



*National Rivers Authority
South Western Region*

**TECHNICAL DEPARTMENT
WATER QUALITY TECHNICAL NOTE
(FOR INTERNAL USE ONLY)**

**ANALYSIS OF RISK OF EC BATHING
WATER FAILURE
South Western Region**

**December 1995
RBWF/02/QA**

**Author: D Carthew
Scientific Officer (Quality Assessment)**

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✓ 3.1

MEMORANDUM



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South Western Region

Subject: ANALYSIS OF RISK OF EC BATHING WATER FAILURE, TECHNICAL NOTE

Please find enclosed a report on the risk of bathing water failure which I hope you might find interesting.

Any feedback welcomed.

David Carthew
Scientific Officer (Quality Assessment)

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AEMs : Brian Sinkins, John Hancock, Ian Legge, Bob Huggins
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1. Summary

The risk of failing the EC Bathing Water Directive at 82 sites has been assessed. It is estimated that between 5 and 33 sites (depending on the sample sets used) pose a risk of >10%. This risk level can be expected to change as schemes to comply with the EC Urban Waste Water Treatment Directive (UWWTD) are commissioned.

2. Introduction

This report contains the results of applying statistical methods for analysing the risk of failing the Directive for 82 identified Bathing Waters. Those EC Bathing Water sites for which improvements specifically to meet the EC Bathing Water Directive (BWD) are scheduled or completed have been excluded (however some improvement to microbiological quality can be expected where improvements are targeted to meet the UWWTD). This assessment uses all (or a sub-set of) routine bathing water samples taken between 1986-1994. The compliance risk analysis is based on exceedences of imperative coliform (total & faecal) standards.

3. Aims & Objectives

The statistical analyses will be used to judge whether an improvement scheme can be justified and/or a development restraint initiated.

4. Background

The imperative coliform standards provided in the Directive and used by the DoE to assess compliance require there to be no more than 10,000 total coliforms per 100 ml and no more than 2,000 faecal coliforms per 100 ml of sample. In order for a bathing water to comply with the Directive, 95% of samples must meet these standards. Thus 2 or more (total) or 2 or more (faecal) exceedences in any one season would equate to failure of the Directive requirements.

CORRECT?
OR NOT?

A non-compliance risk of greater than 10% is considered significant for the purposes of exercising control.

5. Methodology

To assess the likelihood of failure an appropriate distribution is needed so that we can model the nature of bathing water compliance.

Any results which can be expressed as pass/fail follow the binomial distribution. Using this statistical model to describe the behaviour of bathing water quality it is possible to calculate the confidence of compliance for any particular bathing water (it should be noted that samples for testing compliance with the Directive may not always be statistically independent throughout the bathing season). For example, sites with a 90% likelihood of 2 or more exceedences are sites where there is a chance of only 10% that the site will comply for 95% of the time. An explanation of the binomial distribution is given in Appendix A.

All sample exceedences between 1986-1994 have been taken into account (generally confirmed samples were available from 1992 onwards) in assessing the probability of non-compliance with the aid of the ZEBRA software package. The use of ZEBRA is explained further in Appendix A. An automated method for calculating probabilities is described in Appendix B.

Using ZEBRA to provide cumulative probabilities from the binomial distribution for 2 or more bathing water exceedences gives the probability of non-compliance as summarized in Tables 1 and 2, and the Graphs in Appendix C.

6. Analysis of Results

The results in Tables 1 and 2 indicate the bathing waters which have the greatest risk of failing (any above 10% are highlighted). Closer examination, taking different numbers of previous years' data into account, identifies those which are fluctuating and those which are improving or deteriorating.

e.g.

Bathing Waters	Cumulative Probability of Failure Using Previous Years' Data for Faecal Coliforms								
	1986-1994	1987-1994	1988-1994	1989-1994	1990-1994	1991-1994	1992-1994	1993-1994	1994
Burnham Jetty	n/a	85.2	77.8	22.7	5.5	8	4.3	7.8	0

A judgement is required as to what period of data is representative of bathing water quality. Consideration should be given to underlying reasons for the trend detected. External influences, such as disinfection trials, should be observed when selecting the appropriate data set to calculate underlying risk.

7. References

WRc Zebra User Guide, June 1990, version 1.2

TABLE 1

Bathing Waters	Cumulative Probability of Failure Using Previous Years' Data for Faecal Coliforms									
	1986-1994	1987-1994	1988-1994	1989-1994	1990-1994	1991-1994	1992-1994	1993-1994	1994	
1 Beer	16.2	18.2	20.6	19.7	18.4	25.5	25.2	26.4	60.8	60.8
2 Sidmouth (Town)	18.3	18.4	20.8	19.9	26	35.2	38.1	60.8	62.4	62.4
3 Sidmouth (Jacob's Ladder)	0.6	0.8	0.9	1.2	1.7	2.5	4.2	8.8	26.4	26.4
4 Ladram Bay	5.1	5.8	6.7	8.7	11.8	16.8	13.9	26.4	26.4	26.4
5 Dawlish Warren	0	0	0	0	0	0	0	0	0	0
6 Dawlish Town	5.1	5.8	6.7	8.7	11.8	16.8	25.8	8.8	26.4	26.4
7 Dawlish (Croyton Cove)	n/a	2.8	3.2	4.3	5.9	8.6	13.9	26.4	26.4	26.4
8 Teignmouth (Holcombe)	n/a	32.4	38.5	38.1	28.7	28.5	37.3	43.6	68	68
9 Maldencombe	0	0	0	0	0	0	0	0	0	0
10 Watcombe	0	0	0	0	0	0	0	0	0	0
11 Meadfoot	0	0	0	0	0	0	0	0	0	0
12 Beacon Cove	n/a	0	0	0	0	0	0	0	0	0
13 Torre Abbey	10.4	11.2	12.2	14	18.7	28	38.1	8.8	26.4	26.4
14 Hollicombe	0.6	0	0	0	0	0	0	0	0	0
15 Goodrington	13.7	12.7	6.8	8.8	12	17.2	26.4	28.4	26.4	26.4
16 Broadsands	2.4	2.5	3.3	4.3	6	8.8	14.2	26.4	60.8	60.8
17 Shoalstone	0	0	0	0	0	0	0	0	0	0
18 St. Mary's	2.4	2.8	3.2	4.3	1.7	2.5	4.2	8.8	26.4	26.4
19 Dartmouth Castle	2.4	0.8	0.9	1.2	1.7	2.5	4.2	8.8	26.4	26.4
20 Blackpool Sands	0	0	0	0	0	0	0	0	0	0
21 Slapton Sands (Monument)	0	0	0	0	0	0	0	0	0	0
22 Slapton Sands (Torcross)	0	0	0	0	0	0	0	0	0	0
23 Hope Cove	8.3	9.4	10.8	13.9	11.6	18.5	13.8	8.8	26.4	26.4
24 Bantham	5	5.7	6.6	8.6	5.8	2.4	4.1	8.5	0	0
25 Bigbury-on-Sea South	2.4	2.8	3.3	4.3	1.7	2.8	0	0	0	0
26 Bigbury-on-Sea North	0.7	0	0	0	0	0	0	0	0	0
27 Challaborough	8.5	5.9	3.3	4.3	1.7	2.8	0	0	0	0
28 Mothecombe	12.2	9.5	10.9	8.7	11.8	16.8	13.9	26.4	60.8	60.8
29 Bovisand	8.4	9.5	10.9	14	11.8	16.8	25.8	43.6	0	0
30 Millendreath	n/a	9.6	11.1	8.8	1.7	2.6	4.3	8.8	26.4	26.4
31 Pentewan	34.7	28.4	21.1	14.2	1.7	2.8	4.3	0	0	0
32 Polstreath	2.4	0.8	0.9	1.2	1.7	2.6	4.3	8.8	26.4	26.4
33 Port Mellon	2.4	2.8	3.3	4.3	1.7	2.6	4.3	8.8	0	0
34 Gorran Haven (Vault)	2.4	2.8	3.3	4.3	6	2.6	4.3	0	0	0
35 Portluney	12.3	13.9	16.9	14.2	12	17.2	14.2	8.8	0	0
36 Pendower	8.5	5.9	6.8	4.3	6	8.8	4.3	8.8	26.4	26.4
37 Porthallow	13.2	10.8	7.4	7.8	7.4	6.2	6.5	8.2	93.1	93.1
38 Porthostock	0.7	0.8	0.9	0	0	0	0	0	0	0
39 Coverack	16.5	13.9	16.9	14.2	12	8.8	14.2	26.4	60.8	60.8
40 Kennack Sands	0	0	0	0	0	0	0	0	0	0
41 Polurian Cove	5.1	2.8	3.3	1.2	1.7	2.8	0	0	0	0
42 Poldhu Cove	5.1	5.9	6.8	4.3	6	2.8	4.3	8.8	0	0
43 Gunwalloe Cove	0	0	0	0	0	0	0	0	0	0
44 Praa Sands East	0	0	0	0	0	0	0	0	0	0
45 Praa Sands West	0.7	0.8	0.9	1.2	1.7	0	0	0	0	0
46 Perran Sands	2.4	2.8	3.3	4.3	6	8.8	0	0	0	0
47 Porthcurno	0.7	0.8	0.9	1.2	0	0	0	0	0	0
48 Sennan Cove	0	0	0	0	0	0	0	0	0	0
49 Porthreath	0	0	0	0	0	0	0	0	0	0
50 Porthtowan	2.5	2.8	3.3	4.3	6	8.8	4.3	0	0	0
51 Holywell Bay	0.7	0.8	0.9	1.2	1.7	2.6	4.3	0	0	0
52 Crantock	0	0	0	0	0	0	0	0	0	0
53 Fistral Beach	0	0	0	0	0	0	0	0	0	0
54 Towan Beach	5.1	5.9	6.8	8.8	12	8.8	4.3	8.8	26.4	26.4
55 Watergate Beach	5.1	5.9	6.8	8.8	12	17.2	4.3	8.8	26.4	26.4
56 Porthcothan	n/a	n/a	n/a	n/a	n/a	n/a	60.8	60.8	26.4	26.4
57 Treyamon Bay	2.5	2.8	3.3	4.3	6	8.8	4.3	0	0	0
58 Constantine Bay	0	0	0	0	0	0	0	0	0	0
59 Hartland Quay	0.6	0.7	0.9	1.2	0	0	0	0	0	0
60 Woolacombe (Putsborough)	0	0	0	0	0	0	0	0	0	0
61 Woolacombe (Village)	0.6	0.7	0.9	0	0	0	0	0	0	0
62 Bournemouth Hengistbury East	n/a	0	0	0	0	0	0	0	0	0
63 Poole Shore Rd Sandbanks	n/a	0	0	0	0	0	0	0	0	0
64 Shell Bay North	n/a	0	0	0	0	0	0	0	0	0
65 Studland Knoll House	n/a	0.6	0	0	0	0	0	0	0	0
66 Kimmeridge Bay	n/a	12.1	13.8	16.5	22.4	31.1	47.8	69.4	60.8	60.8
67 Lulworth Cove	n/a	8.2	9.3	7.1	9.8	7.3	13.1	8.5	26.4	26.4
68 Durdle Door East	n/a	2.4	2.8	1	0	0	0	0	0	0
69 Durdle Door West	n/a	0	0	0	0	0	0	0	0	0
70 Ringstead	n/a	2.3	2.7	3.5	4.9	7.5	13.6	25.8	26.4	26.4
71 Bowleaze Cove	n/a	0.6	0.7	1	1.4	2.1	4	0	0	0
72 Church Ope Cove	n/a	0	0	0	0	0	0	0	0	0
73 Weymouth Lodmoor	n/a	0	0	0	0	0	0	0	0	0
74 Weymouth Central	n/a	0	0	0	0	0	0	0	0	0
75 West Bay (West)	n/a	0.6	0.7	1	1.4	2.2	4	8.5	0	0
76 Eypemouth	n/a	0.6	0.7	0	0	0	0	0	0	0
77 Seatown	n/a	4.9	5.7	7.3	10.2	18	13.4	25.5	26.4	26.4
78 Charmouth West	n/a	2.3	2.6	3.4	4.8	7.3	13.1	25.5	26.4	26.4
79 Blue Anchor West	n/a	8.6	6.3	4	5.5	6.1	0	0	0	0
80 Bournemouth Jetty	n/a	8.2	7.8	22.7	5.5	8	4.3	7.8	0	0
81 Berrow North of Unity Farm	n/a	25.7	31.7	21.2	5.1	7.5	13.6	23	23	23
82 Bream	n/a	6.2	9.6	7.8	5.3	8	14.2	23	23	23

n/a - data not available

TABLE 2

Bathing Waters		Cumulative Probability of Failure Using Previous Years' Data for Total Coliforms								
		1986-1994	1987-1994	1988-1994	1989-1994	1990-1994	1991-1994	1992-1994	1993-1994	1994
1	Beer	2.4	2.7	3.2	4.2	5.8	8.5	4.1	8.8	28.4
2	Sidmouth (Town)	0.8	0.8	0.9	1.2	1.7	2.5	0	0	0
3	Sidmouth (Jacob's Ladder)	0	0	0	0	0	0	0	0	0
4	Ledram Bay	0.6	0.8	0.9	1.2	1.7	2.5	4.2	8.8	28.4
5	Dawlish Warren	0	0	0	0	0	0	0	0	0
6	Dawlish Town	0.8	0.8	0.9	1.2	1.7	2.5	4.2	0	0
7	Dawlish (Coryton Cove)	n/a	0.8	0.9	1.2	1.7	2.5	4.2	8.8	0
8	Teignmouth (Holcombe)	n/a	2.7	3.2	4.2	5.8	8.5	13.8	8.5	24.6
9	Maldencombe	0	0	0	0	0	0	0	0	0
10	Watcombe	0	0	0	0	0	0	0	0	0
11	Meadfoot	0	0	0	0	0	0	0	0	0
12	Beacon Cove	n/a	0	0	0	0	0	0	0	0
13	Torre Abbey	3.1	3.3	3.8	4.3	5.8	8.8	13.8	0	0
14	Hollcombe	0	0	0	0	0	0	0	0	0
15	Goodrington	2	2.5	0.9	1.2	1.7	2.6	4.3	8.8	0
16	Broadsands	0	0	0	0	0	0	0	0	0
17	Shoalstone	0	0	0	0	0	0	0	0	0
18	St. Mary's	0.8	0.8	0.9	1.2	0	0	0	0	0
19	Dartmouth Castle	0	0	0	0	0	0	0	0	0
20	Blackpool Sands	0	0	0	0	0	0	0	0	0
21	Slapton Sands (Monument)	0	0	0	0	0	0	0	0	0
22	Slapton Sands (Torcross)	0	0	0	0	0	0	0	0	0
23	Hope Cove	0	0	0	0	0	0	0	0	0
24	Banham	0	0	0	0	0	0	0	0	0
25	Bigbury-on-Sea South	0.7	0.8	0.9	1.2	0	0	0	0	0
26	Bigbury-on-Sea North	0	0	0	0	0	0	0	0	0
27	Challaborough	0	0	0	0	0	0	0	0	0
28	Mothecombe	0.8	0.8	0.9	0	0	0	0	0	0
29	Bovisand	0.8	0.8	0.9	1.2	0	0	0	0	0
30	Milendreath	n/a	13.9	15.9	14.2	1.7	2.6	4.3	8.8	28.4
31	Pentewan	30.1	23.4	15.9	14.2	1.7	2.6	4.3	0	0
32	Polstreath	2.4	0.8	0.9	1.2	1.7	2.8	0	0	0
33	Port Mellon	0.7	0.8	0.9	1.2	0	0	0	0	0
34	Gorran Haven (Vault)	0.7	0.8	0.9	1.2	1.7	2.6	4.3	0	0
35	Portluney	5.1	5.9	6.8	8.8	12	17.2	4.3	0	0
36	Pendower	5.1	2.8	3.3	1.2	1.7	2.6	0	0	0
37	Porthallow	81.9	47.8	31.8	32.7	28.4	28.4	28.4	44.9	60.8
38	Porthoustock	0	0	0	0	0	0	0	0	0
39	Coverack	8.5	5.9	6.8	4.3	6	2.8	4.3	8.8	28.4
40	Kennack Sands	0	0	0	0	0	0	0	0	0
41	Pollurian Cove	0.7	0.8	0.9	1.2	1.7	2.6	0	0	0
42	Poldhu Cove	0.7	0.8	0.9	1.2	1.7	0	0	0	0
43	Gurwalloe Cove	0	0	0	0	0	0	0	0	0
44	Praa Sands East	0.6	0.8	0.9	0	0	0	0	0	0
45	Praa Sands West	0	0	0	0	0	0	0	0	0
46	Perran Sands	0	0	0	0	0	0	0	0	0
47	Porthcurno	0	0	0	0	0	0	0	0	0
48	Sennen Cove	0	0	0	0	0	0	0	0	0
49	Porthreath	0	0	0	0	0	0	0	0	0
50	Porthtowan	2.5	2.8	3.3	1.2	1.7	2.8	0	0	0
51	Holywell Bay	0	0	0	0	0	0	0	0	0
52	Crantock	0.7	0	0	0	0	0	0	0	0
53	Fistral Beach	0	0	0	0	0	0	0	0	0
54	Towan Beach	0	0	0	0	0	0	0	0	0
55	Watergate Beach	5.1	5.9	6.8	8.8	12	17.2	4.3	8.8	28.4
56	Porthcothan	n/a	n/a	n/a	n/a	n/a	n/a	28.4	8.8	0
57	Treyamon Bay	0.7	0.8	0.9	1.2	1.7	2.8	0	0	0
58	Constantine Bay	0	0	0	0	0	0	0	0	0
59	Hartland Quay	0	0	0	0	0	0	0	0	0
60	Woolacombe (Putsborough)	0	0	0	0	0	0	0	0	0
61	Woolacombe (Village)	0	0	0	0	0	0	0	0	0
62	Bournemouth Hengistbury East	0	0	0	0	0	0	0	0	0
63	Poole Shore Rd Sandbanks	n/a	0	0	0	0	0	0	0	0
64	Shell Bay North	n/a	0	0	0	0	0	0	0	0
65	Studland Knoll House	n/a	0	0	0	0	0	0	0	0
66	Kimmeridge Bay	n/a	2.4	2.7	3.5	4.9	7.3	13.1	8.5	0
67	Lulworth Cove	n/a	0.6	0.7	0.9	1.3	2.1	3.9	8.5	0
68	Durdle Door East	n/a	0	0	0	0	0	0	0	0
69	Durdle Door West	n/a	0	0	0	0	0	0	0	0
70	Ringstead	n/a	0.6	0.7	0.9	1.3	2.1	4	8.5	0
71	Bowleaze Cove	n/a	0	0	0	0	0	0	0	0
72	Church Ope Cove	n/a	0	0	0	0	0	0	0	0
73	Weymouth Lodmoor	n/a	0	0	0	0	0	0	0	0
74	Weymouth Central	n/a	0	0	0	0	0	0	0	0
75	West Bay (West)	n/a	0.6	0.7	1	1.4	2.2	4	8.5	0
76	Eyemouth	n/a	0	0	0	0	0	0	0	0
77	Seatown	n/a	0.6	0.7	1	1.4	2.2	4	8.5	0
78	Charmouth West	n/a	0.6	0.7	0.9	1.3	2.1	4	8.5	0
79	Blue Anchor West	n/a	2.5	0.8	0	0	0	0	0	0
80	Burnham Jetty	n/a	18.7	9.4	3.8	5.5	8	4.3	7.8	0
81	Berrow North of Unity Farm	n/a	0	0	0	0	0	0	0	0
82	Breen	n/a	0	0	0	0	0	0	0	0

n/a - data not available

Appendix A- Binomial Distribution & Zebra

Using the statistical model of the binomial distribution describes the behaviour of any randomly-sampled process for which there are just two possible results per sample (e.g. pass/fail), and therefore plays a role in the assessment of compliance testing.

The binomial distribution is defined by two parameters: n , the number of times the process is to be observed; and p , the probability of obtaining the outcome of interest (an exceedence, for example) on any one observation. (For example, the binomial distribution describing the possible numbers of sixes in 60 throws of a fair die is $B(n=60; p=1/6)$.)

Worked example :

Calculate the probability of failure based on data available; this can be worked out by dividing the total number of past exceedences by the total number of samples taken, e.g. Burnham Jetty has a total number of samples between the years 1987 - 94 of 169 and total coliform exceedences of 6 therefore the probability (p) of obtaining an exceedence on any one sample (assuming stable water quality) is $6/169 = 0.036$.

The probability $\text{Prob}(r)$ of obtaining exactly r events of interest out of n trials is given by :

$$\text{Prob}(r) = \frac{n!}{(n-r)! r!} p (1-p)^{n-r}$$

Zebra obtains a percentage for $\text{Prob}(r)$ by multiplying the probability by 100.

Using the BinTabl option in Zebra, p is entered along with the number of samples, n , that are taken for each bathing season (i.e. 20). The following output is obtained for Burnham Jetty :

Binomial probabilities for $B\{n = 20; p = 0.036\}$			
r	% Prob. r or less	Prob(r) %	% Prob. r or more
0	48.03	48.03	100.00
1	83.91	35.88	51.97
2	96.64	12.73	16.09
3	99.49	2.85	3.36
4	99.94	0.45	0.51

5	99.99	0.05	0.06
6	100.00	0.01	0.01
7	100.00	0.00	0.00

For non-compliance with the Directive, 2 or more exceedences must occur. Therefore the part of the output that is of interest is the right hand column which gives cumulative probabilities, where the probability of getting 2 or more total coliform exceedences out of 20 samples is 16.09%. (Note : this percentage does not match the one given in Table 2. This is because a spreadsheet was used which increased the accuracy; refer to Appendix B.)

This procedure has been repeated for all sites using data (where available) from 1986-1994 as a cumulative probability to demonstrate the probability of non-compliance for up to 9 years of data.

Appendix B - Alternative to Zebra

Using a spreadsheet (Lotus 1-2-3) to work out the calculations is easier and can be made more automated so that fewer mistakes are made and accuracy is not lost. It can be added to and changed much easier than ZEBRA, with as little work as possible done by hand; additional years' data can be added quickly rather than repeating some of the calculations by hand. Tables can be automatically produced as well as bar charts and any other further data analysis or manipulation which might be necessary to show the data in a preferable format for viewing. This is recommended as an alternative to ZEBRA when doing a large amount of calculations.

All the historical data needed (i.e. the number of samples taken at each site at each year and the number of faecal and total coliform exceedences) has been entered into the spreadsheet. For example :

	A	B	C	D	E	F	G	H	I	J	K	L	M
1			Total	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2	Poldhu Cove	Total Coli Exceedences	1	0	0	0	0	1	0	0	0	0	
3		Faecal Coli Exceedences	3	0	0	1	0	1	0	0	1	0	
4		No. of T.C. Samples	164	12	12	20	20	20	20	20	20	20	
5		No. of F.C. Samples	164	12	12	20	20	20	20	20	20	20	

To update the probabilities to include 1995 data all that is needed is to enter total coliform exceedences, faecal coliform exceedences, number of total coliform samples and the number of faecal coliform samples into the 1995 column. Everything included in the spreadsheet can then be made to automatically update itself, including all the tables and graphs.

Worked example for finding the probability of failure for total coliforms using 1986-1994 data at Poldhu Cove :

For automatic calculation first the Total column needs to be worked out by use of the SUM function, i.e. @SUM(D2..L2) needs to be entered in C2 (assuming the Total for total coli exceedences is cell C2).

The Binomial function built into Lotus 1-2-3 was used to calculate all the

necessary probabilities for the production of the tables and graphs :

`@BINOMIAL(samples predicting for (n); event of interest (r); probability of sample exceedence (p); [probability type])`

In this example $n = 20$; no. of exceedences interested in $(r) = 2$; $p = \text{total exceedences}/\text{total no. of samples} = C2/C4$; probability type = 2 for a cumulative probability (greater than 2 exceedences)

which therefore gives :

`@BINOMIAL(20;2;(C2/C4);2)`

multiply by 100 to produce percentage and round it to two decimal places :

`@ROUND((@BINOMIAL(20;2;(C2/C4);2)*100;2)`

This needs to be done for each required probability to produce the tables given.

Appendix C - Graphs of Significant Sites

The following are graphs of significant sites, i.e. sites which have a risk of non-compliance (faecal or total coliforms) greater than 10% for a least one of the sample sets.





