Sewage-related contaminants in Isles of Scilly groundwater: concentrations, spatial distribution, sources and risk

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Executive summary

On the Isles of Scilly, many sewage discharges are located close to abstraction boreholes. The Islands have recently become subject to the Environmental Permitting Regulations, 2010. Between November 2015 and January 2016 the Environment Agency took samples from 55 boreholes and wells to help to assess the scale of regulation needed and for use in the Water Framework Directive groundwater quality tests.

The main results of the study are:

- Above Drinking Water Standard concentrations of all sewage indicator parameters but boron were recorded
- Nitrate and bacteria showed the most widespread elevated concentrations
- The most impacted islands were St Martin's, St Mary's and St Agnes
- Nitrate concentrations on St Mary's and St Agnes are sufficiently elevated to cause failure of the Water Framework Directive General Chemical Assessment if each island is assessed as a separate Groundwater Body
- Elevated nitrate, bacteria and orthophosphate are likely to result from agricultural land use in addition to sewage discharges
- A significant number of the lower nitrate concentrations were recorded in areas which are uninhabited or where there are few septic tanks
- Further sampling is recommended, in summer, when dilution from rainfall and recharge will be lower and the volume of effluent will be higher
- Further sampling should include additional determinands which are indicative of sewage effluent, e.g. caffeine
- The results of this study indicate that improvements to sewerage systems would be beneficial

Nitrate is the main contaminant of interest to the Environment Agency.

Contents

1. Background

The Isles of Scilly comprise 5 inhabited islands, and a large number of uninhabited islands. St Mary's is the main inhabited island. The other inhabited islands are St Martin's, St Agnes, Tresco and Bryher.

The Isles of Scilly are dependent upon groundwater for water supply. There are few surface water courses on the islands, and these are not abstracted from. The Council of the Isles of Scilly provides a water supply on St Mary's, which comes from groundwater and a desalination plant. The Council also supplies Bryher, from groundwater abstraction. The Duchy of Cornwall operate some groundwater abstractions on St Martin's and St Agnes. On Tresco, all water supply is provided from groundwater by Tresco Estate. A great number of private abstractions also exist across the islands, supplying individual households or groups of households.

The Council of the Isles of Scilly operates a mains sewer network on the western side of St Mary's. Most properties on Tresco are connected to mains sewerage, leading to a treatment plant which discharges to the sea. Aside from these mains sewers, sewage effluent across the islands is treated by septic tanks and discharged to ground. There are a great number of effluent discharges, and many of them are close to water supply abstraction boreholes.

Prior to 2010, the Isles of Scilly were exempt from UK environmental legislation, including the discharge to ground of sewage effluent. This situation was ended in 2010 with the introduction of the Environmental Permitting Regulations.

To help to assess the scale of regulation needed, and to gather information for the Water Framework Directive groundwater quality tests, the Environment Agency took samples from 55 abstraction boreholes and wells across the 5 inhabited islands. This was done between November 2015 and January 2016.

2. Report Purpose

To describe the distribution of elevated contaminant concentrations across the islands, and to assess the likely causes and the risk.

3. Geology, Hydrogeology, hydrochemistry and land use

3.1. Desk study information

The Isles of Scilly are located 45km to the west of Land's End. These granite islands are part of the Cornubian batholith (a line of igneous intrusions), which begins at Dartmoor in Devon, and extends through Cornwall.

According to Watkins, 1999, 'the upper surface of the granite has been very highly weathered, by glacial processes, into a permeable sandy material or head, known locally as Ram'. Over some lower-lying parts of the islands, the granite head is overlain by blown sand, which is also very highly permeable.

The islands are characterised by a general absence of streams (except within the Higher and Lower Moors SSSIs). This indicates that there is minimal runoff and that residual rainfall (after evapotranspiration) infiltrates the drift or bedrock (ESI, 2012). The high bedrock permeability is due to the highly fractured nature of the granite. Groundwater flow through the fractures is likely to be rapid. Fracturing is most highly developed in the upper parts of the granite. The majority of groundwater flow is therefore fairly shallow. Groundwater flow paths are likely to be short and to follow the topography, from the higher land towards the centre of the islands towards the sea, where discharge occurs.

The Rural Payments Agency 'CLAD' dataset includes a very brief description of land use. This is shown in Figure 39.

The land use data show permanent pasture around the perimeters of most of the islands. Further inland, most islands have a mix of 'other eligible crops', permanent pasture, 'other agri-environment scheme' and temporary grass. Some significantly-sized areas are lacking in data.

The land use on Tresco is different to that on the other islands. Large areas around the perimeter of the island are in 'other agri-environment' schemes. Inland, there are some fairly large areas of 'non-agricultural usage'.

3.2. Field study information

Concurrent with the chemical sampling, the depths of the boreholes and the depths from the ground surface to groundwater within them were measured. The groundwater depths recorded at some sample points will have been affected by pumping in those abstraction boreholes.

3.2.1. Unsaturated zone thickness

Figure 35 shows the unsaturated zone thicknesses estimated using the measured groundwater depths below the ground surface, and the topographic elevations taken from the 1: 25 000 scale map (note, however, that in fractured aquifers the groundwater table may not be continuous in the way that it is in aquifers of high matrix porosity, e.g. sandstone). The unsaturated zone at the measured locations is generally thinnest on Tresco (up to 4.7m). This is probably due to the lower-lying ground surface at these sample points. On St Martin's the unsaturated zone exceeds 20m at several points on the high ground on the northern side of the island. The unsaturated zone at the disused Council Airport borehole (sample point code 8221GW45), in an elevated position on St Mary's is 17.3m.

3.2.2. Groundwater level contouring

Groundwater level contours (piezometric contours) were produced in 'ArcMap', using linear interpolation. Groundwater flow can be inferred by drawing 'flow lines' at right angles to the contours, from the highest contours towards the lowest. The contours produced for St Martin's and St Agnes are shown on Figures 40 and 41. Due to the limited number of data points on Bryher, Tresco and St Mary's, it was not possible to produce useful piezometric contours for these islands.

The contours produced for St Martin's show an elevated area around Higher Town, with groundwater levels reducing with distance towards the coast, and towards the western end of the island. This is a roughly similar pattern to the contouring produced by Watkins (2000).

The piezometric contours produced for St Agnes show an elevated area in the central/western part of the island, with groundwater levels reducing from here towards the northern and eastern coasts. Watkins' contours showed this elevated area being located more towards the centre of the island, corresponding to the topographic high point, and indicate radial groundwater flow from this point towards the coast. Watkins' contours are more detailed, having been produced from a larger number of data points.

3.2.3. Borehole depths

Figure 36 shows the borehole depths (where available, borehole depths were taken from Watkins' 1999 study rather than being re-measured). Boreholes serving a hotel, a water distribution network and the Council public water supply are amongst the deepest on the islands (up to 40m deep). One private supply on St Mary's is 60m deep.

3.2.4. Water type

Figure 38 is a Piper plot, which shows the percentage distribution of the major ions in the groundwater samples. Piper plots can be used to identify hydrochemical facies or water 'type'. Recharge water (from rainfall) rapidly forms bicarbonate-type water upon contact with the ground. The longer that groundwater resides in an aquifer, the more mineralised it becomes. A sequence of hydrochemical evolution generally starts with calcite dissolution in recharge areas, producing a calcium-bicarbonate dominated water type (Selinus et al, 2005). Further from recharge areas, sodium bicarbonate waters can be found, indicating deep groundwater, influenced by ion

exchange. In coastal areas, sea water increases the Total Dissolved Solids concentration and the water type changes to sodium chloride.

The positions in which the water samples plot on Figure 38 clearly show a sodium-chloride water type. This reflects the marine influence (sea spray/sea salts in precipitation/saline intrusion) on the groundwater.

Figure 37 shows the water types of the individual samples across the islands. The majority of samples were of sodium-chloride type. A significant number were of sodium-magnesium-chloride type. This is also understood to be reflective of marine influence. There appears to be no particular pattern to the distribution of water types across the islands. It is noticeable, however, that Tresco has only sodium-magnesium-chloride and sodium-calcium-magnesium-chloride water types.

Piper plots can be used to infer information on groundwater residence time in an aquifer and therefore the rapidity of flow. However, it seems that the marine influence on the Isles of Scilly groundwater is dominant to the extent that it masks any other ionic composition information that could otherwise have been gleaned from the analysis.

4. Sampling methodology

Groundwater from 55 abstraction boreholes and wells across the 5 inhabited islands was sampled between November 2015 and January 2016. These boreholes and wells form a small subset of the total. They were chosen to reflect groundwater quality at a range of distances from septic tank discharges.

Disposable plastic bailers were used to obtain the samples from the boreholes and wells, except in a small number of cases, where samples were obtained from the abstraction pipework.

The samples were analysed at the Environment Agency's Starcross laboratory for the following determinands:

Alkalinity to pH 4.5 as CaCO3	Conductivity at 20 C	Oxygen, Dissolved, % Saturation
Alkalinity to pH 8.3 as CaCO3	Conductivity at 25 C	Oxygen, Dissolved, % Saturation
Aluminium	Copper	pH
Ammoniacal Nitrogen as N	Enterococci: Intestinal: Confirmed: MF	pH
Antimony	Enterococci: Intestinal: Presumptive: MF	pH : In Situ
Arsenic	Escherichia coli : Confirmed : MF	Potassium
Barium	Fluoride	Silica, reactive as SiO2
Beryllium	GCMS Scan : Semi-Volatile Scan	Silver
Bicarbonate as HCO3	Iron	Sodium
Boron	Lead	Strontium
Bromate	Lithium	Sulphate as SO4
Bromide	Magnesium	Temperature of Water
Cadmium	Manganese	
Calcium	Molybdenum	Tin

Carbonate as CO3	Nickel	Titanium
Chloride	Nitrate as N	Turbidity
Chromium	Nitrite as N	Vanadium
Clostridium : Sulphite reducing : Presumptive : MF	Nitrogen, Total Oxidised as N	Zinc
Cobalt	Orthophosphate, reactive as P	

Of these, the following chemical species can be used to indicate sewage contamination: Ammoniacal nitrogen, nitrate, bacteria, boron, phosphate, chloride, sodium, calcium, sulphate.

These do not exclusively reflect the impacts of sewage discharges, however. Ammoniacal nitrogen and nitrate also result from animal manure and general decay of waste (e.g. landfills and composting). Bacteria (e.coli, enterococci and clostridium in this study) are present in both human sewage and animal manure.

Phosphate is also used as a fertiliser. Chloride and sodium are also found in sea water, which can enter aquifers close to the coast. Boron can occur naturally, but can also be found in washing powders.

In situ determinands (temperature, pH, electrical conductivity and DO) were measured using a calibrated and Quality Assured hand held YSI meter.

Logistical difficulties meant that samples were not refrigerated after collection. This should be borne in mind when reviewing the bacteria results.

The boreholes and wells were not purged before the samples were taken. However, since the majority of them were frequently used for abstraction, groundwater from the aquifer will have been drawn into them.

Raw, untreated groundwater was sampled and analysed for this study. The consequences for drinking water supply depend upon the individual supply arrangements and treatment in place.

Historical data on chemical concentrations were also obtained for the wells and boreholes operated by the Isles of Scilly Council and the Duchy of Cornwall. These were compared to the Environment Agency sampling results.

5. Contaminant concentrations: results and discussion

The distributions of selected determinands are shown in Figures 1 – 8. With the exception of bacteria results, where determinand concentrations were recorded as being 'below the limit of detection', their concentration has been plotted on the figures as being equal to the detection limit.

5.1. Nitrate

The Drinking Water Standard (DWS) for nitrate as N is 11.3 mg/l. The Water Framework Directive (WFD) Threshold Value (TV) is 8.5 mg/l.

Figure 1 shows that nitrate concentrations above the DWS and TV were recorded in the samples taken from St Martin's, St Mary's, and St Agnes.

5.1.1. Nitrate on St Mary's

See Figure 1a.

Of the 6 samples, 3 showed nitrate concentrations above the TV, and one showed a concentration above the DWS. The concentrations of these 4 ranged between 9.44 mg/l N and 17.1 mg/l N. 3 of these are towards the north of the island. The fourth is the sample from the Council abstraction 'Aunt Joaney's Well' (8221GW01), which is located in the Lower Moors area of the island, close to Moorwell former landfill.

Some of the information collected on the points whose nitrate concentrations exceeded the standards is compared below:

Site name	Nitrate concentration (mg/l)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW38	9.44	886	-	20.5	9.9
8221GW13	11.2	437	Bulb fields and cattle	39.6	9.3
8221GW60	*17.1*	*1050*	*Bulb fields and cattle*	*18*	*11.5*
8221GW01	10.6	523	Wetland with some cattle grazing	-	-

The sites at which elevated concentrations of additional sewage-related contaminants were also recorded (discussed later in this report) are shown in blue italics.

St Mary's was the island on which the largest proportion (66%) of the sample points showed elevated nitrate concentrations.

See Table 1 for full details of information collected on all sample points.

The information held by the Environment Agency indicates that none of the sample points whose nitrate concentrations exceed the TV are within 50m of a septic tank. However, the information on septic tank locations on St Mary's is incomplete. The sewerage network on St Mary's is limited to the main areas of population on the western side of the island. It is assumed that on the eastern part of the island, all properties discharge sewage effluent via septic tanks or via package treatment plants serving multiple properties. The majority of the sample points were on the eastern side of the island.

Aside from 8221GW01, the sample points at which elevated nitrate was recorded are located at farms. It is assumed that these will be inhabited and therefore will have septic tank discharges. The elevated nitrate concentrations recorded may result from both sewage discharges and agricultural inputs. The land use of bulb fields and cattle at 8221GW13 and 8221GW60 may contribute to the elevated nitrate concentrations recorded there.

GCMS analysis was carried out on the groundwater samples from St Mary's to indicate the presence of pesticides. Where pesticides occur together with elevated nitrate, this could indicate groundwater flow from agricultural areas and an agricultural source of the nitrate.

GCMS analysis showed an approximate concentration of 2.1 ug/l of 2,6 dichlorobenzamide (herbicide) at 8221GW13.

For Aunt Joaney's Well (8221GW01), the GCMS analysis showed approximately 0.005 ug/l of N, N Diethyl-m-toluamide, which is an insect repellent. It also showed approximately 0.003 ug/l atrazine, a herbicide (which has a history of usage to control vegetation on roadsides and at amenity sites).

Although elevated nitrate concentrations can be associated with landfills, SLR, 2009 (referenced in ESI, 2012) state that under normal pumping conditions, the cone of depression of Aunt Joaney's Well is not expected to extend as far as the Moorwell former landfill.

5.1.2. Nitrate on St Martin's

Of the 26 samples,one showed a nitrate concentration above the TV and 3 showed concentrations above the DWS. The concentrations of these four ranged between 9.28 mg/l N and 22.9 mg/l N. These elevated concentrations were recorded on the eastern half of the island.

Some of the information collected on the points exceeding these standards is compared in the table below.

Site name	Nitrate concentration (mg/l)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW46	11.7	120	In field used for grazing one horse	43	17.08
8221GW23	*9.28*	*70*	*Flower field*	*28.4*	*9.6*
8221GW53	22.9	37	Grassed field	39.7	10.7
8221GW22	*16*	*38*	*Narrow grassed field. Used for flower growing?*	*25.65*	*6.93*

Of the 4 sample points whose nitrate concentration exceeded the standards, 2 are within 50m of a septic tank. These are the 2 most easterly of the 4 points. These 2 points recorded the highest nitrate concentrations on St Martin's.

5.1.3. Nitrate on St Agnes

See Figure 1c.

Of the 13 samples, 4 showed nitrate concentrations above the TV and 5 showed concentrations above the DWS. The concentrations which exceeded the standards ranged between 8.68 mg/l N and 30.1 mg/l N. The more elevated concentrations were recorded towards the north and west of the island.

Some of the information collected on the points at which the standards were exceeded is compared below. 4 of these points are within 50m of a septic tank.

Site name	Nitrate concentration (mg/l)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW30	30.1	17	Cattle grazing	37.5	9.8
8221GW08	21.2	70	Cattle grazing	42.8	11.4

8221GW09	12.3	71	Cattle grazing	22.8	8.22
8221GW27	10.4	65	Cattle grazing	21.3	3.83
8221GW06	12.8	32	garden	5	3.66
8221GW33	21.4	40	garden	30.48	7.9
8221GW29	9.17	37	Grassed field	29	11.93
8221GW21	8.68	130	Field used for hay. Cattle in field occasionally, and in nearby fields	27.4	9.82
8221GW31	*8.89*	*71*	*Grassed field*	*28.7*	*6.64*

Three significantly elevated (over 20 mg/l as N) nitrate concentrations were recorded on St Agnes. Figure 1c shows that there are clusters of septic tanks on this island. The information gathered during the sampling exercise shows that much of the land is used for cattle grazing. The elevated nitrate concentrations on this island are likely to be due to a combination of sewage and agricultural inputs.

5.1.4. Nitrate on Tresco and Bryher

See Figure 1d.

All recorded concentrations were below the TV and DWS.

5.1.5. Nitrate across the Islands

Figure 39 shows the Environment Agency nitrate sampling results plus the most recent nitrate concentrations recorded by the Isles of Scilly Council and Duchy of Cornwall. From this figure it is noticeable that on St Martin's, a large number of the least elevated nitrate concentrations (0-5 mg/l as N) were recorded on the northern/north-eastern side of the island, which is not inhabited and whose land use is mainly permanent pasture. According to the piezometric contours (Figure 40), these points of lower nitrate concentration are generally not down hydraulic gradient from septic tanks. In contrast, elevated concentrations of some contaminants associated with sewage discharge appeared to be clustered around the settlement of Higher Town.

Similarly, on Bryher (Figure 39), the public water supply boreholes which were sampled are located in an area away from habitation. The nitrate concentrations on Bryher are not elevated. There are only a small number of septic tanks up topographic gradient from the boreholes which were sampled – the majority of septic tanks are on the opposite side of the topographic ridges to the east and south of the abstraction boreholes.

On Tresco, the nitrate concentrations are not elevated. Here there are very few sewage discharges to ground.

At the locations described in the 3 paragraphs above, bacteria concentrations (discussed later in this report) are also generally low – see Figures 3-5 (note, however, that on St Agnes, low bacteria concentrations were often recorded at sample points where nitrate was elevated).

While a number of boreholes on St Martin's, Bryher and Tresco are located away from habitation/septic tanks, on St Mary's and St Agnes most of the abstraction boreholes are located in inhabited areas and close to septic tanks. St Mary's and St Agnes are the only islands whose average nitrate concentrations are sufficiently elevated that they would cause failure of the Water Framework Directive General Chemical Assessment if the islands were assessed as individual groundwater bodies.

Comparing the unsaturated zone thicknesses (Figure 35) to the nitrate concentrations shown in Figure 1 gives an impression that the locations on St Martins and St Mary's at which the greatest unsaturated zone thicknesses were measured correspond to those at which lower nitrate concentrations were measured. However, they also correspond to the less inhabited areas, where there is little influence from septic tanks. Nitrate is conservative (does not breakdown in the presence of oxygen, so its concentration would not be expected to reduce in areas of thicker unsaturated zone. It seems that any connection between unsaturated zone thickness and nitrate concentration may therefore be coincidental.

Comparison of Figure 36 and Figure 1 indicates that on St Agnes, greater nitrate concentrations were recorded at the deeper boreholes. It is not clear whether there may be a link between borehole depth and nitrate concentration on this island. No such correspondence is shown on the other islands.

Nitrate concentrations are likely to vary seasonally. The Environment Agency sampling was carried out in the winter. In the summer the dilution of contaminants in groundwater is reduced, due to reduced rainfall. In addition, the population of the Isles of Scilly increases significantly in the summer, due to visitors. The resident population is approximately 2000, but there are approximately 100 000 visitors over a year, with the majority visiting between May and September. This means that the volume of sewage discharge will increase significantly in summer, and therefore that the concentrations of sewage-related contaminants would be likely to increase (however, set against this, increased plant activity [nitrate scavenging] and an increased soil moisture deficit, preventing flushing to groundwater, may reduce summer nitrate concentrations to some degree [ESI, 2012]).

5.2. Bacteria

The Environment Agency does not currently view bacteria as a groundwater pollutant. Nevertheless, in this study the groundwater samples were analysed for e.coli, clostridium and enterococci. Bacteria in groundwater are indicators of input from sewage discharges and animal wastes. The purpose of analysing for bacteria in this study was to give additional information on the degree of impact on groundwater from sewage discharges and animal wastes. The more elevated the bacteria counts, the more impacted by sewage discharges/animal wastes the groundwater is likely to be.

E.coli can be viewed as evidence of fresh faecal contamination, while clostridium is more resistant, and can indicate historic contamination.

The DWS for e.coli, clostridium and enterococci is 0/100 ml. Figures 3 - 5 show that bacteria counts above the detection limit of 1 CFU/100 ml (for enterococci) and 1 No/100 ml (for E.coli and clostridium) were recorded on every island. The figures indicate that the highest bacteria counts were generally recorded towards the eastern end of St Martin's. Tresco and Bryher showed the lowest counts.

A sub-set of the samples were 'prepped' for DNA analysis of the bacteria to distinguish between a human and ruminant origin. However, the bacteria counts were only high enough (>100/100 ml) for DNA analysis of two of the samples

Logistical difficulties meant that samples were not refrigerated after collection. This should be borne in mind when reviewing the results.

The laboratory 'limit of detection' is set at 1 CFU/100ml (or 1 No/100ml). Because counts exceeded the limit of detection in a large number of samples, the tables in the sections below only show the sites at which more than 10 CFU/100ml or 10 No/100ml were recorded.

5.2.1. Bacteria on St Mary's

See Figures 3a, 4a, and 5a.

There appears to be no particular pattern to the distribution of bacteria counts. The highest value was an e.coli count of 71/100 ml, recorded at the Council's Aunt Joaney's Well (8221GW01). The lowest value was <1.

The table below shows the sites on St Mary's whose bacteria counts exceeded 10/100ml.

Site name	Bacteria count (CFU/100ml or No/100ml)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW45	Clostridium: 54 Enterococci: 16	508	Next to road in grassed field	36.55	17.83
8221GW59	E.coli: 71	142	Marshland. Biobubble 200m away	2.1	0.9
8221GW60	*E.coli: 19*	*1050*	*Bulb fields and cattle*	*18*	*11.5*

In addition to elevated bacteria, 8221GW60 had an elevated nitrate concentration.

As noted in the nitrate section of this report, the distances between the abstraction points in the table above and septic tanks are fairly long. This could indicate that the bacteria recorded on St Mary's are more likely to originate from cattle manure rather than human waste (since the counts were less than 100/100 ml it was not possible to carry out DNA analysis to differentiate between the two). However, as noted previously, we only have very limited information on septic tank locations on St Mary's.

5.2.2. Bacteria on St Martin's

See Figures 3b, 4b and 5b.

13 of the 26 samples showed bacteria counts above 10/100 ml. This is the largest number recorded on any of the islands.

The higher counts appear to be concentrated towards the east of the island, around Higher Town. The highest count was 4400/100 ml clostridium. However, this result is likely to be due to fragments of dead bird in the sample. The next highest count was 818/100 ml clostridium, from a sample in Higher Town. The lowest value was <1.

The table below shows the sites on St Martin's whose bacteria counts exceeded 10/100ml.

Site name	Bacteria count (CFU/100ml or No/100ml)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW37	Enterococci: 48	78	garden	22	14

8221GW12	Enterococci: 22	108	Unused field filled with bracken	8.05	9.95
8221GW23	*Enterococci: 440* *E.coli: 20* *Clostridium: 4400*	*70*	*Flower field*	*28.4*	*9.6*
8221GW26	Enterococci: 36 E.coli: 173 Clostridium: 350	55	Unused field	15.7	14.9
8221GW47	Enterococci: 250 E.coli: 25 Clostridium: 27	30	garden	23.85	4.3
8221GW15	E.coli: 23	106	Field used for grazing one horse	41.8	22.95
8221GW54	*E.coli: 14* *Clostridium 818*	*30*	*Grass/bare soil*	*35*	*4.2*
8221GW52	*Clostridium: 64*	*49*	*garden*	*7.9*	*9.1*
8221GW25	Clostridium: 800	43	garden	4.15	27.8
8221GW22	*Clostridium: 40*	*38*	*Narrow grassed field. Used for flower growing?*	*25.65*	*6.93*
8221GW16	Clostridium: 58	55	Cattle grazing	35	4.5
8221GW17	Clostridium: 153	153	Holiday let	33.5	5
8221GW10	*Clostridium: 41*	*137*	*Cattle grazing*	*35*	*14.5*

Five of the samples in the table above also showed elevated concentrations of orthophosphate/nitrate/ammoniacal nitrogen. These are highlighted in purple text in the table above. Septic tanks are located within 50m of 3 of these abstractions.

DNA analysis on the bacteria sample from 8221GW47 showed neither ruminant nor human bacteriodetes markers. This, together with the fact that the chemical indicators of sewage contamination were below the Drinking Water Standards, may indicate that groundwater in this location is not impacted by contamination from septic tanks.

Figures 4b and 5b indicate that elevated clostridium concentrations on St Martin's are more widespread than elevated e.coli concentrations. Since e.coli is an indicator of recent contamination and clostridium is an indicator of historic contamination, this could possibly be taken as evidence of an improvement in conditions.

5.2.3. Bacteria on St Agnes

See Figures 3c, 4c and 5c.

4 of the 13 samples showed bacteria counts above 10/100 ml. The highest concentration recorded was 36 CFU/100 ml enterococci.

The table below shows the sites on St Agnes whose bacteria counts exceeded 10 CFU/100ml.

Site name	Bacteria count (CFU/100ml or No/100ml)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW10	Clostridium: 27 E.coli: 21 Enterococci: 14	171	Narcissus field	19.51	8.8
8221GW31	*E.coli: 15* *Enterococci: 36*	*71*	*Grassed field*	*28.7*	*6.64*
8221GW32	Enterococci: 14	26	Grassed field	16.95	6.45
8221GW07	E.coli: 200	185	Edge of grassed field – cattle in adjacent field, 0.5 m away.	20.7	6.9

DNA analysis on the bacteria sample from 8221GW07 showed ruminant bacteroidetes markers only. This, together with the fact that the chemical indicators of sewage contamination were below the Drinking Water Standards, indicates that groundwater in this location may not be impacted by contamination from septic tanks. During the sampling visit, cattle were observed very close to this abstraction point.

5.2.4. Bacteria on Tresco

See Figures 3d, 4d and 5d.

The highest result was 12 CFU/100 ml, on the west of the island. This was the only site with a concentration above 10 CFU/100 ml.

The details are shown below:

Site name	Bacteria count (CFU/100ml or No/100ml)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW39	Enterococci: 12	182	Grass surrounding tennis court	25.25	4.65

5.2.5. Bacteria on Bryher

See Figures 3d, 4d and 5d.

The highest recorded count was 1 CFU/100ml.

All the boreholes sampled are operated by the Isles of Scilly Council. These boreholes are located in an uninhabited area, and there are few septic tanks up topographic gradient from them. This may account for the low counts.

5.2.6. Bacteria across the islands

The distribution of elevated and less elevated bacteria counts appears to roughly reflect that of nitrate concentrations.

5.3. Ammoniacal nitrogen

The laboratory analysed for 'ammoniacal nitrogen as N'. Ammoniacal nitrogen is composed of ammonium and un-ionised ammonia. The Drinking Water Standard of 0.5 mg/l is for total ammonia (ammonia and ammonium).

Figure 2 shows that ammoniacal nitrogen was recorded at a concentration exceeding the DWS at only one location. This was on the eastern part of St Martin's. The concentration was 2.07 mg/l.

The details for this site are given below:

Site name	Ammoniacal nitrogen concentration (mg/l)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW54	*2.07*	*30*	*Grass/bare s*	*35*	*4.2*

The groundwater level at this site is fairly close (4.2 m) to the ground surface. The unsaturated zone, in which aerobic conditions may be expected, causing conversion of ammonium to nitrite (briefly) and then nitrate, is therefore of limited thickness. This could be a contributory factor to the high ammoniacal nitrogen concentration at this site. There are, however, several other boreholes and wells on St Martins with similar unsaturated zone thicknesses – see Table 1 for the full information. Note, however, that the nitrate concentration at 8221GW54 was relatively low, at 0.33 mg/l: nitrate concentrations at sites on St Martin's with comparable unsaturated zone thicknesses were generally around an order of magnitude higher than the concentration at 8221GW54. This indicates conversion of ammonium to nitrate at these sites. It may be that the conditions at 8221GW54 are not highly aerobic. This would cause little conversion of ammonium to nitrate. The recorded dissolved oxygen percentage at 8221GW54 was fairly low (34%) compared to the values generally recorded at sampling points across the Scillies – see Figure 9 and section 3.7.

5.4. Orthophosphate

The standard for 'protection of surface waters intended for abstraction for drinking water' (A1 waters) for phosphate is 0.4 mg/l. Figure 6 shows that the only island on which this concentration was exceeded was St Martin's (at 4 locations). The highest recorded concentration was 1.9 mg/l, to the east of Higher Town. 3 of the 4 exceedences were around Higher Town, in the east. One was at Middle Town.

The exceedences recorded on St Martin's are shown in the table below:

Site name	Orthophosphate concentration (mg/l)	Distance from nearest septic tank (m)	Land use	Borehole/ well depth (m)	Groundwater level (m below ground level)
8221GW52	*0.71*	*49*	*garden*	*7.9*	*9.1*
8221GW23	*0.921*	*70*	*Flower field*	*28.4*	*9.6*
8221GW54	*1.09*	*30*	*Grass/bare soil*	*35*	*4.2*
8221GW19	*1.9*	*137*	*Cattle grazing*	*35*	*14.5*

All the sites in the table above also have elevated bacteria counts. The two contaminants occurring together could indicate an influence from sewage effluent. However phosphate is also used as a fertilizer, and bacteria occur in animal manure. In addition to elevated orthophosphate, 8221GW54 also has an elevated ammoniacal nitrogen concentration, and 8221GW23 has an elevated nitrate concentration.

5.5. Chloride

The DWS for chloride is 250 mg/l. Figure 7 shows that concentrations exceeding this value were recorded on all islands except St Mary's. Concentrations recorded from all 4 of the sampled Bryher abstraction points exceeded 250 mg/l. On St Martin's, concentrations of samples from 3 of the sites exceeded the DWS. Two of these sites were on the western side of the island, at Lower Town, and the other was at Higher Town on the eastern side. On Tresco, the sample from one site exceeded the DWS – this site was on the western side of the island.

The smaller islands are likely to experience a greater degree of sea spray/sea salts in precipitation/saline intrusion than St Mary's. It is notable that the chloride concentrations at all the sampling locations on Bryher are above the DWS, while concentrations of other contaminants on this island are not elevated.

It is considered most likely that elevated chloride concentrations from sea water would mask any chloride impacts from waste water. As described in the 'water type' section of this report, analysis of major ion composition showed that the groundwater sampled was predominantly of sodium chloride type, which reflects marine influence on groundwater.

5.6. Boron

The DWS for boron is 1000 ug/l. Figure 8 shows that none of the concentrations at the boreholes sampled exceeded the DWS.

5.7. Dissolved oxygen

Dissolved oxygen percentage can affect the concentrations of contaminants such as nitrate and ammoniacal nitrogen. Figure 9 shows the distribution of dissolved oxygen percentages recorded.

Dissolved oxygen percentages ranged from 4.5% to 91.7%. The majority of recorded concentrations exceeded 40%. The lowest concentrations (up to 55%) were recorded on Tresco.

6. Comparison with Isles of Scilly Council and Duchy of Cornwall data

Figure 14 shows the distribution of nitrate concentrations recorded by the Isles of Scilly Council in December 2015 on St Mary's and Bryher. The concentrations are broadly comparable to those recorded on these islands in the Environment Agency sampling exercise (November 2015 – January 2016) and shown in Figure 1.

Figure 15 shows the distribution of ammonium concentrations recorded by the Isles of Scilly council in November and December 2015 on St Mary's and Bryher. None exceeded the DWS of 0.5 mg/l. This result is very similar to that obtained by the Environment Agency sampling.

Figure 16 shows the distribution of e.coli concentrations recorded by the Isles of Scilly council between October and December 2015 on St Mary's and Bryher. The highest count is 3, which is low compared to the values recorded in the Environment Agency sampling exercise.

Figure 17 shows e.coli data collected by the Duchy of Cornwall for St Martin's and St Agnes in 2012 and 2013 (the most recent data available). All values were zero. The only Duchy supplies sampled in the Environment Agency sampling exercise were one of the Higher Town Community boreholes on St Martins, and Plump Well on St Agnes. The Environment Agency e.coli result was 1 No/100ml. The Environment Agency e.coli result for Plump Well was 1 No/100ml.

Figures 18a and 18b show nitrate data collected by the Duchy of Cornwall for St Martin's and St Agnes in 2012 and 2013 (the most recent data available). The data show a broadly similar pattern to that shown by the data from the Environment Agency 2015 – 2016 sampling exercise.

Time-series contaminant concentration data obtained from the Isles of Scilly Council are shown in Figures 19 - 34. The time period is from around 2002 to 2015.

Figures 19 – 26 show that ammonium concentrations were below the DWS of 0.5 at all Council boreholes and wells except Carrs. The exceedences at Carrs were recorded between 2006 and 2012. More recent data show lower values, below the DWS.

Figures 19 – 26 show that he DWS of 11.3 for nitrate as N has been regularly exceeded at Carrs, Aunt Joaney's Well, Rocky Hill, and Vellans. Rocky Hill shows the highest concentrations – up to around 22 mg/l nitrate as N. The trend at Rocky Hill appears to be declining, though concentrations above 11.3 have been recorded in recent years. Concentrations at the majority of the Council boreholes appear to have been broadly declining since around 2009. None of the nitrate concentrations at the abstraction points on Bryher exceeded the DWS.

E.coli concentrations recorded at the Isles of Scilly Council boreholes and wells are graphed in Figures 27 – 34. The graphs show that recent counts have been below 10. However, earlier results have been in the tens, with occasional spikes in the hundreds.

To summarise this section, nitrate and ammonium concentrations recorded by the Isles of Scilly Council and Duchy of Cornwall were similar to those recorded in the recent Environment Agency sampling exercise. The bacteria concentrations recorded by the Environment Agency were elevated above those recorded by the Isles of Scilly Council and Duchy of Cornwall, however. Concentrations of nitrate at the majority of the Council boreholes appear to have been broadly declining since around 2009.

7. Summary of observations

- The following determinands can be used to indicate sewage contamination: ammoniacal nitrogen, nitrate, bacteria, boron, phosphate, chloride.
- Of these, elevated (above Drinking Water Standard) concentrations of all but boron were recorded

- Nitrate and bacteria showed the most widespread elevated concentrations
- The most impacted islands were St Mary's, St Martin's and St Agnes
- Elevated concentrations of some, but not all, contaminants associated with sewage discharge appear to be clustered around the eastern end (Higher Town) of St Martin's
- Contaminant concentrations recorded on Tresco and Bryher were generally low
- The abstraction boreholes on Bryher are located away from habitation and sewage discharges
- There are only a small number of sewage discharges on Tresco – most properties are connected to mains sewerage, leading to a treatment plant which discharges to sea.
- A significant number of the lower nitrate concentrations were recorded in areas which are uninhabited or where there are few septic tanks
- The elevated nitrate, bacteria and orthophosphate concentrations are likely to be due in part to agricultural land use, in addition to sewage discharges
- Nitrate and ammonium concentrations recorded in the Environment Agency study were of a similar magnitude to those recorded by the Isles of Scilly Council and Duchy of Cornwall. The Environment Agency samples showed more elevated bacteria concentrations, however.
- If each island is assessed as a separate Groundwater Body then the nitrate concentrations recorded are sufficiently elevated to cause St Mary's and St Agnes to fail the Water Framework Direct chemical classification tests (General Chemical Assessment). The 5 islands are currently classified as one groundwater body, however, and on this basis the Isles of Scilly Groundwater Body would pass the tests.
- Elevated ammoniacal nitrogen was only recorded at only one location (on St Martin's). This may indicate that groundwater is generally sufficiently oxygenated to allow rapid conversion of ammonical nitrogen to nitrate.
- On the Isles of Scilly, elevated chloride concentrations are more likely to be due to sea spray/sea salts in precipitation/saline intrusion than to waste water discharge
- Groundwater flow through the fractured granite aquifers of the Isles of Scilly is likely to be rapid, along short flow paths, to discharge to sea. Groundwater is generally fairly highly oxygenated.

8. Conclusions

Analysis of the Environment Agency samples showed elevated concentrations of most of the sewage indicator parameters. These determinands can also indicate agricultural inputs, however, and distinguishing between the two sources has posed a problem in this study. Possible means of overcoming this are described in the recommendations section. However, taking an overview of nitrate concentrations across the islands, it is noticeable that a significant number of the lower concentrations (0-5 mg/l as N) were recorded in areas which are uninhabited or where there are few septic tanks. This could be taken to indicate that, although agricultural inputs are likely to be responsible for a proportion of the impact, the impact from sewage discharges is sufficient to be discernible above this. This suggests that improvements in sewerage systems would be beneficial on the islands whose sample results showed elevated contaminant concentrations (St Mary's, St Agnes and St Martin's). This should be taken into account in considerations relating to a sewerage undertaker for the islands.

The Environment Agency is likely in future to extend its groundwater quality network to the Isles of Scilly. This network would be made up of a number of Isles of Scilly Council, Duchy of Cornwall and Tresco Estate abstraction boreholes. Samples would be taken periodically to ascertain whether groundwater was at 'poor' or 'good' chemical status under the Water Framework Directive , and whether 'measures' were necessary to improve its quality.

9. Recommendations

- The groundwater sampling exercise should be repeated in the summer/autumn because contaminant concentrations are likely to be at their highest at this time of year. The results would therefore show a maximum impact.
- To better understand the sources of the elevated contaminant concentrations (ie sewage or agriculture), analysis of future groundwater samples for substances indicative of a human source, e.g. caffeine and certain pharmaceuticals such as carbamazepine, should be included. The Environment Agency's Starcross laboratory is capable of analysing for both caffeine and carbamazepine.
- In any further sampling exercise it would be useful to carry out DNA analysis on all samples with sufficiently elevated bacteria results. This would also aid in distinguishing between human and animal sources. However, if this testing had been carried out on all of the November 2015 – January 2016 samples whose counts were sufficiently elevated, it would have only added a further 6 results.
- The 5 islands of the Isles of Scilly are currently classified and assessed as a single Groundwater Body for the Water Framework Directive chemical classification. However, a hydraulic connection between the islands is extremely unlikely. The effect of carrying out the analysis for all islands combined would be to average the results giving an overall pass (for nitrate), and obscuring the results of those islands with significantly elevated contaminant concentrations (it would be possible, however, to produce and implement separate action plans for each island, addressing the different issues). Re-classifying the islands as 5 separate groundwater bodies in future is recommended.

10. Figures

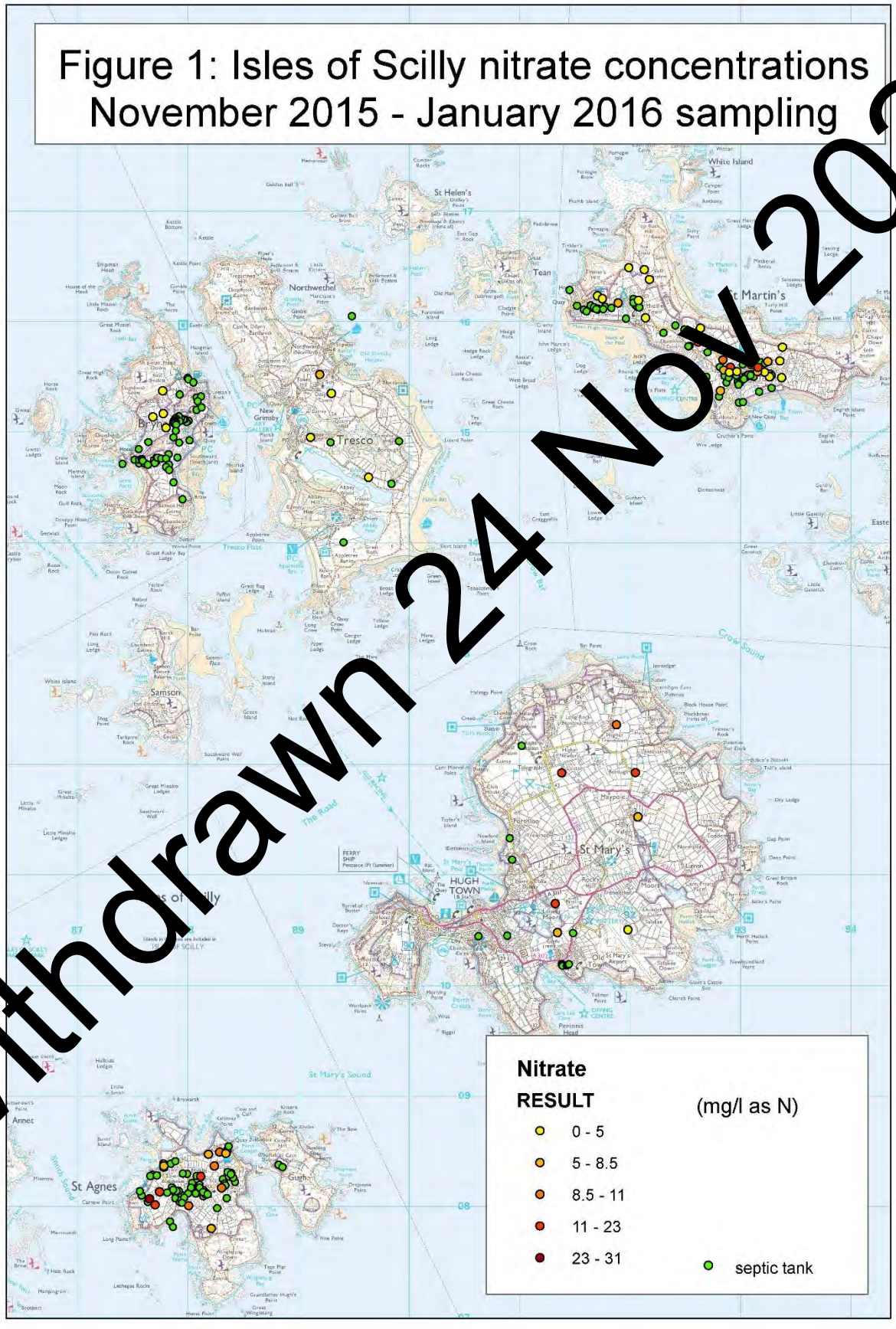
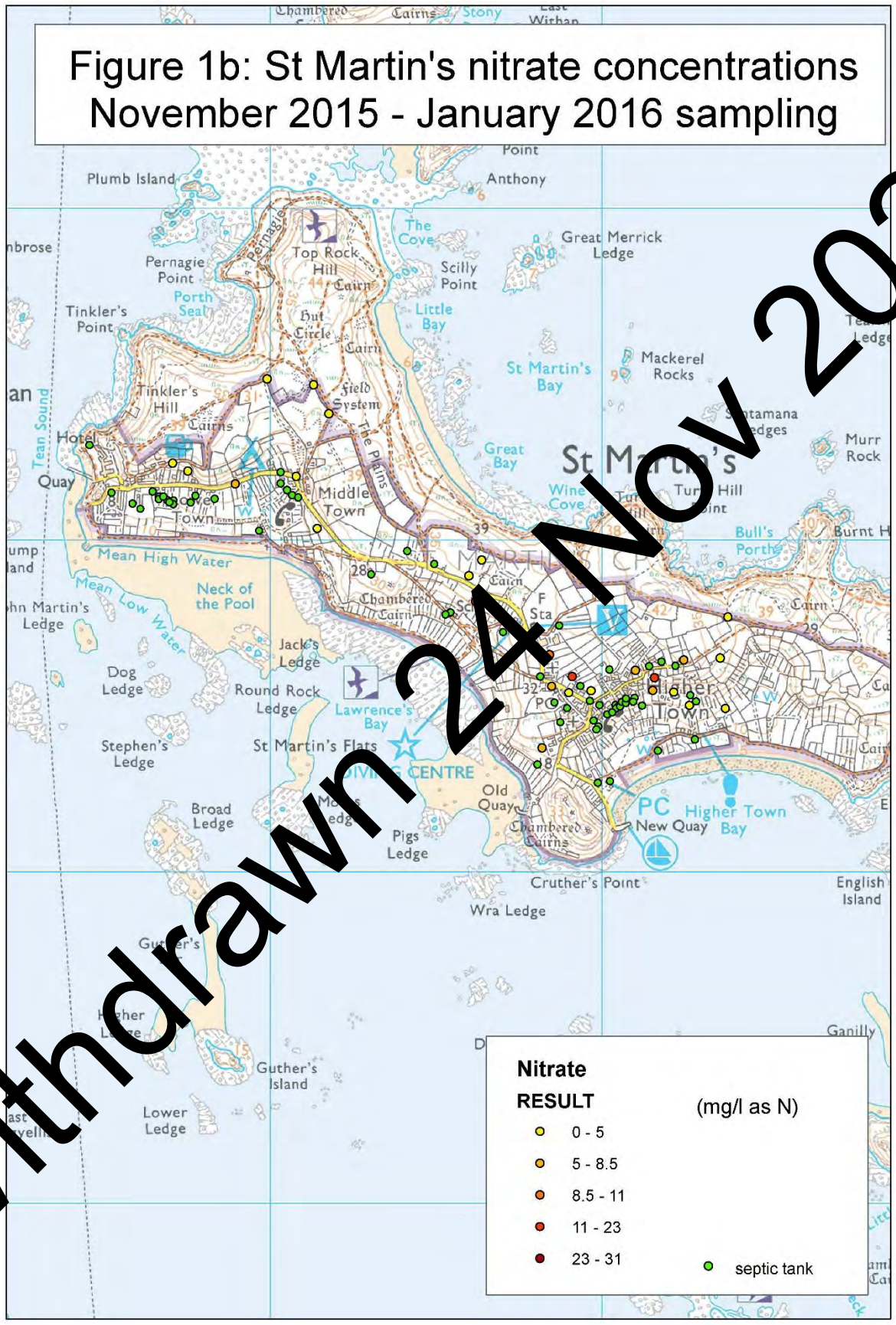



Figure 1a: St Mary's nitrate concentrations
November 2015 - January 2016 sampling
Nitrate
RESULT
(mg/l as N)
0 - 5
5 - 8.5
8.5 - 11
11 - 23
23 - 31
septic tank
FERRY
SHIP
Penzance (P) (Summer)
HUGH TOWN
Porthloo
Old Town
Peninnis Head
Halangy Point
Bar Point
Innisidgen
Carn Morval Point
Taylor's Island
Newford Island
Rat Island
Newman
Barrel of Butter
Doctor's Keys
Woolpack Point
Tolman Point
Church Point
Giant's Castle
Porth Hellick Point
Newfoundland Point
Dropnose Point
The Bow
Inner Head
Outer Head
Withdrawn 24 Nov 2020



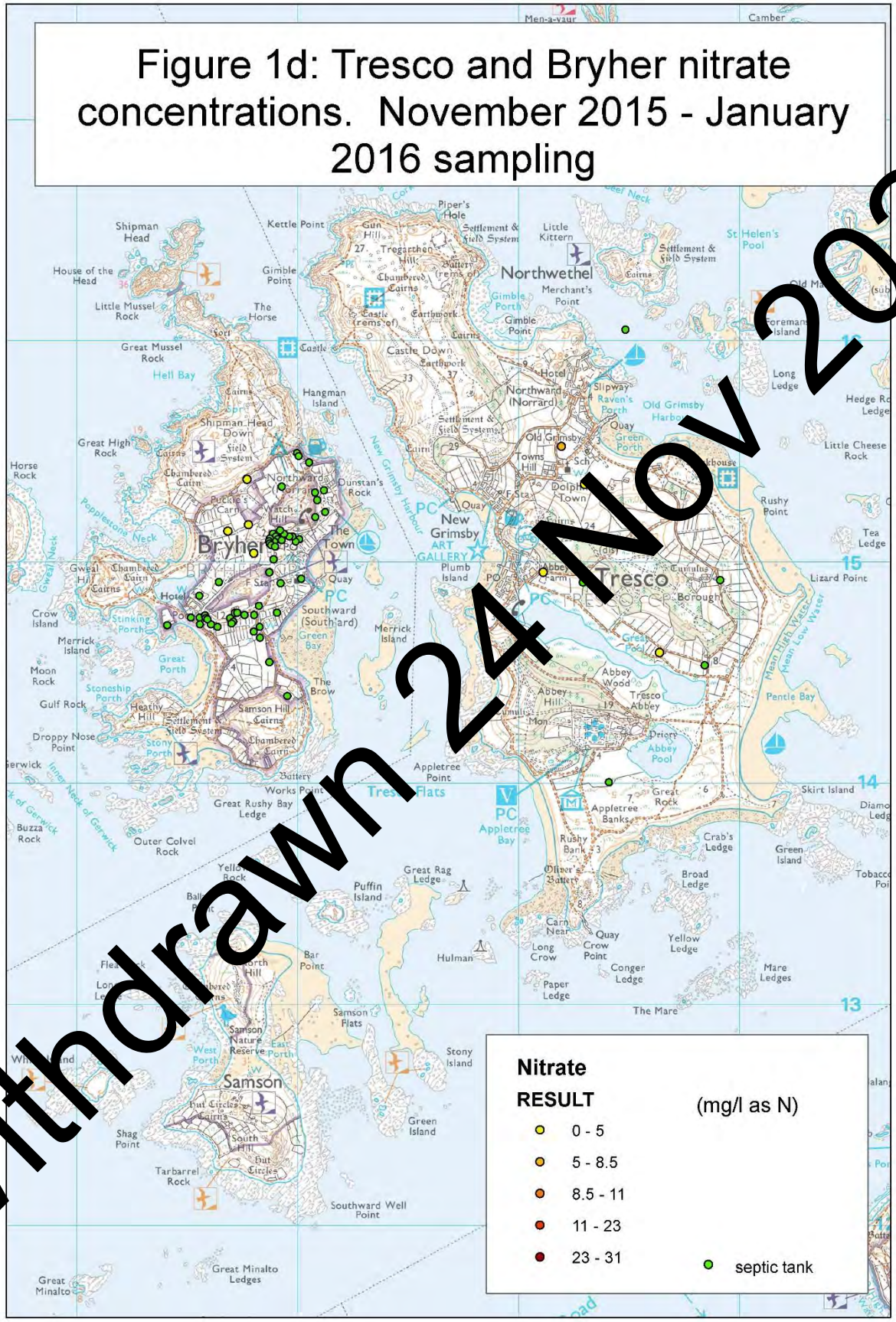
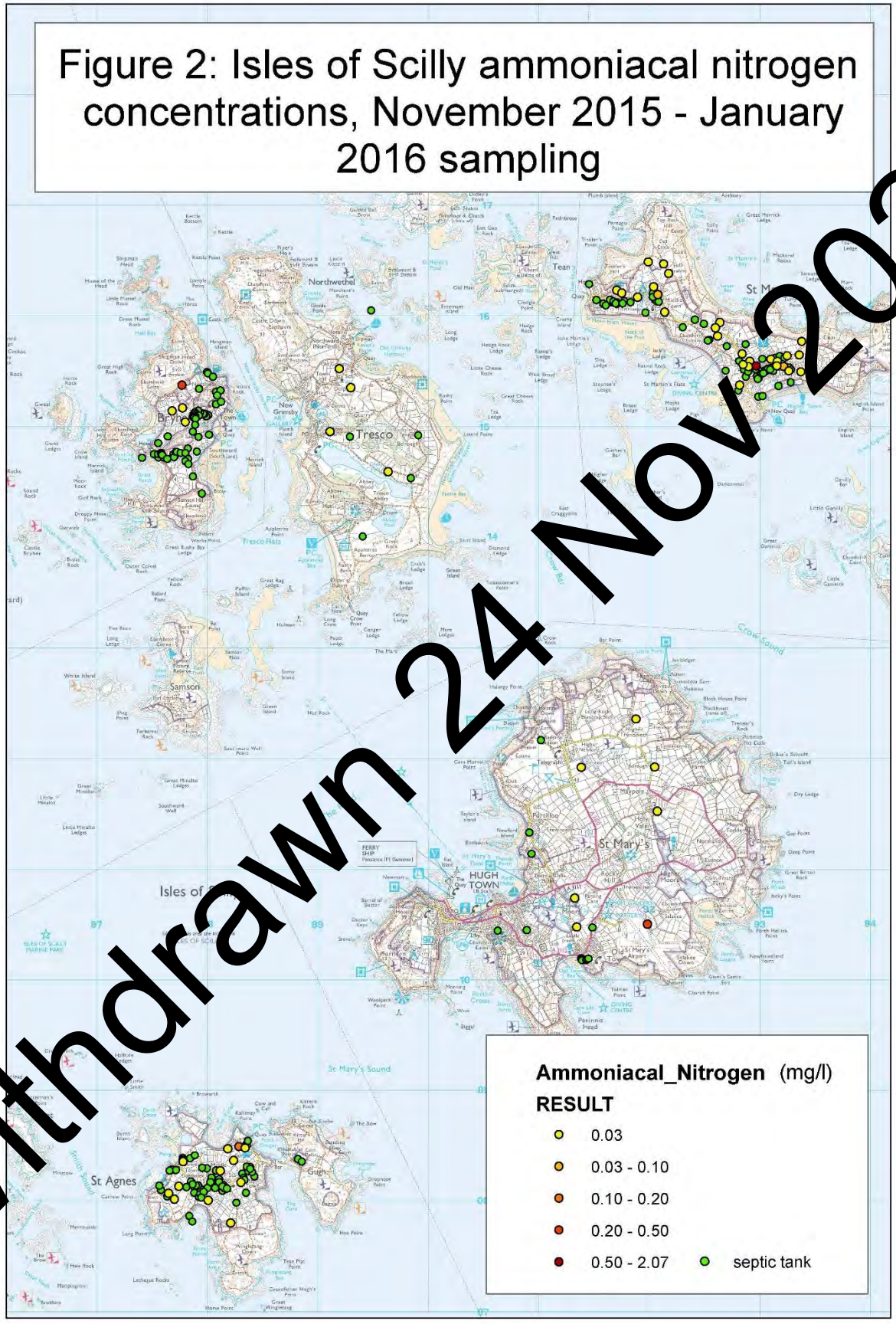
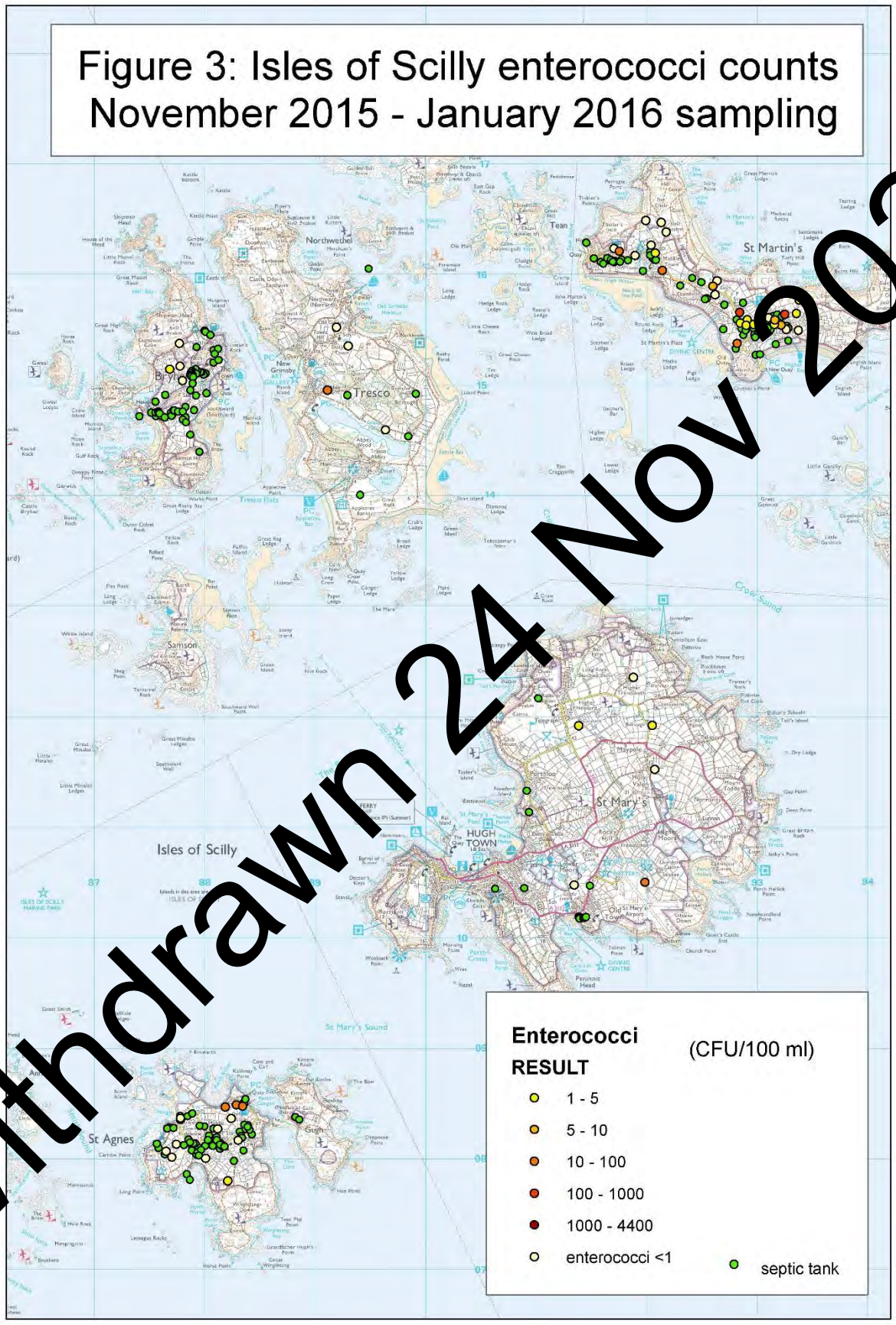
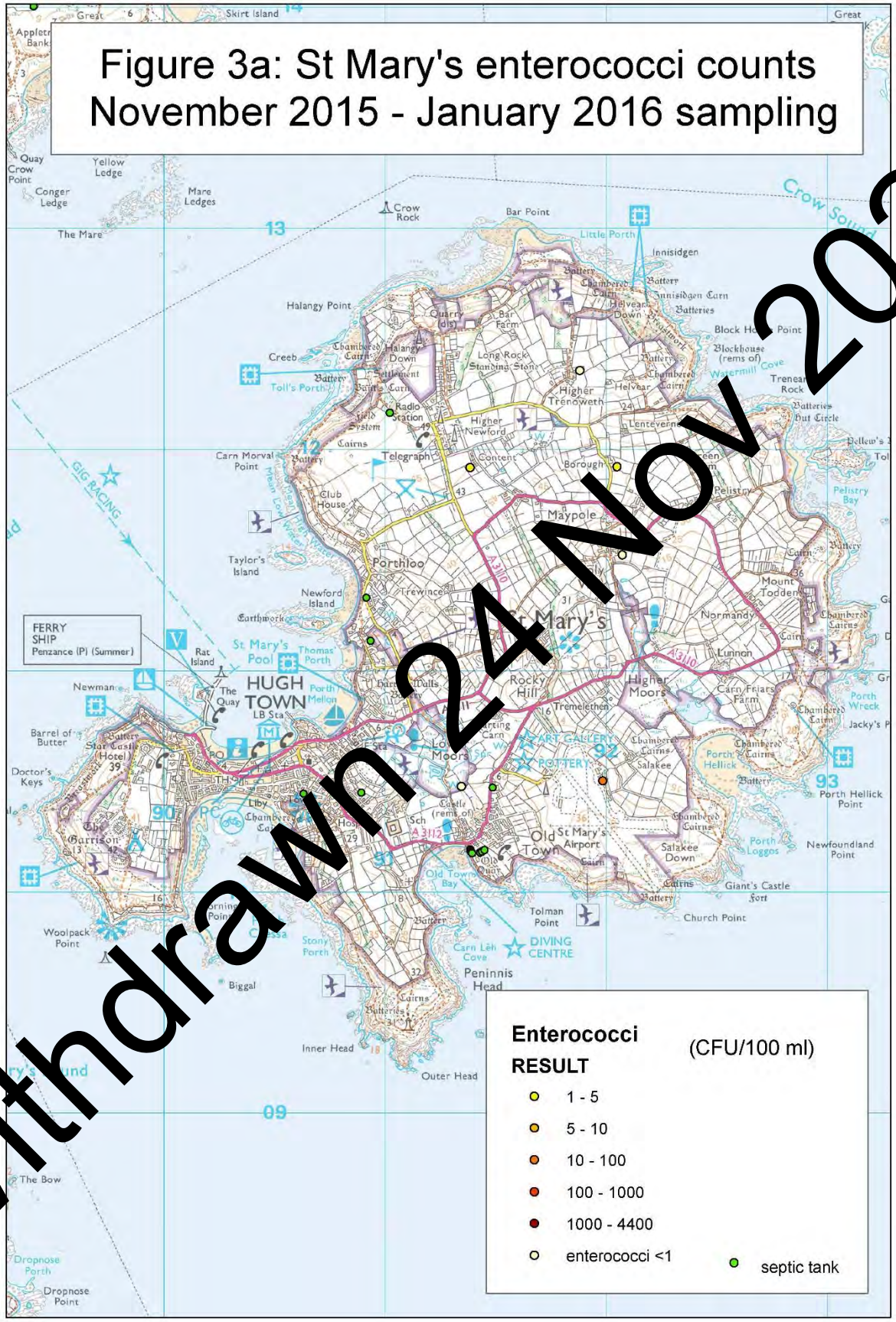


Figure 1d: Tresco and Bryher nitrate concentrations. November 2015 - January 2016 sampling
Nitrate
RESULT
(mg/l as N)
0 - 5
5 - 8.5
8.5 - 11
11 - 23
23 - 31
septic tank
Bryher
Samson
Tresco
New Grimsby
Northwethel
Northward (Norrard)
Southward (Southard)
Withdrawn 24 Nov 2020

Figure 2: Isles of Scilly ammoniacal nitrogen concentrations, November 2015 - January 2016 sampling







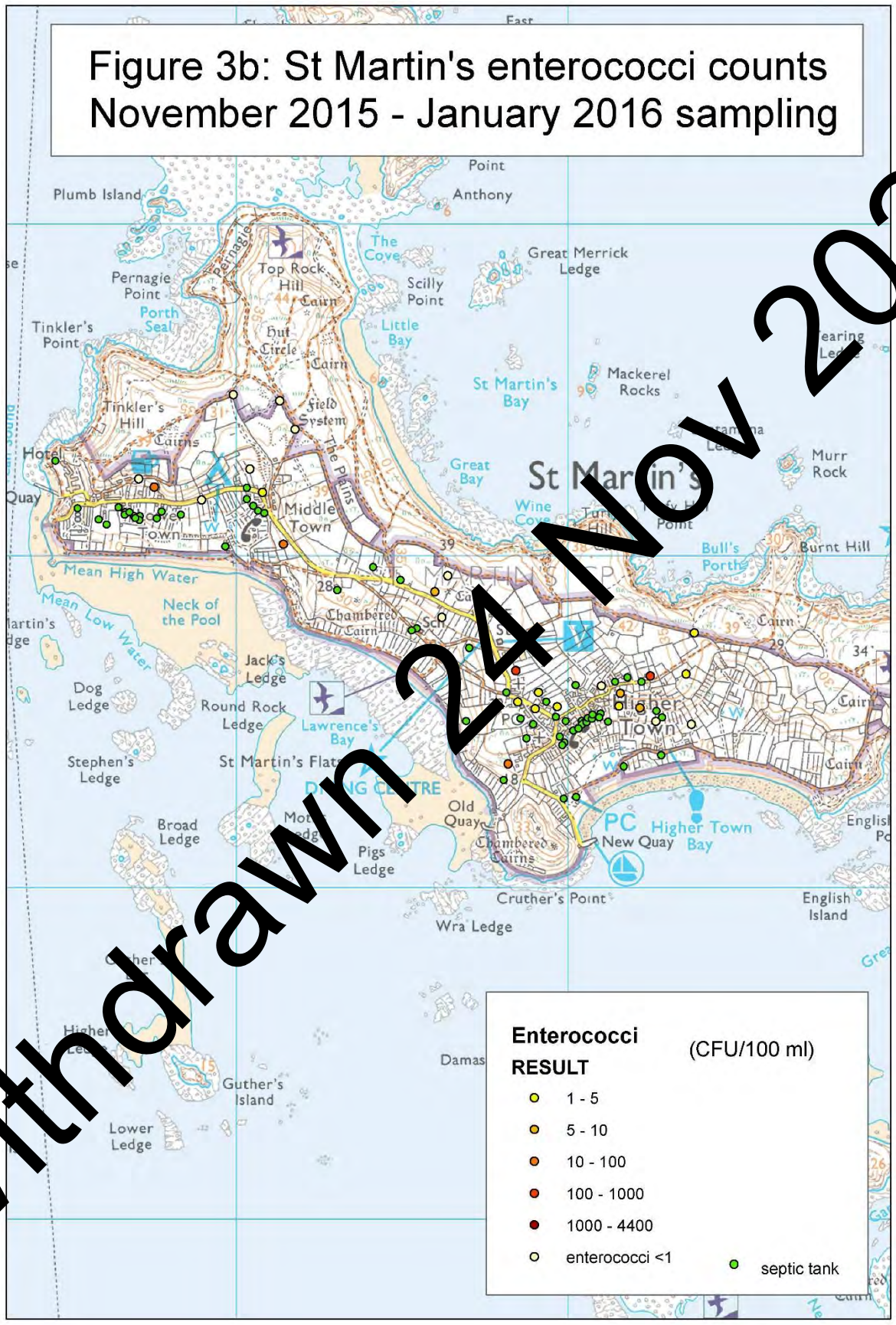


Figure 3d: Tresco and Bryher enterococci counts November 2015 - January 2016 sampling