water quality by reducing agricultural runoff and faecal pollution in the Exe Estuary catchment include:

- Countryside Stewardship, including Catchment Sensitive Farming (CSF) – A major attribute of CSF is the monitoring of environmental improvements following advice and interventions on farming practice across priority areas, including those in SW England (**Appendix 16**). To date, a total of 127 different CSF measures have been advised on farm infrastructure, livestock and manure management, land use and soil management, pesticide and fertiliser management. Farm infrastructure, livestock and manure management measures have contributed to -91% FIO reductions (Natural England, 2019).
- The introduction of CSF Farming Rules for Water (The Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018) – These rules require reasonable precautions to ensure that manure and fertiliser applications do not 'exceed the needs of the soil and crop on that land' or 'give rise to a significant risk of agricultural diffuse pollution'. Rules for arable land include establishing crops early in the autumn months, and during dry conditions; planting headland rows and beds across the base of any sloping land; under-sowing or sowing a cover crop to stabilise soil after harvest; removing compacted soil; establishing grass (buffer) strips in valleys, or along contours or slopes, or gateways. For managing livestock precautionary measures include: moving livestock regularly; erecting fencing around controlled waters; wintering livestock on well-drained, level fields (DEFRA, 2018b).
- South West Water's "Upstream Thinking" programme - By 2050, SWW intends to implement catchment management for over 80% of their catchments, to improve raw drinking water quality and to restore landscapes for Biodiversity Net Gain (SSW, 2018).

7 Pesticide pollution

7.1 Sources

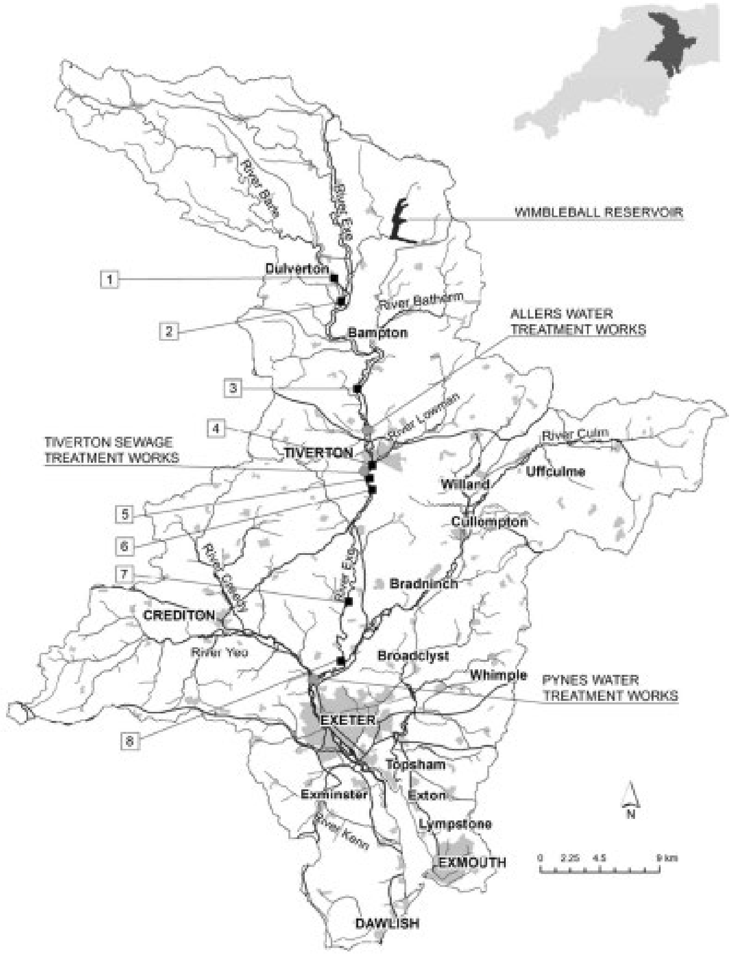
Pesticides, particularly herbicides are used in large quantities on agricultural land within South West England catchments (**Appendix 17**).

There is evidence of pesticide pollution in the Exe main operational catchment. South West Water's raw water monitoring data for Allers and Pynes Water Treatment Works show that some pesticides are detectable in the middle and lower reaches of the River Exe for most of the year (**Appendix 9**). The acid herbicides MCPA, mecoprop and triclopyr plus chlorotoluron and the slug treatment metaldehyde have been among the most frequently detected pesticides at the intake for Pynes WTW in the period 2008-2013, indicating both grassland and arable sources. During the 2008-2013 period detections of individual compounds increased and in particular the maximum concentration of MCPA exceeded the 0.1 μg/L standard in 2009 (SWW).

The East Devon Rural Diffuse Pollution Project commissioned by the East Devon Catchment Partnership identified 50 farms across the East Devon catchments of the Clyst (and also the Otter and Axe) with high risk of causing diffuse water pollution (Brown, 2018). 44 farms were growing maize in large fields prone to runoff due to sloping land, and either slowly permeable, compacted and/or eroding soils. 27 farms were investigated and all showed high runoff during heavy rain events, and 5 farms had a serious impacts on watercourses (defined by the EA as Category 2 water incidents). A detailed analysis was also carried out using soil maps provided by Cranfield University and showed that: >93% of the land used was at high risk of run-off; <19% of the land used for maize production was (naturally) freely drained; 60% of land used for maize production was at risk of erosion; >50% of maize land had a high risk of slurry pollution (Brown, 2018). It is not clear at this stage how conditions may change under the adoption of the 'Farming Rules for Water' (The Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018).

To better understand the sources, transport and fate of acid herbicides in catchments SWW deployed calibrated Chemcatcher® passive samplers at eight strategically located monitoring stations along the river Exe from Dulverton to the intake of Pynes water treatment works in Exeter in May and June/July 2013 (**Figure 10**). These samplers captured time-weighted average concentrations (over 16 days) of 2,4-D, dicamba, dichlorprop, fluroxypyr, MCPA, MCPB, mecoprop, tricolpyr enabling the detection of diffuse pollution. 2. Based on both spot sampling and Chemcatcher® sampling, the concentrations of all herbicides were generally low (below the analytical limit of detection) in the upper catchment above Station 3 - Ironbridge (SS94261782) while concentrations of MCPA and mecoprop were elevated at Station 4 - the confluence of the River Lowman (SS95381200) and persisted to a lesser extent downstream. A significant pollution incident involving fluroxypyr (2.09 μg/L) and triclopyr (5.03 μg/L), a factor of 20 and 50 above the Drinking Water Directive limit of 0.1 μg/L was detected on one occasion by both spot sampling and Chemcatchers® in Jun/July 2013. The pollution incident was detected in Calverleigh Stream (SS93101452) close to the confluence with the River Exe, just below the intake to Allers WTW at Bolham Weir. Calverleigh Stream drains dairy pasture land treated periodically with acid herbicides. A spike in MCPA (0.17 μg/L) was also detected here by the Chemcatchers®, but this short-term pollution event involving MCPA was missed by sequential spot sampling (Townsend et al., 2018).

Figure 10: River Exe catchment showing the eight locations for the Chemcatcher® deployments



7.2 Solutions

Diffuse water pollution from agriculture in England and Wales is being addressed by the Department for Environment, Food and Rural Affairs' (Defra) Catchment-Sensitive Farming (CSF) as part of Countryside Stewardship. Farm infrastructure and pesticide management implemented through CSF have contributed to significant reductions in pesticide concentrations in rivers (-88%), including SW England (Natural England, 2019).

Reductions in pesticide pollution in the Exe Estuary catchment are being delivered through South West Water's Upstream Thinking programme, including the Headwaters of the Exe catchment and Exmoor Mires Projects (2015-2020). In these projects Devon Wildlife Trust and Westcountry Rivers Trust, in partnership with South West Water have provided advice on farm management and habitat regeneration (wooded slopes, wet grassland / marshland and farm ponds) to address pesticide (particularly acid herbicide) pressures on river ecology and drinking water quality in the Exe main catchment (SWW, 2021b).

Whole catchment-based risk assessment tools can help identify major pollution sources and target interventions. For example, an acid herbicide wash-off exploration tool has been developed at the University of Exeter with Westcountry Rivers Trust. This has been used to explore the potential impacts of acid herbicide wash-off (i.e. agricultural weed killer run-off from grassland) on water quality in relation to environmental quality standards (e.g. EQS short-term for mecoprop is 24 µg/L in freshwater and 1.7 µg/L in saltwater). These standards are designed to protect the most susceptible environmental species, in this case phytoplankton, which are the primary food source for wild and farmed bivalve shellfish. The tool has also been used to illustrate the benefits of different herbicide application and soil management strategies on river and estuarine water quality (Webber et al., 2021).

8 Nutrient enrichment

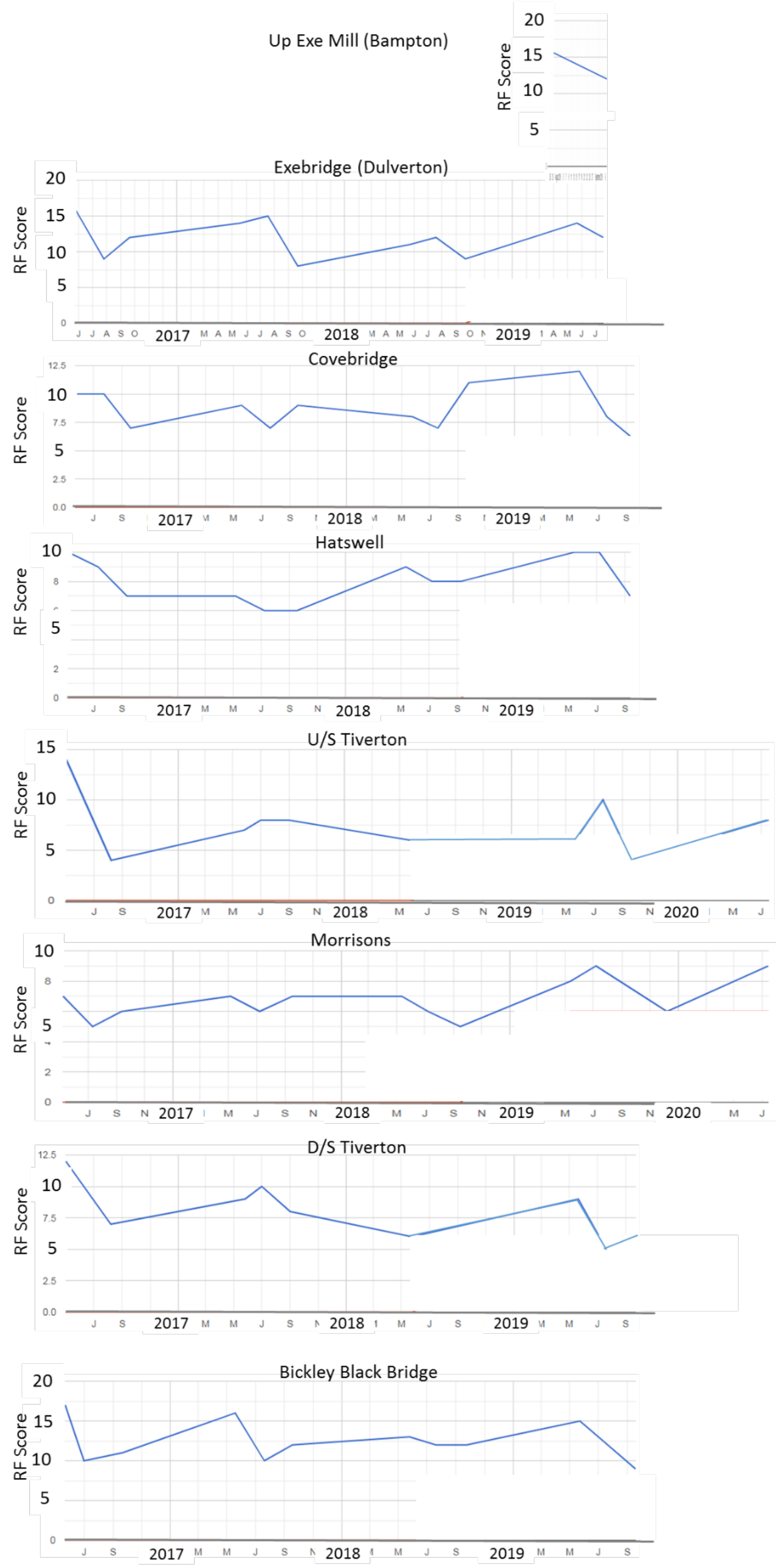
Nutrient enrichment includes inputs of macro-nutrients: carbon, nitrogen and/or phosphorus, each of which, in excess, can cause imbalances in river ecosystem structure and function. For example, excess carbon can lead to organic enrichment which can impact severely on aquatic invertebrate fauna diversity (Hawkes, 1998), while excess nitrogen (nitrate, nitrite, ammonium) and/or phosphorous (phosphate) can fuel algal blooms, which can smother habitats and cause oxygen depletion in the water column when blooms breakdown (a process called eutrophication). Algal blooms can also liberate metabolites which can cause tainting and odour issues in drinking water at low ng/l levels and act as a source of toxins such as microcystins (from blue-green algae).

8.1 Sources

8.1.1 Organic carbon

The Exe catchment is exposed to diffuse sources of organic enrichment from livestock grazing on improved and unimproved grassland. Point source sewage discharges may also lead to localised effects on water quality and on the biodiversity of aquatic invertebrates, with the loss of stonefly and caddisfly larvae being a sensitive indicator of organic enrichment (Hawkes, 1998). River invertebrate monitoring undertaken by the Riverfly Partnership https://www.riverflies.org/content/DataExplorer at eight stations spanning the upper Exe (Bampton) down to Bickleigh, below Tiverton shows typical seasonal variation in biodiversity (Riverfly (RF) score), with no noticeable inter-annual trends (2016-2020). There are also no strong indications of changes in biodiversity upstream and downstream of discharges from sewage treatment works, but there was a small reduction in the RF score in 2019 downstream of Tiverton (**Figure 11**).

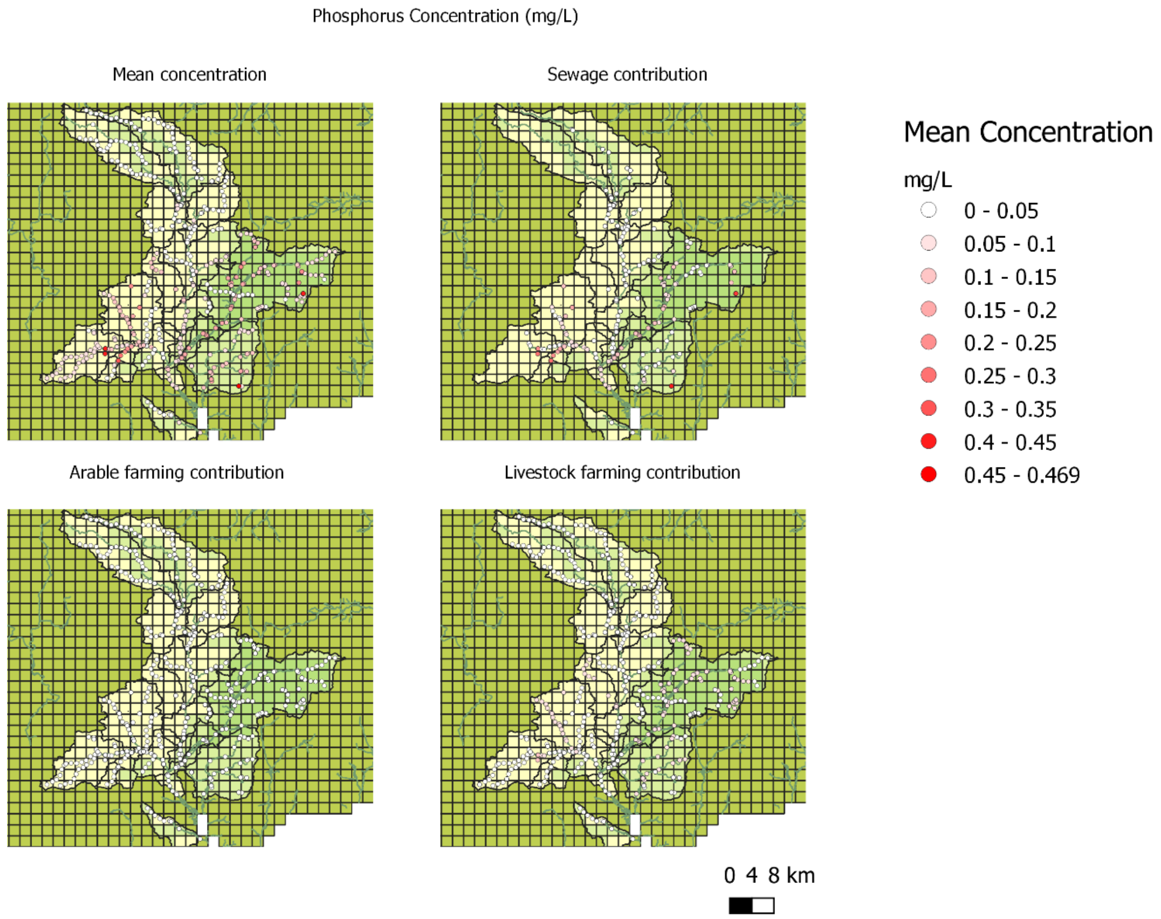
11: Variation in aquatic invertebrate biodiversity measured using the Riverfly (RF) score from the upper Exe (Bampton) down to Bickleigh, below Tiverton (2016-2020)



8.1.2 Phosphorous

Source Apportionment-GIS (SAGIS) modelling has been developed by UK Water Industry Research (UK-WIR) to identify and quantify sources of pollution (**Figure 12** – UK CEH 2021) (Comber et al, 2013). Source apportionment indicates that nutrient enrichment by phosphorous in the Exe catchment is caused mainly by point source sewage discharges (Westcountry Rivers Trust, 2014), with the prime sources being human excreta and domestic detergents (Comber et al., 2012). Urban and agricultural runoff are also significant sources of phosphorus in some parts of the Exe Estuary catchment, particularly in the Culm and the headwaters of the Creedy and West Exe One water body in the Creedy and West Exe (Holly Water – NGR SS8594207109) has persistently been classified as 'Poor' with respect to levels of phosphorous (measured as phosphate). Nine other water bodies in the Creedy and West Exe operational catchment were classified as 'Moderate' (i.e. not achieving the objective of 'Good') in 2019. Dissolved inorganic phosphorous is often associated with fuelling algal growth and eutrophication in rivers, leading to oxygen depletion in the water column. Only one water body - upper River Yeo (NGR SX7766198346) was classified as 'Moderate' in 2019 in terms of dissolved oxygen concentration (Environment Agency, 2021b).

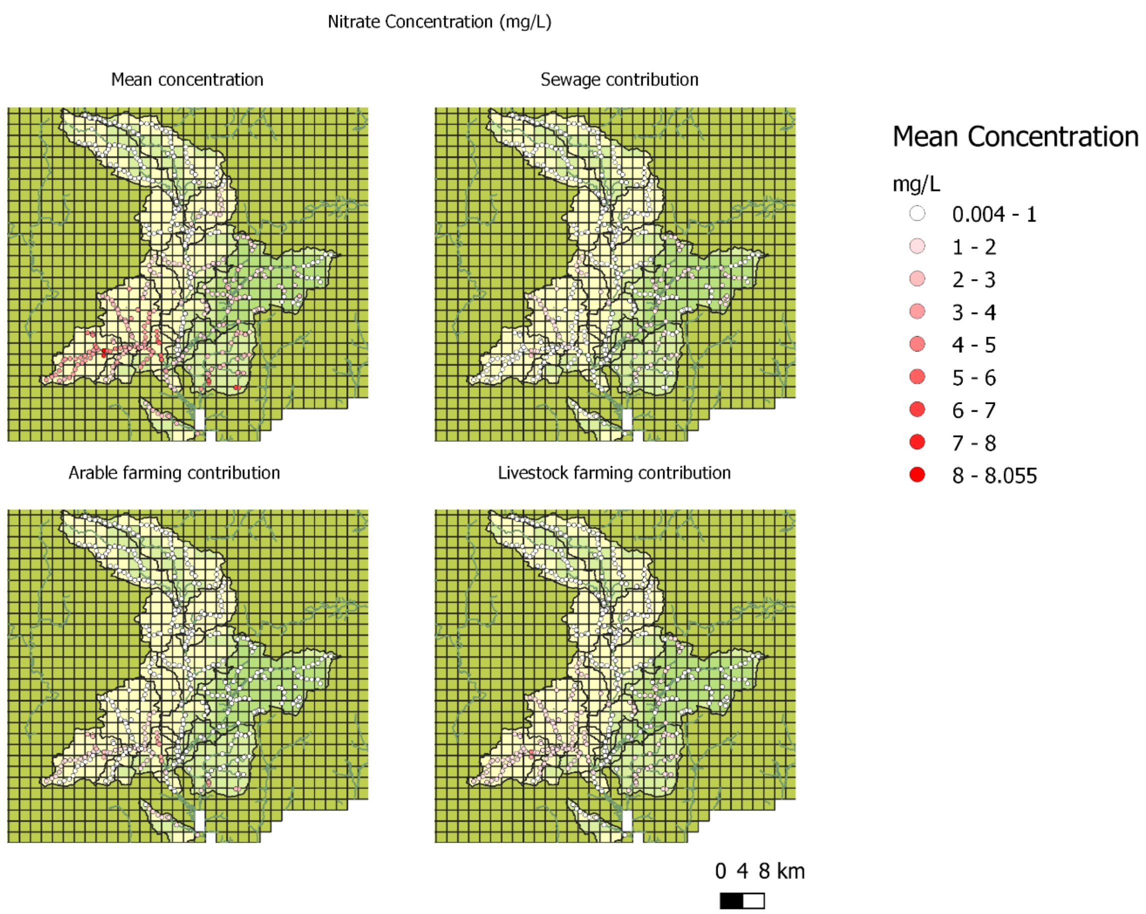
Figure 12: Source apportionment for phosphate in the Exe Estuary catchment



8.1.3 Nitrogen

Source Apportionment-GIS (SAGIS) modelling (**Figure 13** – UK CEH 2021) (Comber et al, 2013) indicates that nitrogen inputs are attributable more to diffuse agricultural runoff from arable land and improved grassland, following the use of nitrate-based fertilisers and livestock manure and slurry, which is rich in ammonia and ammonium. Dissolved inorganic nitrogen is more often associated with eutrophication in estuaries, i.e. excessive algal growth, which can significantly reduce dissolved oxygen concentrations when the biomass biodegrades. There is some historical evidence of algal blooms in the Exe Estuary, which have been linked to elevated nutrient concentrations and possible eutrophication impacts (including on mussel populations) (Langstone et al., 2003). More recently there appear to have been improvements and signs of eutrophication were not detected in 2014 and 2019 (Exe Estuary Management Partnership, 2014; Environment Agency, 2021b). Furthermore, dissolved oxygen levels in the Exe Estuary are consistent with 'Good' status under the WFD and relevant shellfish and bathing water standards (**Appendix 18**) (Environment Agency, 2021b).

Figure 13: Source apportionment for nitrogen in the Exe Estuary catchment



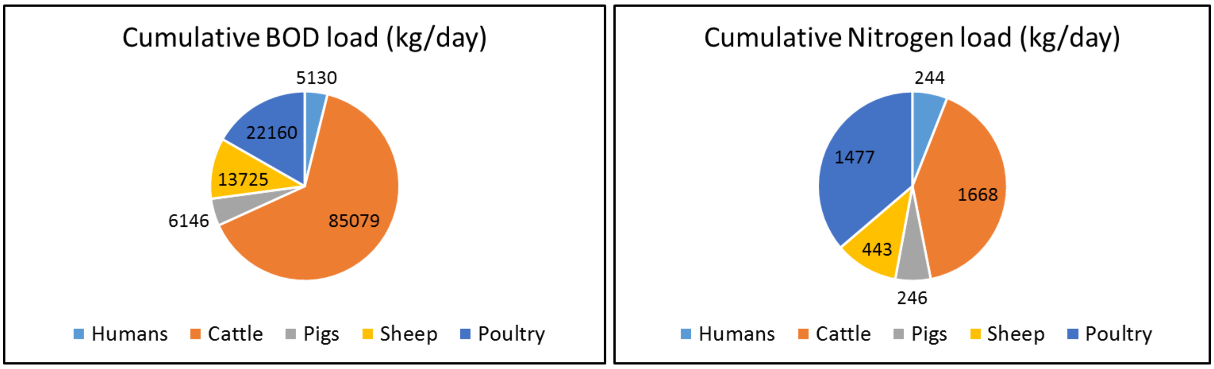
Simple calculations based on livestock numbers and human population numbers in the Exe Estuary catchment indicate that Biochemical Oxygen Demand (BOD) caused primarily by the breakdown of organic carbon and the nitrification of ammonia in human and livestock excreta is likely to be dominated by cattle (dairy and beef herds) (**Table 13; Figure 14**). In terms of relative BOD loading, a dairy cow is equivalent to about 50 people. Therefore, a single herd of 250 dairy cows is equivalent to a population of 12,500, about the size of Honiton (East Devon Catchment Partnership, 2018). A total of 125,045 cattle and 302,595 sheep were recorded within the Exe Estuary catchment according to the 2010 agricultural census. The equivalent human population census in the Exe Estuary catchment was 377,000 (2011) (CEFAS, 2013). Biological oxygen demand specifically due to nitrogen (through nitrification) are dominated by both cattle and poultry faeces (**Table 13; Figure 14**).

Table 13: Calculated daily organic pollution loads (biological oxygen demand) and loads due to nitrogen from human and livestock faeces produced in the Exe Estuary catchment

Data sources: a) Lorimor et al. (2004); b) AgCensus (2010); c) CEFAS (2013); d) Modern Farmer (2021)
Biological oxygen demand, the amount of oxygen required to degrade organic material, i.e. faeces.
Nitrification demands twice as much oxygen as carbon respiration on a molar basis:
Nitrification: a) $2NH_4^+ + \underline{3O_2} \rightarrow 2NO_2^- + 4H^+ + 2H_2O$*; b)* $2NO_2^- + \underline{O2} \rightarrow 2NO_3$ *.....versus*
Respiration: $C + \underline{O_2} \rightarrow CO_2$
The following ratio [2C/N] can be used to calculate the proportion of total BOD, which is due to N

Source	a) Per capita BOD from faeces (kg/day)	b), c) Population number in Exe Estuary Catchment	Cumulative BOD load (kg/day)	d) C/N ratio	Cumulative Nitrogen load (kg/day)
Humans	0.01	377000	5130	20	244
Cattle	0.68	125045	85079	50	1668
Pigs	0.14	45166.7	6146	24	246
Sheep	0.05	302595	13725	30	443
Poultry	0.01	1628488.4	22160	14	1477

Figure 14: Calculated daily organic pollution loads (biological oxygen demand) and loads due to nitrogen from human and livestock faeces produced in the Exe Estuary catchment



8.2 Solutions addressing nutrient pollution

Phosphorus (phosphate)

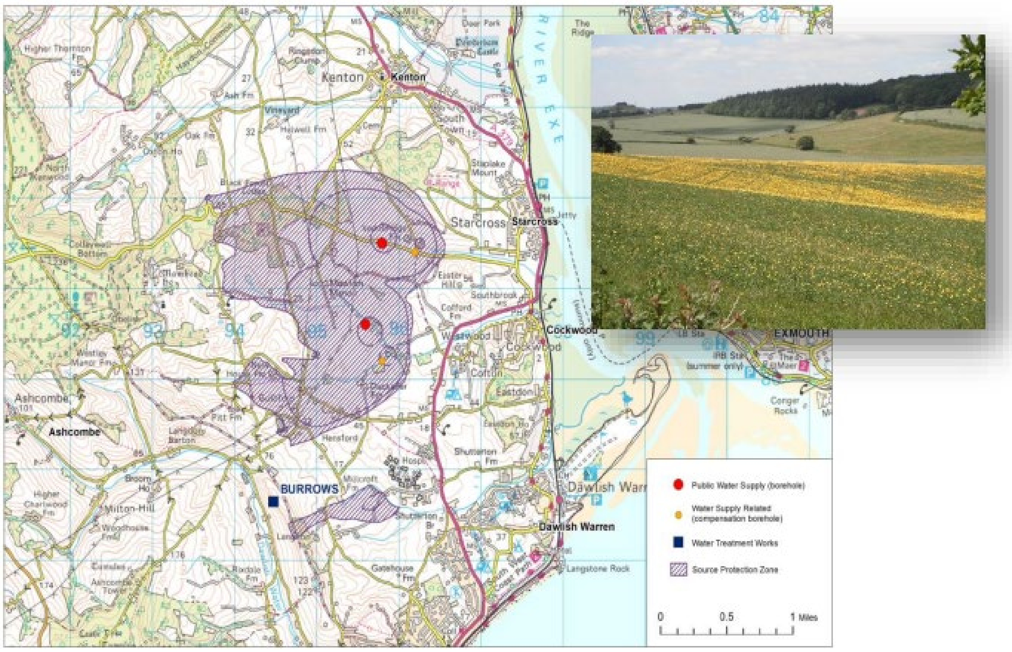
In 2020 South West Water invested substantially in phosphate removal by activated bed Sewage Treatment Works (STWs) (£4.255 million) and filter bed STWs (£4.144 million) (SWW, 2020). No data were available concerning the performance of these asset upgrades at the time of preparing this report.

Nitrogen (nitrate)

Under the Nitrate Pollution Prevention Regulations 2015 farmers operating in Nitrate Vulnerable Zones are required to follow existing rules for: i) using and storing organic manure (manure) or manufactured fertiliser (fertiliser) – e.g. avoiding areas near surface water, boreholes, springs or wells; ii) crop planting and harvesting; iii) managing livestock on farmland/ pasture; iv) managing soils – e.g. calculating the amount of nitrogen available for crop uptake, restricting the timing of ploughing or planting, sowing cover crops, to reduce soil erosion and leaching (DEFRA, 2018a).

Work is being undertaken to reduce the leaching of nitrate fertilisers around the Otter and Cofton Cross (Starcross) drinking water boreholes on the eastern and western sides of the Exe Estuary (**Figure 15**). Through the Environment Agency's 'Diffuse Pollution Pilot Project' and South West Water's Upstream Thinking programme, farms around Cofton and the Otter Valley have implemented cover cropping, integration of fertiliser and manure nutrient supply, and avoidance of slurry and manure spreading at high risk times. Porous light sandy soils in the Otter Valley are particularly susceptible to leaching and nitrate levels are high in the groundwater aquifer (Environment Agency, 2021b). To combat the problem Westcountry Rivers Trust have been trialling a soil conditioning product (ZEBATM), a biodegradable starch polymer which can absorb and retain water over 400 times its original volume.

Figure 15: Water source protection zone for Cofton Cross drinking water boreholes



9 Suspended solids

9.1 Sources

Suspended solids concentrations in the river Exe are due to the erosion of soils and the resuspension of sediments, which increase following heavy rainfall.

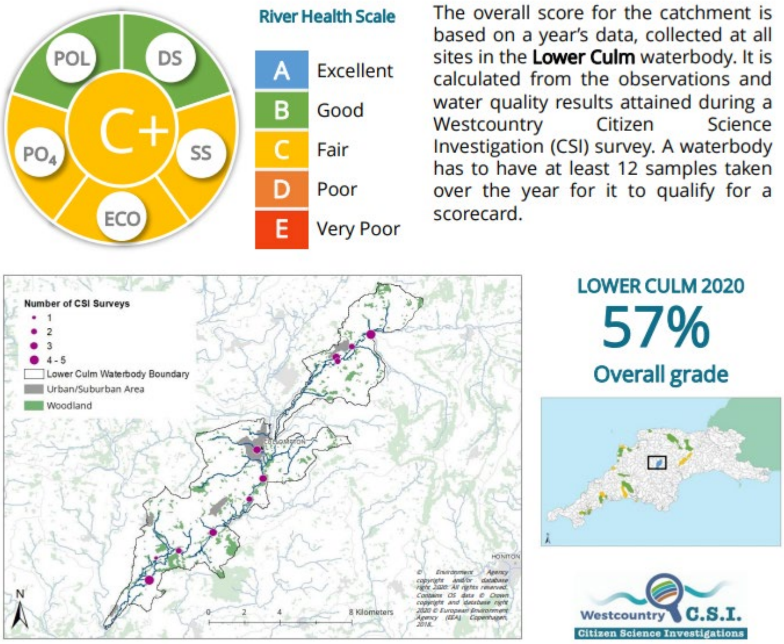
In the Exe main operational catchment suspended solids concentrations have been shown to range considerably from 2-590 mg/L, with mean concentrations of 15.5 and 12.25 mg/L being recorded in 2012 and 2013, respectively (Magdalena et al., 2015). These mean annual concentrations are compliant with a guideline standard of 25 mg/L (annual mean) under the Freshwater Fish Directive (78/659/EEC), prior to the Water Framework Directive, which contains no standards for suspended solids.

Under the East Devon Rural Diffuse Pollution Project Cranfield University showed that: >93% of the land used for maize cultivation in the Culm operational catchment was at high risk of run-off; and 60% was at risk of erosion. Furthermore, a large proportion of farms (19%) in the catchment were identified by the Environment Agency as causing Category 2 (serious) water incidents, with suspended solids concentrations exceeding 500 mg/L (Brown, 2018).

The Lower Culm has been shown to be impacted by elevated concentrations of suspended solids (SS) according to monthly river water sampling and analysis coordinated by Westcountry Rivers Trust's Citizen Science Investigations in 2020 **(Figure 16**).

Figure 16: CSI Score Card for the Lower Culm in 2020

The overall score (C+) is underpinned by sub scores for: Suspended Solids (SS); Phosphate (PO4); Ecosystem health (ECO); Dissolved solids – conductivity (DS); Visible pollution (POL).



9.2 Solutions

Measures to mitigate soil erosion and suspended solids concentrations in the Culm have included establishing crops early in the autumn months, and during dry conditions; planting headland rows and beds across the base of any sloping land; establishing grass (buffer) strips in valleys, or along contours or slopes, or gateways (Brown, 2018).

The Headwaters of the Exe project implemented in Upstream Thinking Phase 2 (2015-2020) has focused on mitigating sediment inputs to the upper Exe catchment (as well as reducing pesticide pollution). As of May 2019, almost 30% of the upper catchment (3,500 ha above the moorland line) has been engaged in Upstream Thinking with physical activities, including establishment of new hedges, farm track management and other works to provide alternative livestock drinking supplies and protect watercourses (Centre for Resilience in Environment Water and Waste, 2021).

10 Metal pollution

10.1 Sources

10.1.1 Pollution from abandoned mines

Post-medieval (post AD1500) iron workings, known as 'Roman Lode' are in evidence west of Simonsbath, such as Wheal Eliza, a former iron and copper mine next to the river Barle. Many other mines were established on Exmoor later in the 19th century across Exmoor to Porlock following the success of the Brendon Hill iron mines. These mines spanned Devon and Somerset and exploited thin lodes of high quality ore (often lying below the water table) to produce significant amounts of copper prior to 1900 (Claughton, 1997; Suirat, 2010). It is worth noting that shafts and spoil heaps litter the moors and are not always marked on maps although most are recorded on the Somerset Heritage Environment Register.

Widespread mine closures at the turn of the 19th/ 20th Century and subsequent flooding and leaching of mine waters into ground waters, rivers and streams, has become a major issue in the UK (Gamble et al., 2020). Metal mines in the ore fields of South West England have been highlighted as particularly problematic, continuing to cause pollution, despite being closed for over a hundred years (Environment Agency 2008a). Pollution from abandoned mines affects 5% of water bodies in the South West river Basin District, with surface waters and groundwater being contaminated with dissolved metals such as iron, lead, copper, zinc or cadmium (Environment Agency 2016b). Tin and the metalloid element arsenic are also recognised contaminants in rivers in Devon and Cornwall (Environment Agency, 2008b). Nevertheless the Exe Estuary catchment is not categorised as highly polluted (Coal Board, 2020) and pollution from abandoned mines is not among the reasons for not achieving good status (RNAG) under the Water Framework Directive (Environment Agency, 2021b).

10.1.2 Sewer discharges and sewage sludge biosolids application to land

Aqueous sewage discharges and storm water discharges containing metals derived from domestic sources and urban road runoff (with metal-containing brake dust and engine oils etc.), and also sewage sludge applied to land can also contribute to metal loads entering the Exe estuary catchment.

10.2 Solutions

Although no-one can be held liable for the pollution from abandoned metal mines, which closed long before legal obligations came in to force in 1999 (Environment Agency, 2008a), some pollution mitigation is being implemented in the SW River Basin District (particularly in Cornwall) via the Environment Agency's Abandoned Metal Mines Programme (Environment Agency, 2016b). Pollution control measures include managing runoff from mine spoil heaps, reducing mine flooding and treating mine drainage water (Environment Agency 2008a).

Controlling urban runoff and sewer overflows is also important for reducing metal pollution. Metals are most likely to settle and accumulate in sewage sludge and DEFRA Guidance on the use of biosolids derived from sewage sludge in agriculture should be followed (DEFRA, 2018c) including regularly testing sludge for concentrations of potentially toxic elements (PTEs): arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, zinc). There are restricted times of application of biosolids to crops, maximum permissible annual rates of application to soil and ~~a~~ maximum permissible concentrations in soil (**Appendix 19**). South West Water has reported 98.7-100% compliance with sewage sludge (biosolids) standards in recent annual reporting periods (2014-2020) (SWW, 2020).

11 Emerging contaminants

11.1 Human pharmaceuticals

11.1.1 Sources

The main source of human pharmaceuticals in UK rivers is excretion into sewer systems and the subsequent discharge of effluent from receiving Sewage Treatment Works (STWs) (Melvin et al., 2016). Pharmaceuticals may also enter watercourses following the application of sewage sludge-derived biosolids to land as fertilizer. Available literature suggests that this risk is medium-low for most pharmaceuticals, with the exception of fluoroquinolone antibiotics (e.g. ciprofloxacin), hormones (e.g. ethinylestradiol) and antimicrobials (e.g. triclocarban, triclosan), which are resistant to conventional sewage treatment (Mejías et al., 2021). These (and other) human pharmaceuticals present an emerging environmental concern due to their increasing use, environmental exposure and also their propensity for eliciting unintended effects in wildlife, such as causing antimicrobial resistance and chronic impacts on biodiversity e.g. via hormone disrupting effects on organism development and reproduction (Tyler and Goodhead, 2010; Ford AT, Le Blanc, 2020). The Water Framework Directive watch list of emerging chemicals of concern contains eight substances/groups, five of which are pharmaceuticals, including: i) macrolide antibiotics (erythromycin, clarithromycin, azithromycin); ii) amoxicillin; iii) ciprofloxacin; and hormones iv) ethinylestradiol; v) estradiol and estrone (EU, 2018).

11.1.2 Solutions

UK Water Industry Research (UKWIR), water companies including South West Water and UK regulatory agencies initiated the Chemical Investigations Programme (CIP) to conduct extensive sewage effluent monitoring to assess the removal efficiencies of different sewage treatment processes and to identify pharmaceuticals that present the highest residual risk to the environment post treatment. Based on available dilution data as many as 890 STW in the UK (~13%) were shown to be at risk of exceeding threshold effect concentrations (T) after mixing of their effluents with receiving river water. Pharmaceuticals most likely to exceed threshold effect concentrations were shown to include the hormones - Ethinylestradiol and Estrone; anti-inflammatory drugs - Ibuprofen and Diclofenac; antibiotics - Azithromycin, Clarithromycin and Ciprofloxacin; the betablocker Propranolol; and the stomach acid treatment Ranitidine (Comber et al., 2018).

Monthly CIP monitoring data for a range of pharmaceuticals (11 in total, including hormones, antibiotics, non-steroidal anti-inflammatory drugs, anti-tension and anti-depressant drugs) in final effluents discharged from Countess Wear STW in Exeter in 2010/11 are presented in **Appendix 20**. The data showed that the hormones - Ethinylestradiol, Estradiol and Estrone and the antibiotics – Erythromycin and Oxytetracycline frequently exceeded their respective threshold effect concentrations (**Figure 17**). Dilution by a factor of ≥10 would be required to ensure no unintended effects in wildlife or build-up of antibiotic resistance; this dilution is only likely to be achieved several hundred meters downstream in the Exe Estuary.

Figure 17: Pharmaceutical concentrations in effluent from Countess Wear Sewage Treatment Works in 2010/11 showing exceedance of threshold effect concentrations

The off-the-chart value for Oxytetracycline in July 2010 was 6 μg/L. Threshold effect concentrations (T) for hormones are "Therapeutic Water Concentrations" (Gunnarsson et al., 2019); Threshold effect concentrations (T) for antibiotics: Erythromycin - Predicted No Effect Concentration (for microalgal growth); Oxytetracycline – Minimum Inhibitory Concentration (for bacterial growth) (AMR Industry Alliance, 2018).

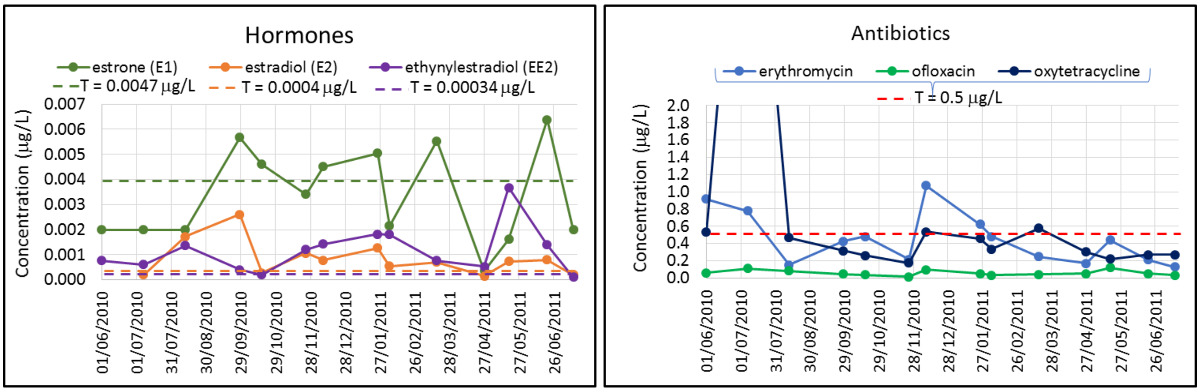


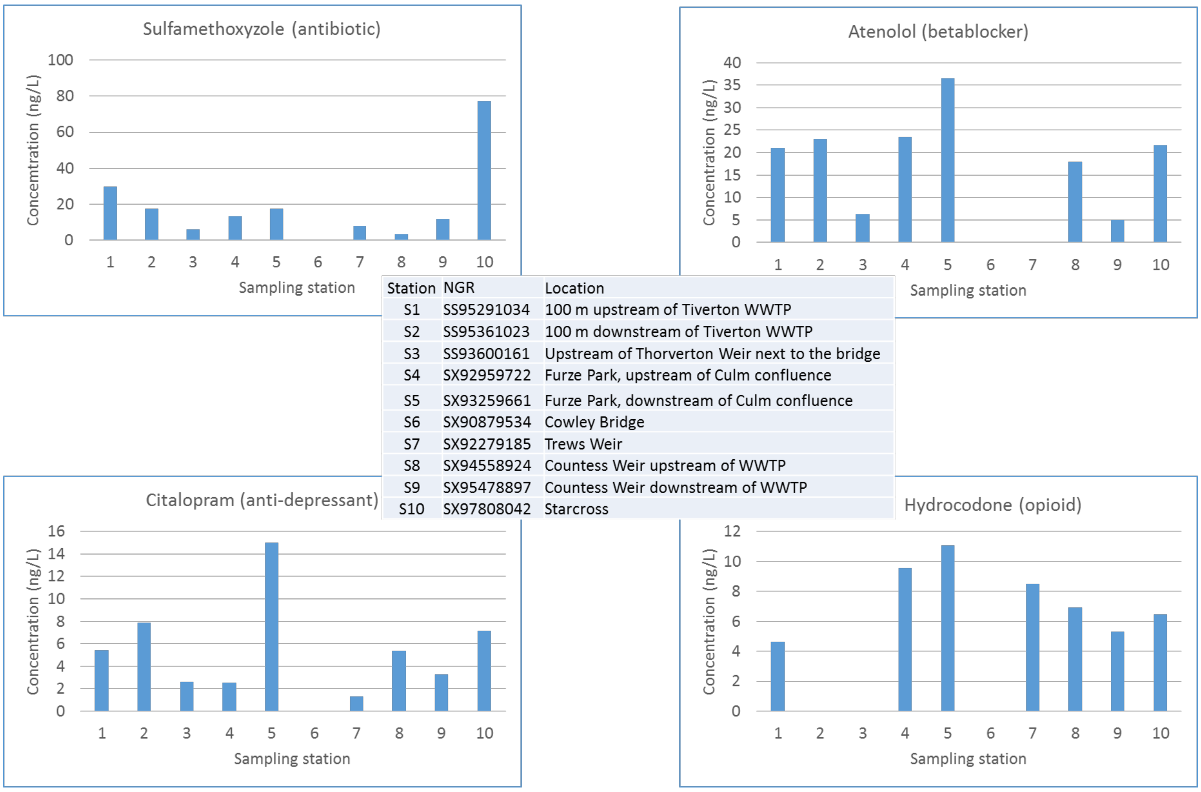
Table 14: Levels of detection of non-steroidal anti-inflammatory drugs (NSAIDs) on Chemcatcher® disks deployed in the River Exe in spring 2013

River water sampling stations	National Grid Coordinates	Mean mass on Chemcatcher® disk (ng)		
		Diclofenac	Ibuprofen	Naproxen
C2) River Exe at Exebridge pumping station	SS93012447	<1	3	4
C5) River Exe upstream of Tiverton sewage treatment works	SS95191104	<1	7	6
C6) River Exe downstream of Tiverton sewage treatment works	SS95381018	2	36	69
C8) River Exe at Northbridge intake	SX93009710	<1	15	30

Spatial variation in concentrations of pharmaceuticals along the river Exe from Dulverton to the intake of Pynes water treatment works in Exeter (**Figure 10**) was demonstrated by Chemcatcher® passive sampling data obtained by Westcountry Rivers Trust in May and June/July 2013 (**Table 14**). The concentrations of three non-steroidal anti-inflammatory drugs (NSAIDS) – Diclofenac, Ibuprofen, Naproxen were generally low (below the analytical limit of detection) in the upper catchment above Tiverton STW (Stations C1-5), and increased by a factor of ~10 at Station C6 (SS95381018) downstream of Tiverton STW. Concentrations remained elevated (3 to 5 times upstream concentrations) at Station C8 - Northbridge intake to the Pynes drinking Water Treatment Plant in Exeter (SX93009710).

Additional spot sampling and analysis of river water was conducted in June 2020 under the South West Environmental and Economic Prosperity (SWEEP) programme (https://sweep.ac.uk/) in collaboration with the Global Monitoring of Pharmaceuticals programme (https://www.globalpharms.org/). Water was sampled from 10 stations (S1 to S10) along the River Exe from above Tiverton STW to Starcross in the Exe Estuary. A total of 58 pharmaceuticals were analysed, of which 19 were detected, albeit at concentrations below threshold environmental effect concentrations (**Appendix 21**). Nevertheless these spatial data identified a number of hotspots. Highest pharmaceutical concentrations in the River Exe generally occurred at the confluence of the River Culm (Station S5 - SX93259661). Concentrations downstream of major Sewage Treatment Works in Tiverton (Station S2 - SS95361023) and Exeter (Station 9 - SX95478897) were not exceptionally high, but concentrations were elevated (particularly for the antibiotic Sulfamethoxazole, but did not exceed minimum selective concentrations - Bengtson Palme Industry Alliance, 2018) in the large water body of the Exe Estuary at Starcross (Station S10 - SX97808042) (**Figure 18**). The elevated concentrations in the estuary may be due to the Kenton and Starcross Sewage Treatment Works (**Appendix 11**) or nearby intermittent discharges e.g. combined sewer overflows.

Figure 18: Pharmaceutical concentrations in the River Exe and Exe Estuary in June 2020.



Station	NGR	Location
S1	SS95291034	100 m upstream of Tiverton WWTP
S2	SS95361023	100 m downstream of Tiverton WWTP
S3	SS93600161	Upstream of Thorverton Weir next to the bridge
S4	SX92959722	Furze Park, upstream of Culm confluence
S5	SX93259661	Furze Park, downstream of Culm confluence
S6	SX90879534	Cowley Bridge
S7	SX92279185	Trews Weir
S8	SX94558924	Countess Weir upstream of WWTP
S9	SX95478897	Countess Weir downstream of WWTP
S10	SX97808042	Starcross

11.2 Veterinary medicines

11.2.1 Sources

Since the Exe Estuary catchment is dominated by improved grassland used for livestock grazing, there is likely to be a significant farming input of veterinary medicines. Many of these medicines are also used as human pharmaceuticals or pesticides and present similar risks to non-target species, including fish, aquatic invertebrates and plants. A high percentage of topically applied veterinary medicines (e.g. ectoparasite treatments, sheep dips) can be washed off the bodies of livestock. Orally administered medicines can also be excreted by livestock. Consequently, there is a high potential for environmental exposure, including contamination of watercourses by livestock that drink from them or graze nearby (Boxall et al., 2002). Veterinary medicines used to treat domestic pets can also enter watercourses directly or via the domestic sewage network. For example, sewage discharges have been shown to cause widespread contamination of English rivers with two commonly used veterinary flea products fipronil and imidacloprid (Perkins et al., 2021).

Prioritisation of veterinary medicines with the greatest potential for environmental impact has been based collectively on the amount used; usage pattern; metabolism; persistence in manure and slurry; sorption to soil/sediment and persistence in the environment; and ecotoxicity (although data are limited in many cases) (Boxall et al., 2002). Within the highest priority group, antibiotics are ranked highest based on sales volume, followed by coccidiostats (for treating protozoan parasites), organophosphate sheep dip chemicals, anthelmintics (wormers), general anaesthetics, ectoparasiticides, antifungal agents, antiseptics and immunological products (**Appendix 22**). The over-use of antibiotics in human and veterinary medicine has been linked to the development of antibiotic resistance, which poses a severe threat to human and animal health. The Highest Priority Critically Important Antibiotics (HP-CIAs) include: Fluoroquinones, 3rd and 4th generation Cephalosporins and Colistin) (Veterinary Medicines Directorate, 2020). Some other veterinary medicines, such as the insecticide Cypermethrin, are also classified as 'Priority Substances' under the Environmental Quality Standards Directive (2008/105/EC) due to their environmental toxicity and therefore require progressive reduction or phasing out (Environment Agency, 2019d). Substances thought to pose the greatest threat are further identified as 'Priority Hazardous Substances', such as the organophosphate insecticide Diazinon, which was banned in the EU and UK 2006 (**Appendix 22**).

Monitoring data confirming the levels of exposure of veterinary medicines in rivers, including the Exe, are limited. Spot sampling and analysis of water from 10 sampling stations in the River Exe and Exe Estuary was conducted in June 2020 under the South West Environmental and Economic Prosperity (SWEEP) programme (https://sweep.ac.uk/) in collaboration with the Global Monitoring of Pharmaceuticals programme (https://www.globalpharms.org/). Six prioritised veterinary medicines (**Appendix 22**) were included in the chemical analysis - the fluoroquinone antibiotics Enrofloxacin, Lincomyacin, the macrolide antibiotics Tilmicosin and Tylosin, the pyrimidine antibiotic Trimethoprim and the anaesthetic Lidocaine. Only Lidocaine was detected, at 4.4-19.7 ng/L, with peak concentrations recorded at Furze Park, downstream from the confluence of the Culm (SX93259661). Cattle were observed paddling in the river at this location during sampling.

11.2.2 Solutions

The veterinary profession and livestock sectors established targets for responsible reductions in the use of antibiotics in the UK (Responsible Use of Medicines in Agriculture Alliance, 2017). The use of Highest Priority Critically Important Antibiotics (HP-CIAs) in food-producing animals (adjusted for animal population size/biomass) has reduced dramatically from 0.65 mg/kg in 2015 to 0.21 mg/kg (-74%) in 2019 (**Table 15**). The dairy and beef sectors exceeded their target of 50% reduction in cattle injectable HP-CIAs, achieving a 72% reduction between 2016 and 2020 (Veterinary Medicines Directorate, 2020).

Table 15: The use of Highest Priority Critically Important Antibiotics (HP-CIAs) in food-producing animals (adjusted for animal population size/biomass) in 2015 to 2019

	2015	2016	2017	2018	2019	Compared with 2015
Fluoroquinolones (mg/kg)	0.35	0.23	0.16	0.15	0.13	↓ 61%
3rd/4th generation cephalosporins (mg/kg)	0.17	0.14	0.11	0.06	0.03	↓ 82%
Colistin (mg/kg)	0.12	0.02	0.0006	0.0007	0.0002	↓ 99.9%
Total HP-CIAs (mg/kg)	0.64	0.38	0.26	0.21	0.17	↓ 74%

The total amount of antibiotics (all categories, without adjusting for animal population size/biomass) has also reduced over the same period has also reduced dramatically (by -44.5%). The greatest reduction has been achieved for pigs and poultry (-55%), for which the largest volumes of antibiotics are used (**Table 16**).

Table 16: Total amount of active ingredient of antibiotics sold per year in the UK for the treatment of different livestock (tonnes) in 2015 to 2019

Livestock	**2015**	**2016**	**2017**	**2018**	**2019**
Pigs and poultry only	214.2	127.4	97.3	99.7	96.4
Pigs only	49.4	39.7	33.0	23.8	28.5
Poultry only	38.0	26.5	15.0	12.9	14.9
Cattle only	14.1	15.3	13.7	13.0	12.0
Fish only	0.71	1.6	3.4	1.6	3.1
Multiple food-animals (incl. sheep)	29.2	23.4	29.3	27.5	24.4
Companion animals (excl. horse)	12.7	14.7	14.4	13.4	12.5
Horse only	13.4	14.9	6.7	2.4	2.1
combination of food- and non-food-animals	36.5	32.3	35.3	32.1	38.3
Total		**408.2**	**295.8**	**248.1**	**226.4**

Following pollution incidents arising from cypermethrin in sheep dip, the UK government temporarily suspended marketing authorisations of these products in 2006 and these authorisations were withdrawn by manufacturers in 2010 (Environment Agency 2019d). Cypermethrin products are used on cattle and sheep and applied topically as 'pour-on' products. Between 2010 and 2016 the amount of cypermethrin sold for use as a veterinary medicine in the UK was in the range 7000 to 10000kg, rising to over 13,000kg in 2017.

The risks and trends of veterinary medicine use in the Exe Estuary catchment have also been receiving attention in the Headwaters of the Exe project, within the third phase of Upstream Thinking (2020-25). Faecal egg counting is being used to reduce a farm's reliance on wormers by targeting veterinary medicine use to times when it is needed, helping to save cost, reduce chemicals in the environment and to manage wormer resistance. The project is also considering undertaking monitoring of veterinary medicines in the Exe catchment to understand the importance of agriculture livestock and other sources of chemicals, such as domestic sewage and domestic pets (Farming and Wildlife Advisory Group South West, 2021).

12 Summary

The status of the Exe Estuary catchment with respect to key water quality (WQ) elements is summarised below (**Figure 19**).

Figure 19: Status of water quality elements in the Exe Estuary catchment

Priority substances include mercury and poly-brominated diphenylethers (both with atmospheric input pathways). WQ - Water quality. CSOs - Combined Sewer Overlfows. CSF - Catchment Sensitive Farming.

WQ element	Current status	Trend	Confidence in trend	Source id	Measures needed
Faecal indicators			! ! !		CSO spill reduction Flood management
Priority Substances			! ! !		Chemical use stopped
Pesticides			! ! !		Drinking water protection
Metals			! ! !		Continue to monitor sources
Nutrients			! !		Source controls are reducing algal blooms
Suspended solids			! !		CSF measures for maize cultivation
Pharma-ceuticals	?	?	!		Monitoring of sewage discharges
Veterinary medicines	?	?	!		Monitoring of rivers after administration

Key: Red = poor, Amber = moderate, Green = good, = variable, = no change, = improving
! = low confidence, ! ! = medium confidence, ! ! ! = high confidence

All water quality elements can impact on environmental health to some degree; impacts are likely to be greatest for priority hazardous substances, including mercury and poly-brominated diphenyl ethers (PBDEs), which are currently responsible for the failure to achieve ‘Good’ ecological status under the Water Framework Directive. Pesticides, particularly acid herbicides used to control broad-leaved weeds on arable land and grassland, are also frequently detected in water bodies throughout the non-tidal catchment. Impacts on aquatic plants (macrophytes and algae) are mitigated to some extent by ‘first flush’ episodes during which short-lived spikes in herbicide concentrations occur in rivers following heavy rainfall events. Faecal pollution, indicated by faecal indicators (*E. coli* and intestinal enterococci) is also associated with heavy rainfall, due to land runoff and sewer overflows. Impacts are mainly due to precautionary restrictions around the use of bathing waters and the sale/consumption of shellfish from estuary and coastal waters – to protect human health. Faecal indicators may not always reliably reflect concentrations of bacterial and viral pathogens that cause human illness, nevertheless the presence of raw sewage in rivers is not socially or environmentally acceptable and is currently one of the biggest environmental issues in the public eye. Metal, nutrient and suspended solids concentrations currently present no major causes for concern, although there are isolated hotspots in the West Exe and Creedy for nutrients and in the Culm for nutrients and suspended solids. Metal pollution from mine water in the upper Exe around Exmoor appears to be minimal. Water quality status is uncertain with respect to human pharmaceuticals and veterinary medicines; more monitoring data are needed to assess the impacts of sewage discharges and inputs from farmyard steadings.

The issue of plastic pollution has not been addressed in this report.

13 Conclusions and recommendations

There are a number of anthropogenic pressures on water quality in the Exe Estuary catchment. The main sources of contamination are diffuse agricultural runoff containing pesticides, nutrients and faecal contaminants and urban waste water (sewage) discharges carrying similar chemical and microbial mixtures. The relative importance of these two major sources varies seasonally and spatially across the catchment depending, for example, on farming activity and rainfall.

Climate change in the form of increasingly frequent high rainfall events during winter months is adding to pressures on water quality by driving increased land runoff and sewer overflows. Although these pressures on water quality extend across much of catchment, there are some notable hotspots in the West Exe and Creedy (e.g. where soils are highly porous with high potential for leaching of nitrate fertilzers) and in the Culm (e.g. where maize cultivation leaves soils exposed and eroded by winter rain).

Activities (agricultural and urban), which impair water quality and flood management upstream in the catchment have the potential to impact negatively activities all the way downstream, including shellfish aquaculture, tourism and conservation (the Exe Estuary hosts one of the largest populations of overwintering water birds in the UK). Contaminant inputs which are closer to these sensitive receptors have greater potential for impact.

The impacts of continuous sewage treatment works (STW) discharges are not notably greater for the larger population centres of Cullompton, Tiverton and Exeter, since treatment processes are scaled in proportion to the populations served.

The impacts of intermittent discharges from storm tank overflows (STOs) and combined sewer overflows (CSOs) are likely to be more significant around the larger population centres. However, data on their operation beyond spill frequency (i.e. spill volumes, time and duration of each spill) are lacking – these data are essential for confirming if overflows correspond with high rainfall and runoff. Progressive reductions in these intermittent discharges of untreated sewage and impacts on water quality will be implemented by water companies, including South West Water under the Environment Act (2021).

Water quality monitoring is key to assuring compliance with environmental policy and legislation, including the updated Environment Act (which calls for progressive reduction in intermittent sewage discharges) and the 25 Year Environment Plan to deliver clean and plentiful water (e.g. through Environmental Land Management Schemes and the new Farming Rules for Water). There are major benefits in collating monitoring data and predictive models from disparate sources (regulatory, research and community initiatives) to build a bigger, more coherent picture, as we have attempted to do in this report. Additional benefits in terms of monitoring efficiency and data comparability would be gained by aligning water and associated environmental sampling and analysis spatially and temporally.

There is a need to better quantify risks to human and environmental health from faecal-borne pathogens, including those with antibiotic (antimicrobial) resistance. There is also an urgent need to quantify concentrations of antibiotics in the environment and to establish the importance of human pharmaceuticals in sewage and sewage sludge versus veterinary medicines, which are also present in sewage, but also used widely in the treatment of livestock within the catchment.

There is a need to better integrate water quality and flood management, since water quality and flood risks are intrinsically linked. This has been highlighted in the most recent South West River Basin Management Planning review https://www.gov.uk/government/collections/draft-river-basin-management-plans-2021#south-west-rbd.

Increasingly frequent storm conditions and sea level rise have the potential to impact directly on the Exe Estuary and coastal zone by scouring sediments and shellfish beds. Major storms in 2013/14 removed a large proportion (>99.9%) of wild mussels in the Exe Estuary and prompted the installation of coastal defences at Dawlish Warren, which have subsequently been eroded by long-shore drift, carrying sediment towards the mouth of the estuary. The increasing sediment loads in the estuary have halted the relaying and farming of mussels leading to both economic and environmental impacts, including reducing habitat and food availability for estuarine bird and fish populations.

Estuarine and coastal shellfish are sensitive receptors, indicators (sentinels) and regulators (bio-remediators) of water quality, as well as highly sustainable food sources. If the shellfish production industry is to flourish, there is an urgent need to give it the same kind of support and financial incentives being offered to terrestrial-based food production from agriculture.

Maintaining and improving water quality in the Exe Estuary catchment will bring numerous ecosystem benefits beyond food production and tourism. These services and benefits need to be properly evaluated, so that remedial measures can be targeted most effectively.

14 Acknowledgements

This work was funded by the Natural Environment Research Council's Regional Impact from Science of the Environment (RISE) initiative, Grant NE/P011217/1: South West Partnership for Environmental and Economic Prosperity (SWEEP). The authors are very grateful to advice, data and information provided by Amy Binner (University of Exeter Business School), Simon Browning (Westcountry Rivers Trust), Rob Lamboll (Natural England), Anna Gocher (South West Water) and David Smith (South West Water).

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