Expanding opportunities for the microbial community

The EU Water Framework Directive and the US Clean Water Act

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Abstract

Catchment microbial dynamics is an emerging discipline driven by the operational demands of the EU Water Framework Directive which has remarkable similarity to the earlier US Clean Water Act. The lessons of the US legislation for the European science community suggest that the principal reason for water quality impairment in catchment systems is microbial contamination as indexed by faecal indicator organisms. EU science effort to date, as we grapple with the implementation challenges of the Water Framework Directive, has focused overwhelmingly on nutrient pollution in surface fresh waters where phosphorus is the key driver of eutrophication and ecological impairment. This emphasis will shift to the microbial parameters as regulatory agencies seek to use the tools established in the Water Framework Directive to ensure compliance with standards established in daughter Directives covering bathing and shellfish growing waters. This will present opportunities and challenges to the microbiological community. They will increasingly be asked questions and offered research challenges to quantify and gain new process knowledge of catchment microbial processes and, specifically, microbial fate and transport of relevance to the demands of catchment microbial models. This area of investigation is perhaps 30 years behind the nutrient modelling community but rapid progress is possible through the application of established modelling platforms with the applications and exploration of new microbial tools which can better offer parameterisation of key model sectors to place microbial modelling on a par with catchment nutrient, sediment and BOD communities. This paper explores these challenges and suggests key areas for early attention.

What are CWA and WFD?

CWA

1. Impaired Water
2. TMDL
   i. Integrated Catchment Management

WFD

1. Non-compliance
2. POM (Article 11)
   i. Integrated Catchment Management

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Lessons of CWA for WFD

Why are opportunities Expanding?

The CWA Top 10

17/05/2011

Causes of Impairment for 303(d) Listed Waters

Description of this table

NOTE: Click on a cause of impairment (e.g. pathogens) to see the specific state-reported causes that are grouped to make up this category. Click on the "Number of Causes of Impairment Reported" to see a list of waters with that cause of impairment.

Cause of Impairment Group Name	Number of Causes of Impairment Reported
Pathogens	10,913
Metals (other than Mercury)	7,461
Nutrients	7,003
Organic Enrichment/Oxygen Depletion	6,504
Sediment	6,271
Polychlorinated Biphenyls (PCBs)	6,179
Mercury	3,782
pH/Acidity/Caustic Conditions	3,733
Cause Unknown - Impaired Biota	3,386
Turbidity	3,085
Temperature	3,012
Pesticides	1,866

The CWA Top 10 17/05/2011

National Cumulative TMDLs by Pollutant

This chart includes TMDLs since October 1, 1995.

Description of this table

NOTE: Click on the underlined "Pollutant Group" value to see a detailed list of pollutants. Click on the underlined "Number of TMDLs" value to see a listing of those TMDLs for the pollutant Group.

Pollutant Group	Number of TMDLs	Number of Causes of Impairment Addressed
Pathogens	9,134	9,368
Metals (other than Mercury)	7,963	8,145
Mercury	6,946	6,978
Nutrients	4,785	5,698
Sediment	3,553	4,102
Organic Enrichment/Oxygen Depletion	1,918	2,021
Temperature	1,847	1,854
pH/Acidity/Caustic Conditions	1,798	1,854
Salinity/Total Dissolved Solids/Chlorides/Sulfates	1,542	1,595
Ammonia	1,084	1,147
Turbidity	1,049	1,185
Pesticides	1,004	1,064

Some Catchment Basics

- FIOs have multiple sources
  - Livestock are important
    - Rivers after rainfall similar to treated effluent
  - Treated effluent is often disinfected
  - Intermittent discharges are rarely measured – hence an unknown input?
- FIO flux is highly episodic
  - Rainfall driven / system breakdowns

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Faecal indicator sources

Creature	Faecal production (g per day)	*E. coli* per g faeces	*E. coli* load (per day)
Human	150	1.3×10^7	1.9×10^9
Cow	23600	2.3×10^5	5.4×10^9
Hog	2700	3.3×10^6	8.9×10^9
Sheep	1130	1.6×10^7	1.8×10^{10}
Ducks	336	3.3×10^7	1.1×10^{10}
Turkeys	448	3.0×10^5	1.3×10^8
Chickens	182	1.3×10^6	2.4×10^8
Gulls	15	1.3×10^8	2.0×10^9

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FIO Loading
(some 'ball-park' calculations)

- 100 sheep = 1000 people
- Sewage treatment
  - = 1000 fold reduction in FIO concentration
  - i.e. reduces 1,000,000pe to 1,000pe

HENCE

- 1,000,000 people = 100 sheep in terms of approximate loading to the catchment

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Policy/Economic Drivers

- Bathing Water
- Shellfish Waters
- Water Supplies
  - Small supplies

One Example

1. New EU standards for bathing waters will be in force by 2015 with the first sampling 2012.
2. These standards are tighter and will result in fewer Blue Flag beaches throughout the EU

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What is the new approach?

3. The WHO have called for real-time prediction of bathing water quality

AND

4. Provision of real-time information to the public as a foundation for public health protection

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COSTS £m	From	To
Good	3163	4858
Excellent	4999	7818
Three Events	1621	2443
SAVINGS £m		
Good	1542	2415
Excellent	3378	5375

Does not include CSOs improved to one spill/season

	NPV of total benefits	NPV of total costs	
Option 1	0	9-14	
Option 2a	1104-1923	3163-4858	~Good
Option 2b	1638 -3497	4999-7818	Excellent
Option 3a	2215	2530-3846	One event
Option 3b	2215	1621-2443	Three events

eftec

Valuation of Benefits to England and Wales of a Revised Bathing Water Quality Directive and Other Beach Characteristics Using the Choice Experiment Methodology

Final report submitted to

Department for Environment, Food and Rural Affairs

by

Economics for the Environment Consultancy Ltd

25 June 2002

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Cascade CONSULTING

Department for Environment, Food and Rural Affairs

Revision of the Bathing Water Directive: Summary of Phases 1 and 2

PROPOSAL FOR A DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL TO REVISE DIRECTIVE 76/160/EEC CONCERNING THE QUALITY OF BATHING WATER
PARTIAL REGULATORY IMPACT ASSESSMENT

1. Title

This Regulatory Impact Assessment (RIA) considers the potential impact of the proposal (COM(2002) 581 final) for a Directive of the European Parliament and of the Council to revise Directive 76/160/EEC concerning the quality of bathing water (hereafter referred to as "the revised Directive"), which the Commission agreed and published on the 24th October 2002.

2. Purpose and intended effect of measure

(i) Objective

The revised Directive updates the existing Bathing Water Directive in order to further protect public health in the EU, by limiting faecal contamination of popular bathing places.

It aims to review and streamline the parameters for setting water quality standards, focussing on fewer microbiological indicators and setting stricter standards. Better information will be also provided to the public, making use of locally and regionally available facilities and the Internet.

The revised Directive aims to be coherent with other EU water related legislation, in particular the Water Framework Directive.

(ii) Background

The 1976 Bathing Water Directive requires Member States to meet quality standards at waters within its scope. The purpose of the quality standards is to reduce the risks

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What is the result?

5. With ‘real time prediction’ we can protect the health of bathers and enmaintain present levels of blue flag beaches
6. The approach is an ‘option’ not a regulatory requirement and is outlined in the EU Bathing Water Directive (2006)

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What do we need to deliver?

- Black-box models
  - – Advisory notices – sample discounting
  - – Essential to keep the '**Blue Flags**'
- Linked catchment and near-shore models **that work**
  - – i.e. '**Predictive**' not just '**Protective**'
    - Scheme design and investment
    - Prediction at difficult sites

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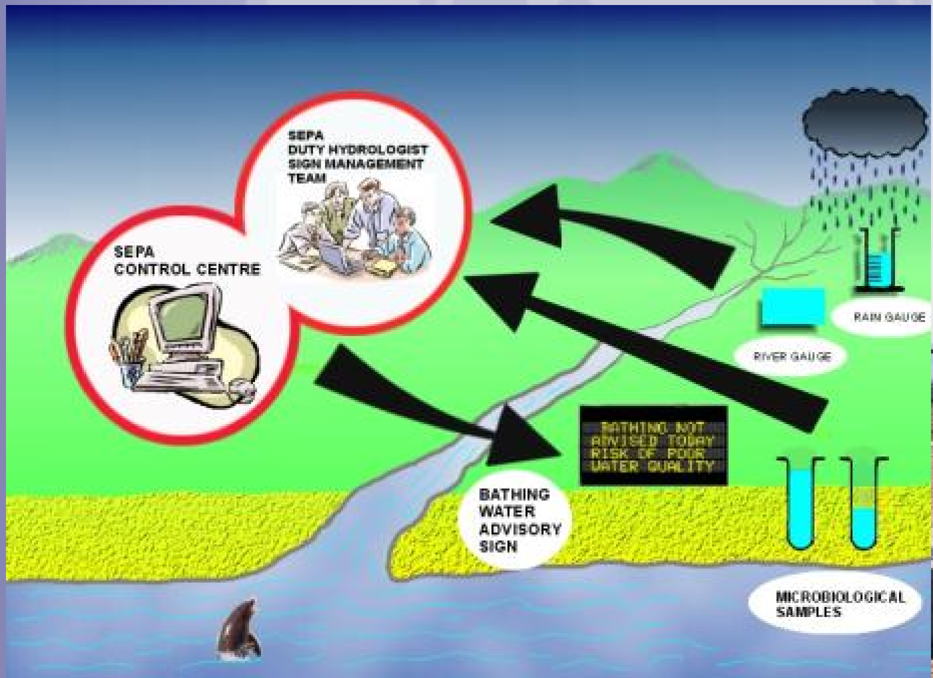
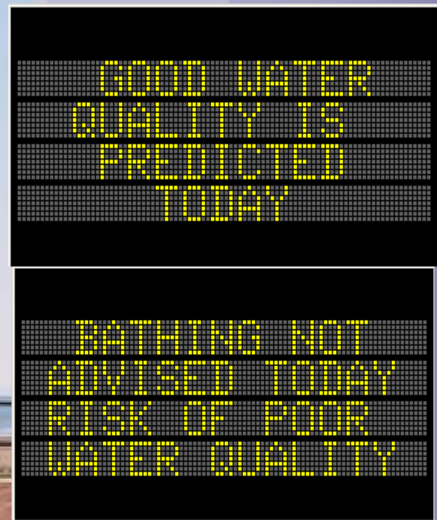
Do Black Box Models Work?

Scottish Approach





Problems

- **Model calibration data**
  - ‘**Bathing Day**’ is the modelling unit
  - Spot compliance samples provide the calibration data
    - **Diurnality** introduces random variation and increase model error reducing explained variance
    - **Censored data** (< and >) and measurement imprecision in cfu and/or MPN counts would further reduce model utility

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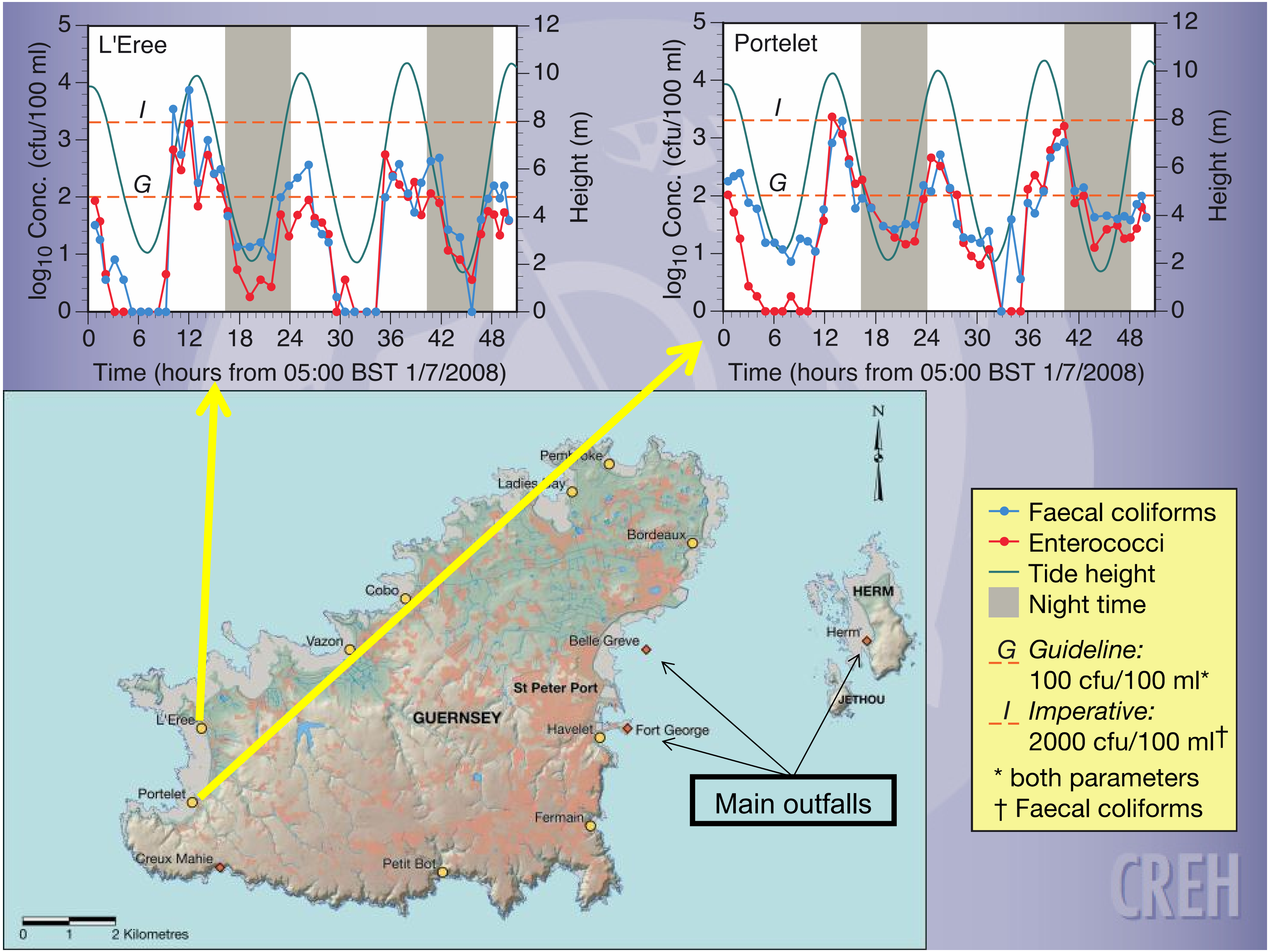

L'Eree
Portelet
I
G
log10 Conc. (cfu/100 ml)
Height (m)
Time (hours from 05:00 BST 1/7/2008)
0
6
12
18
24
30
36
42
48
Faecal coliforms
Enterococci
Tide height
Night time
G Guideline:
100 cfu/100 ml*
I Imperative:
2000 cfu/100 ml†
* both parameters
† Faecal coliforms
Main outfalls
GUERNSEY
HERM
JETHOU
St Peter Port
Bordeaux
Cobo
Vazon
Belle Greve
Herm
Havelet
Fort George
L'Eree
Portelet
Fermain
Creux Mahie
Petit Bot
0
1
2 Kilometres
N
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Solutions

- Characterise the '**bathing day**' water quality for model building
  - **multiple sampling events** during daylight
    - 07:00 to 19:00
  - Measure FIOs with **enhanced accuracy** through the bathing day
    - Triplicate enumeration / >100+ml filtered

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What if it does not work?

- The back-up plan
  - ‘**predictive**’ not ‘**protective**’ hydrodynamic and water quality modelling
  - ‘**real-time**’ not ‘**constant**’ T_{90} microbial decay coefficients

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How to do it

Programme of new field investigations to drive model development

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650
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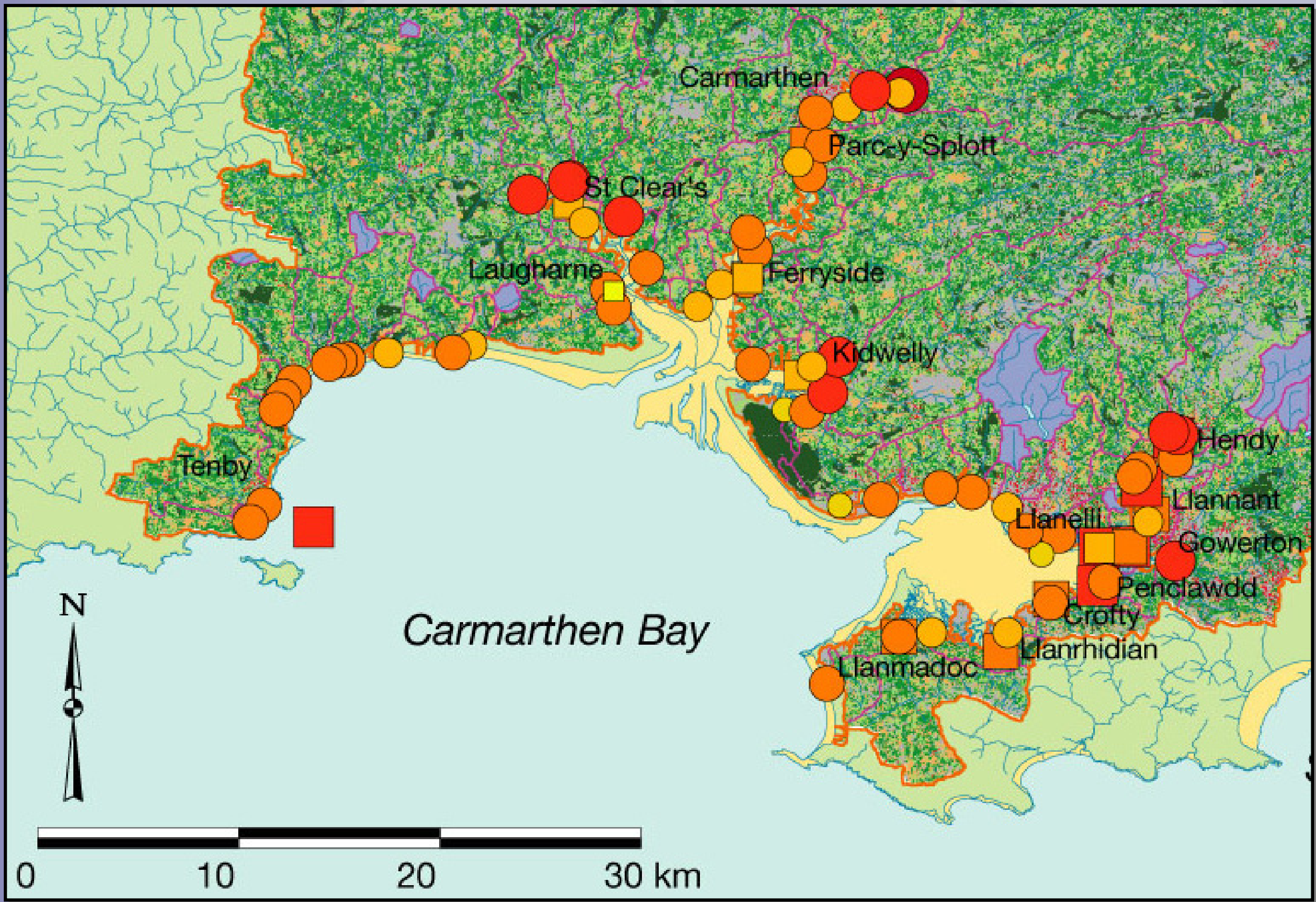
Carmarthen Bay example



High flow Presumptive *Escherichia coli* load (per second):

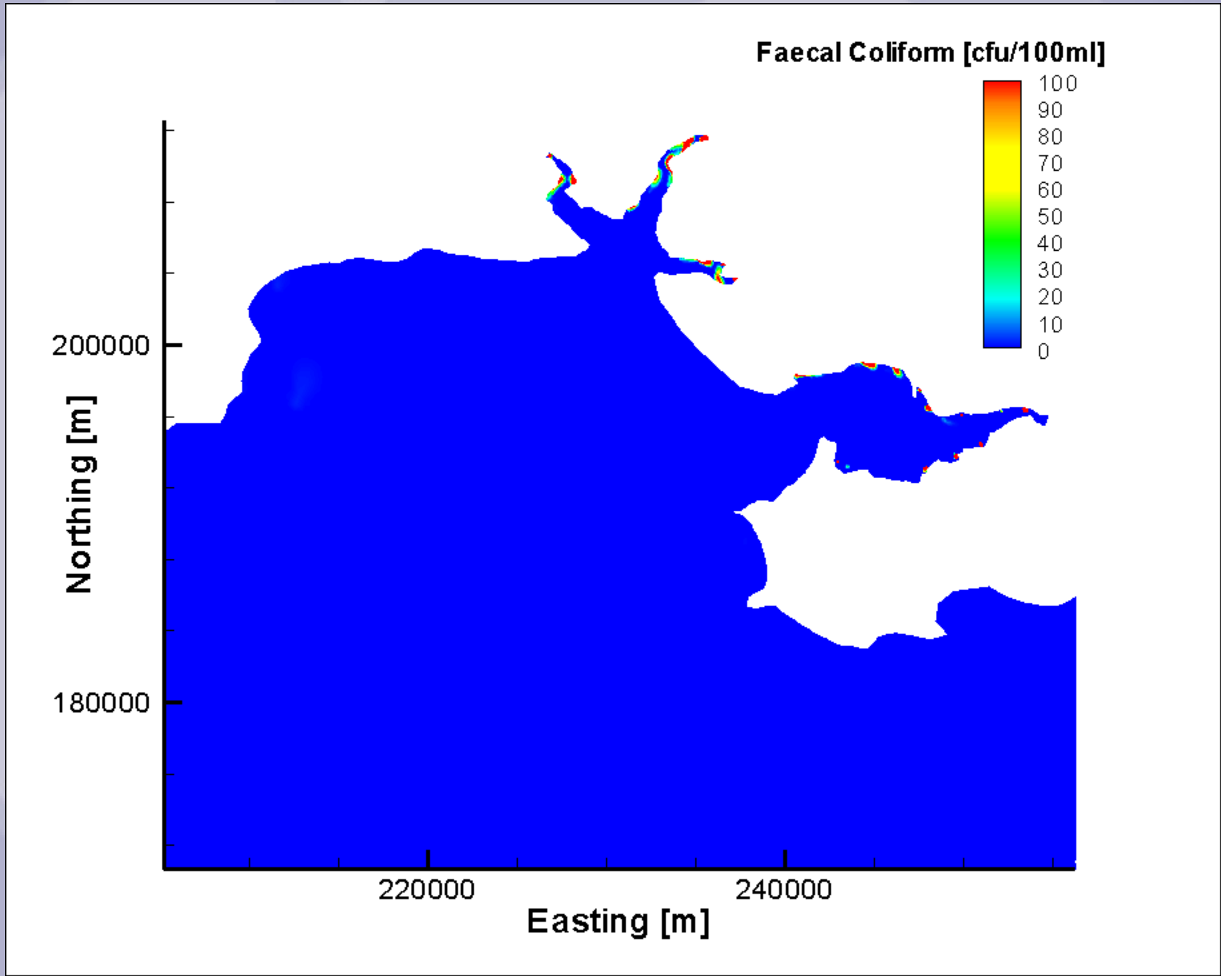
Sewage	Rivers	
▪	•	$10^3 - 10^4$
▪	•	$10^4 - 10^5$
▪	•	$10^5 - 10^6$
▪	•	$10^6 - 10^7$
▪	•	$10^7 - 10^8$
▪	•	$10^8 - 10^9$
▪	•	$10^9 - 10^{10}$
▪	•	$10^{10} - 10^{11}$

An Roinn Airgeadais Department of Finance
YR UNDEB EWROPEAIDD INTERREG IIIA
EUROPEAN UNION INTERREG IIIA
Llywodraeth Cynulliad Cymru Welsh Assembly Government

Input estimates: high flow

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD
CREH Centre for Research into Environment and Health

Carmarthen Bay example



Microbial Source Tracking

Does it have a role?

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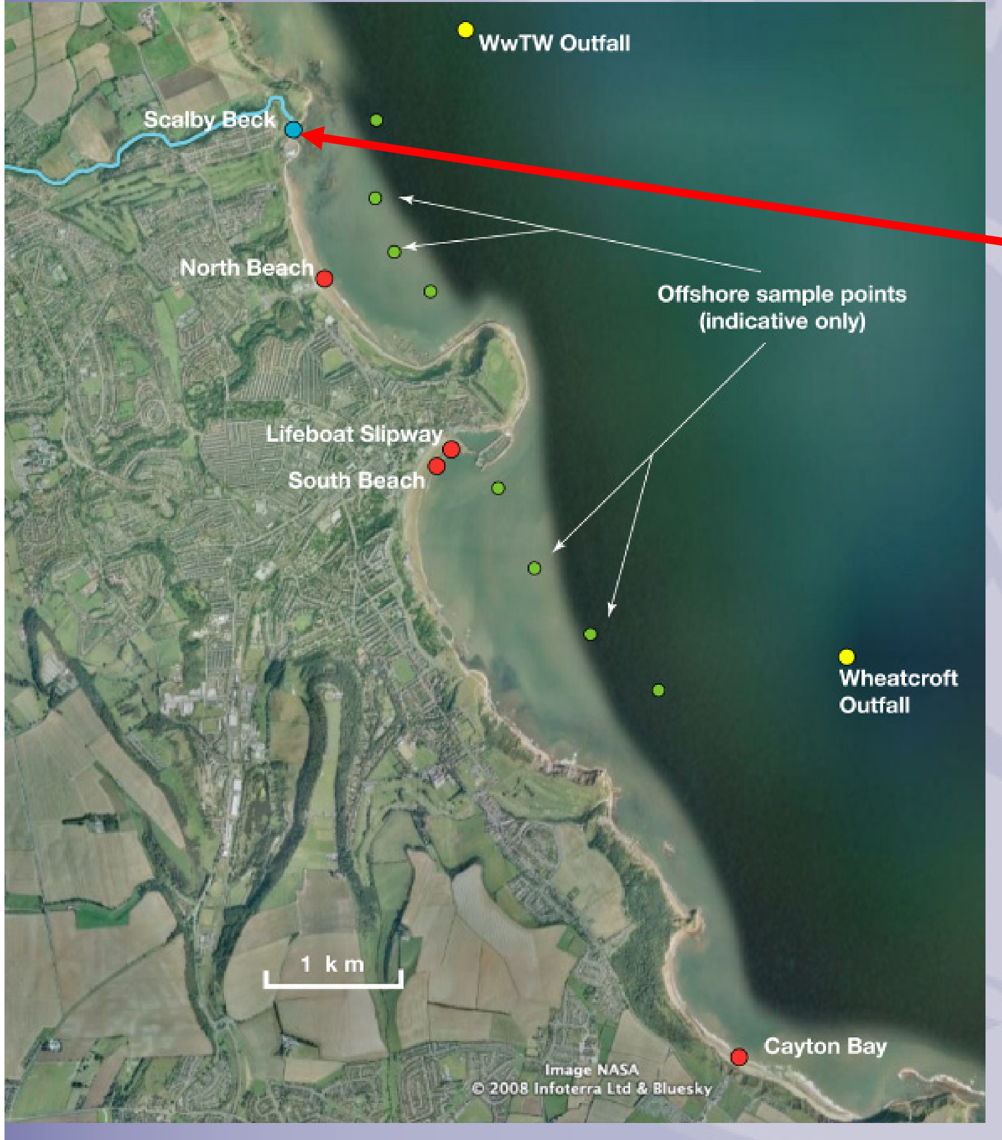
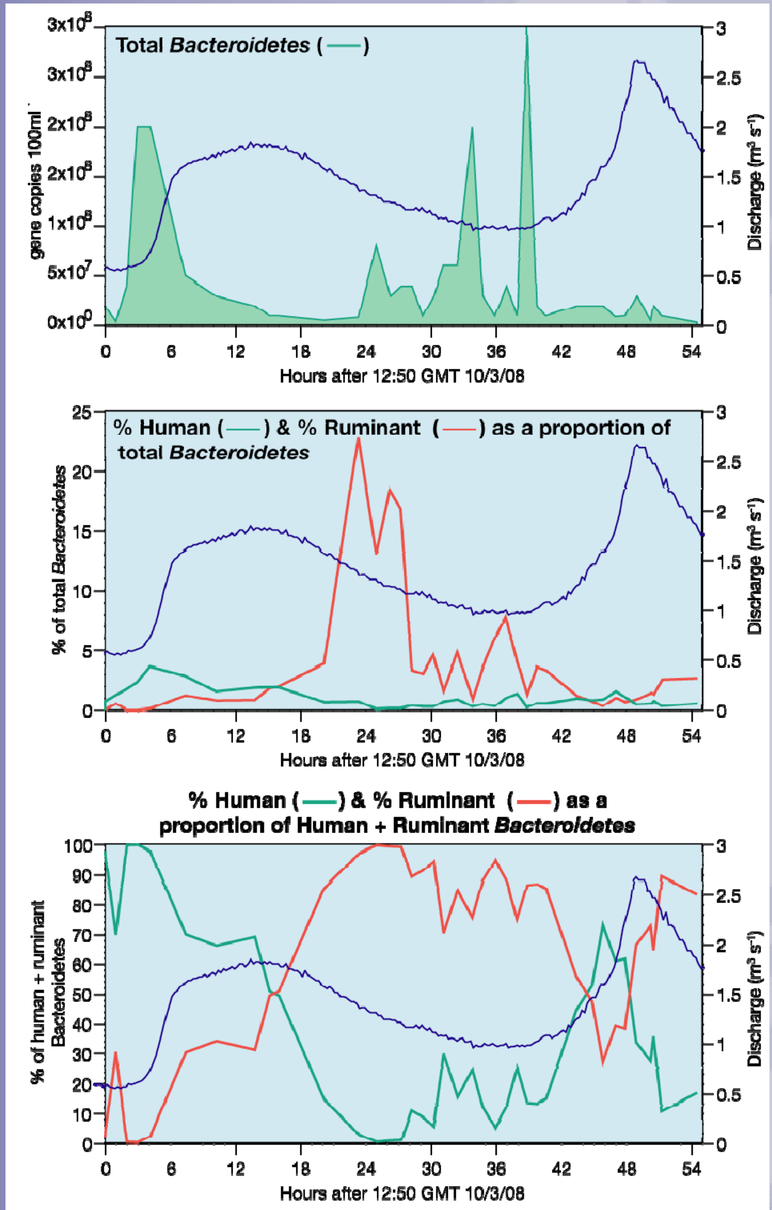


Riverine Signals

1. Variable MST signal in Scalby Bk



Sample	Source
1	
2	
3	MIXED
4	HUMAN
5	HUMAN
6	HUMAN
7	MIXED
8	MIXED
9	MIXED
10	MIXED
11	MIXED
12	MIXED
13	RUMINANT
14	RUMINANT
15	RUMINANT
16	RUMINANT
17	MIXED
18	RUMINANT
19	RUMINANT
20	MIXED
21	MIXED
22	MIXED
23	MIXED
24	RUMINANT
25	MIXED
26	MIXED
27	MIXED
28	MIXED
29	MIXED
30	MIXED
31	MIXED
32	MIXED
33	MIXED
34	MIXED
35	MIXED
36	MIXED
37	MIXED
38	MIXED
39	MIXED

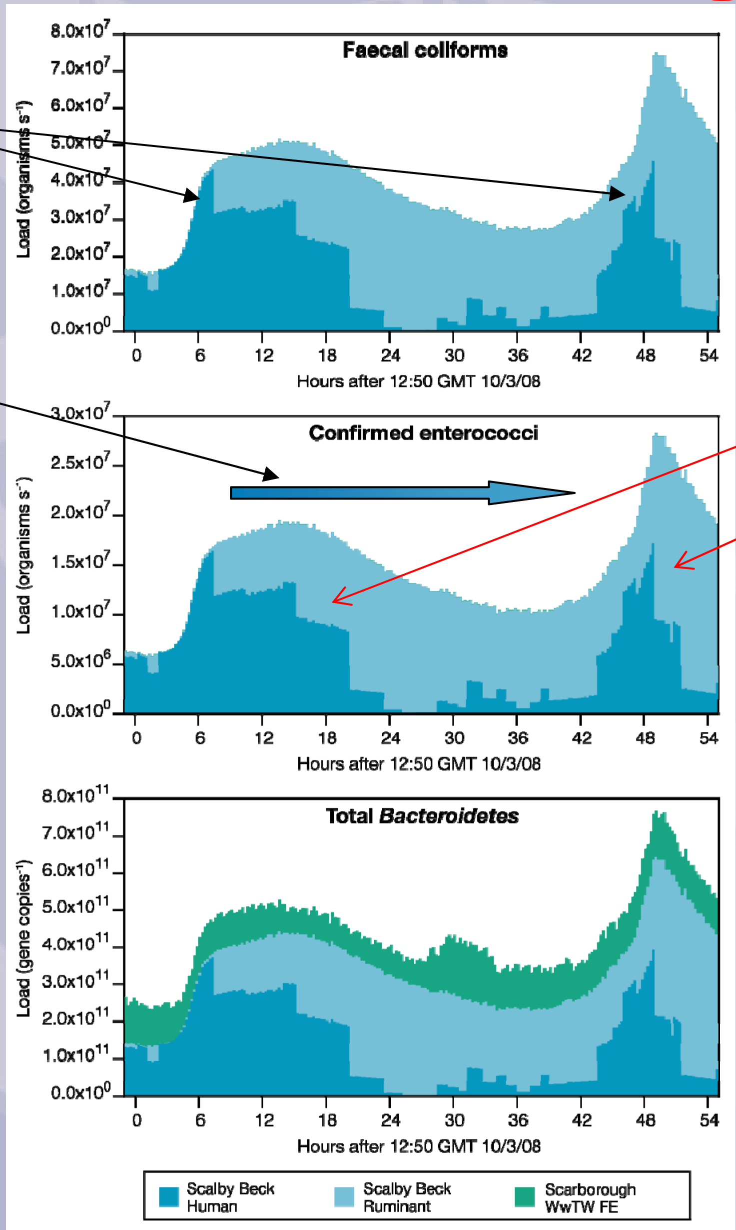
HUMAN	3
RUMINANT	7
MIXED	29
ABSENT	0
	0

HUMAN	**Human >90% of both markers**
RUMINANT	**Ruminant > 90% of both markers**
MIXED	**Human/Ruminant 10-90% of both markers**
ABSENT	**Human and Ruminant markers absent.**
	Blank = Specific markers <1% total *Bacteroidetes*. Box coloured according to presence/absence of markers (i.e. pink = Human only, green = Ruminant only, grey = both present (mixed), white = < 200,000 total *Bacteroidetes* in sample

Riverine MST signal

CSO spill?

Transition to ruminant dominance after CSO spill



Scalby Beck & WwTW FE flux of organisms

‘Human’

signal increases were associated with sewage infra-structure spills during storm events

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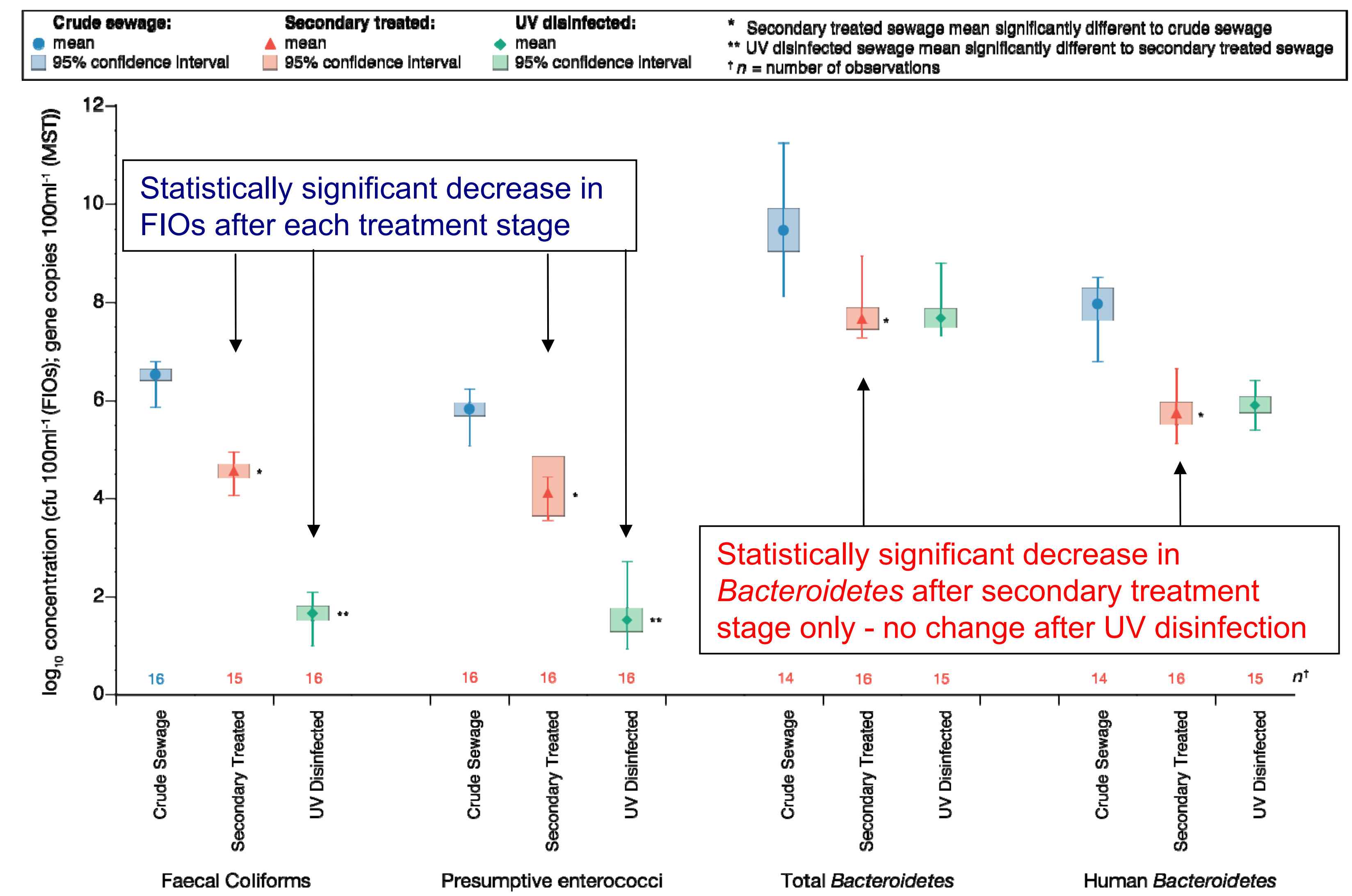
3. UV disinfection did not attenuate *Bacteroidetes* concentrations



In general, Human dominance indicated at all beaches…

Sample	North Bay	South Bay RNLI slipway	South Bay compliance point	Cayton Bay
1				
2				
3				
4		HUMAN		
5				
6				
7	HUMAN			
8	MIXED			
9			RUMINANT	
10	HUMAN	MIXED	MIXED	
11	no data	MIXED		HUMAN
12	HUMAN			HUMAN
13	HUMAN	HUMAN	HUMAN	
14	HUMAN		HUMAN	
15	MIXED			HUMAN
16	HUMAN	RUMINANT	HUMAN	
17	HUMAN		HUMAN	
18	HUMAN	MIXED	HUMAN	
19		HUMAN	HUMAN	
20	HUMAN	HUMAN	HUMAN	
21	MIXED	HUMAN	HUMAN	
22	MIXED			HUMAN
23	HUMAN		HUMAN	
24	HUMAN	HUMAN		
25	HUMAN		MIXED	HUMAN
26	HUMAN		MIXED	HUMAN
27	MIXED	HUMAN	MIXED	HUMAN
28	HUMAN			HUMAN
29			RUMINANT	
30				
31	HUMAN			HUMAN
32	HUMAN	HUMAN		
33	MIXED			
34	HUMAN		MIXED	HUMAN
35				MIXED
36	MIXED			
37	MIXED	MIXED	HUMAN	HUMAN
38	MIXED	HUMAN		HUMAN
39	HUMAN			HUMAN
40	HUMAN	HUMAN	HUMAN	MIXED
41	HUMAN	HUMAN	HUMAN	
42				MIXED
43			HUMAN	HUMAN
44	HUMAN			HUMAN
45	HUMAN		HUMAN	
46	HUMAN	HUMAN		
47	HUMAN			
48		HUMAN		HUMAN
49	HUMAN	HUMAN	HUMAN	HUMAN
50	HUMAN	HUMAN	HUMAN	HUMAN
51	HUMAN	HUMAN	MIXED	
52	MIXED	HUMAN		HUMAN
53		MIXED	HUMAN	HUMAN
54	HUMAN	HUMAN		HUMAN

HUMAN	**42**	**38**	**39**	**40**
RUMINANT	**0**	**1**	**3**	**0**
MIXED	**11**	**10**	**9**	**10**
ABSENT	**0**	**3**	**2**	**4**
	0	**2**	**1**	**0**

Human=	**Human >90% of both markers**
Ruminant=	**Ruminant > 90% of both markers**
Mixed=	**Human/Ruminant 10-90% of both markers**
Absent=	**Human and Ruminant markers absent.**
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Dominance of human (pink)

But…

Some samples negative for specific markers - low recovery of general marker from all these samples (i.e. <200,000)

Some 'flipping' to ruminant (green)

Approx 50% samples below 1% threshold

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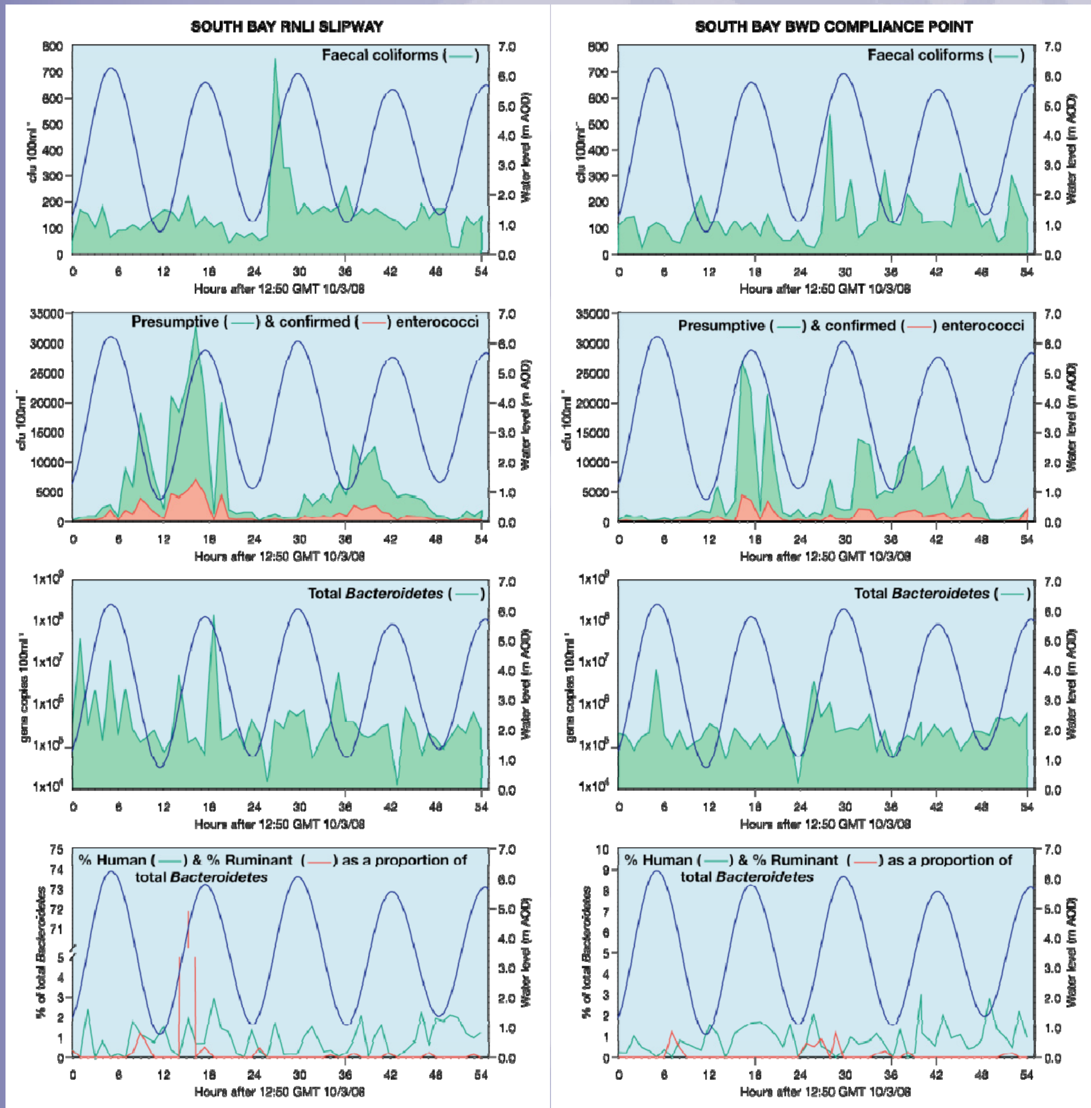
South Bay Sampling Sites

South Bay temporal variability (1)



Correlations between concentrations at RNLI slipway and compliance point

Parameter	Correlation Significance *p*
Faecal Coliforms	<0.001
Pres. Enterococci	<0.001
Conf. Enterococci	0.032
General *Bacteroidetes*	Not significant
Human Marker	Not significant
Ruminant marker	Not significant

NB. Correlations between relative proportions (e.g. % human) of MST variables also not significant

Implications…..

- Samples from a single point do not adequately characterise a body of water due possibly to:
  - random variability in the method result
- The lack of correlation with FIOs is concerning suggesting that the MST signal does not reflect the faecal indicator inputs

Recommendations…..

Multiple (several 10s) bathing water samples through a range of conditions required to establish human/ruminant balance

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Control efforts

do they work for FIO flux?

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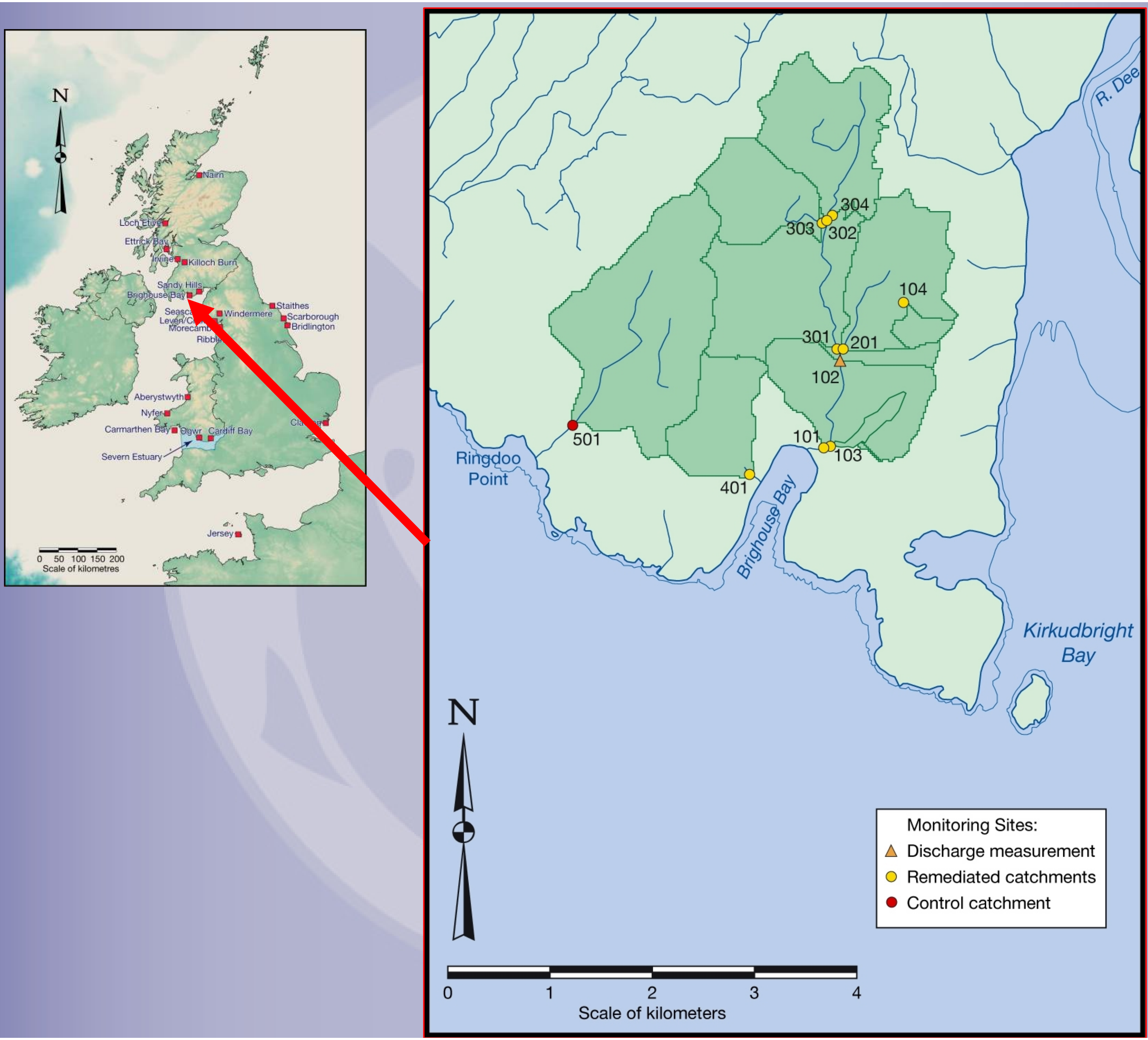
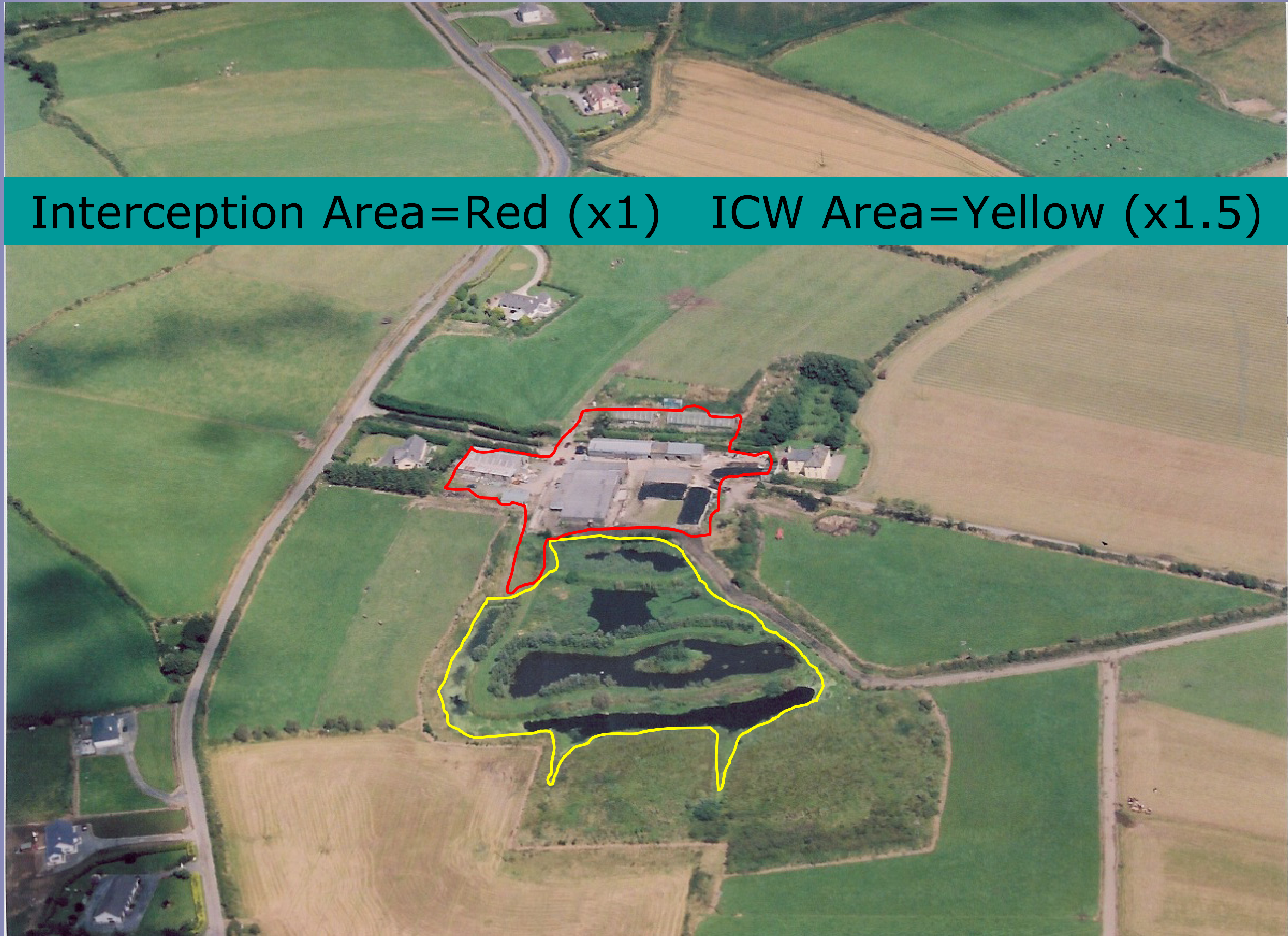

N
Nairn
Loch Etive
Ettrick Bay
Irvine
Killoch Burn
Sandy Hills
Brighouse Bay
Staithes
Windermere
Scarborough
Bridlington
Aberystwyth
Nyfer
Carmarthen Bay
Ogwr
Cardiff Bay
Severn Estuary
Jersey
0 50 100 150 200
Scale of kilometres
R. Dee
304
303
302
104
301
201
102
501
101
103
401
Ringdoo Point
Brighouse Bay
Kirkudbright Bay
N
Monitoring Sites:
Discharge measurement
Remediated catchments
Control catchment
0 1 2 3 4
Scale of kilometers

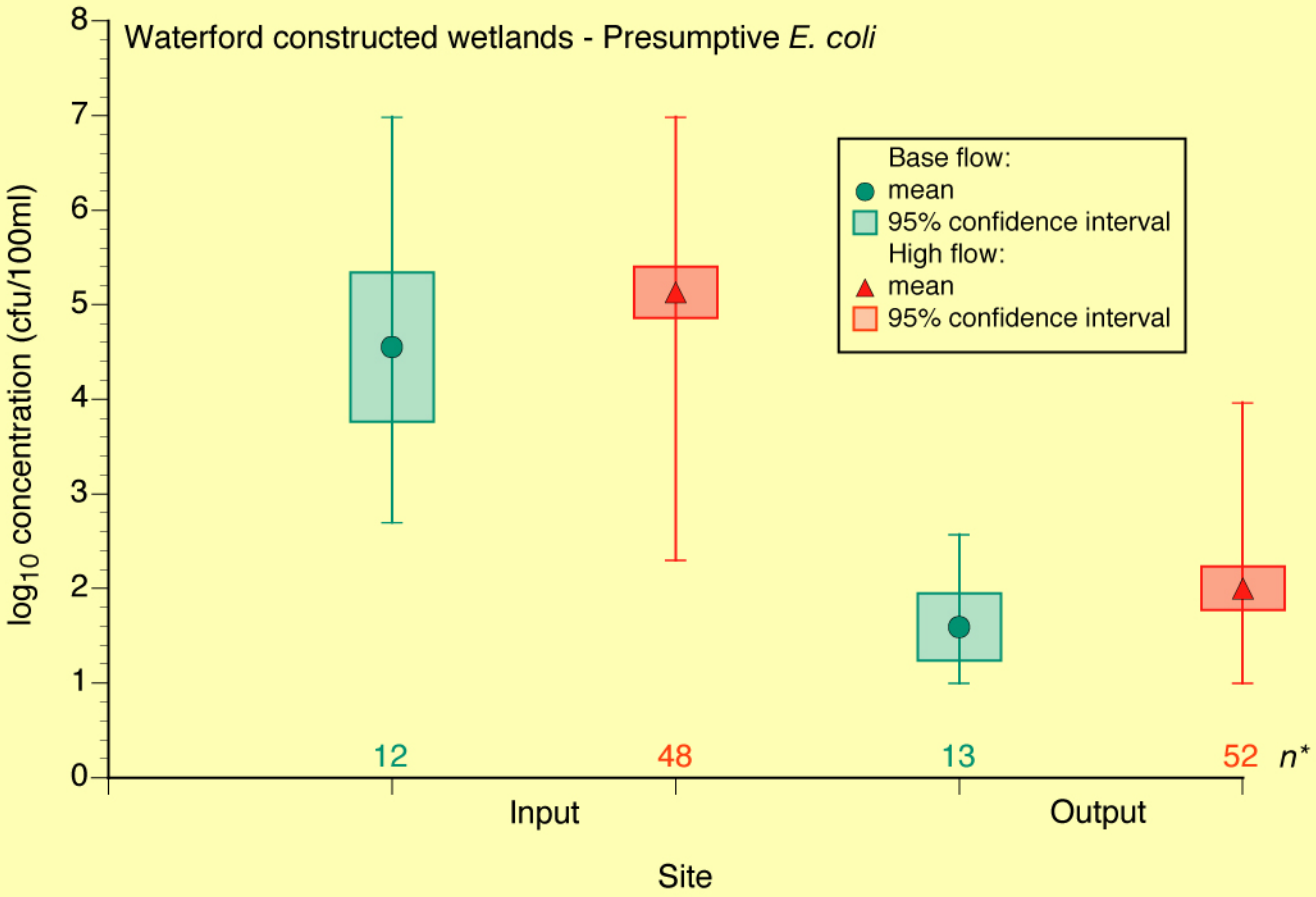
After
Before

Result

- 60 – 80% reduction in high flow FIO flux to bathing waters
  - Simple stock exclusion from watercourses

Constructed Farm Wetlands


Interception Area=Red (x1) ICW Area=Yellow (x1.5)



*n = number of samples

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Uncertainty and opportunity

1. **How do we characterise the ‘bathing day’ for predictive ‘black-box’ models?**
   i. Compliance data does not do this because of diurnality, usage patterns and pollutant inputs
2. **How long do FIOs live in near-shore waters: it varies with irradiance , temperature, predation etc etc!**
   i. Present models assume single day and night T_{90} values
   ii. **Real-time T_{90} data is sparse but essential** for predictive process-based models

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Uncertainty and opportunity

3. **Can MST give us reliable quantitative source apportionment data**
   i. e.g. % human and % ruminant FIO concentration at a compliance site?

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Uncertainty and opportunity

5. **What do we do to attenuate diffuse catchment fluxes of FIOs?**
   i. **Stock exclusion fencing**
   ii. Vegetated filter strips
   iii. **Wetland restoration**
   iv. Woodchip Corrals
   v. Controls on farm waste disposal
      a. Treatment
      b. Spreading

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Uncertainty and opportunity

6. **What do we do to attenuate intermittent discharges from combined sewage systems?**
    i. **Does UV work on intermittent discharges**?
    ii. Can chemical systems provide alternatives without environmental impacts?

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Further information, reports and papers
http://www.ies.aber.ac.uk/en/staff/subpages/research/101
or email to
dvk@aber.ac.uk