Southern Water Beachbuoy – Water Quality Review

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Executive Summary

An expert review from a water quality perspective has been undertaken to review the present situation with Beachbuoy (BB) and to make recommendations designed to improve accuracy and user trustworthiness and confidence in the public health predictions provided or implied by the BB system in the future.

The key points from the review are provided below.

1. BB suggests microbial standards for SWS bathing waters which are derived from health-based criteria suggested by the World Health Organisation (WHO) (2003) and adopted by the EU Bathing Waters Directive (BWD) (2006). Having used these health-based criteria Southern Water Services (SWS) need to make improvements to the approach to predict microbial water quality in Beachbuoy since these criteria were designed by WHO (and later adopted by the EU in their Bathing Water Directive (2006)) to predict health risk amongst the bathing community.
2. It is essential to predict intestinal enterococci (IE) concentration with BB as this is the only microbial parameter proven, by the UK epidemiological studies in saline waters (WHO (2003), Kay et al. (1994, 2004a), EU BWD (2006), Pruss (1998)), to predict health outcomes in the bather community. The prediction of IE by BB should be tested and proven with a well-designed testing and validation programme in the SWS bathing zones. This programme must use enhanced precision for the enumeration of IE in coastal bathing waters. Using the enumeration approach which is commonly adopted for regulatory 'compliance' samples

would produce data with insufficient precision for use in modelling (see Table 1 below). Further detail on the sampling is provided in the appendix.
3. The programme design in 2 should be approved by regulators (in this case the Environment Agency (EA) and local public health professionals (e.g. Chief Environmental Health Officers (CEHOs) in local communities).

Through the review, the following recommendations have been made, alongside their timeframes.

1. Updating of the modelling to incorporate percentile values as triggers for the BB warnings. Short term.
2. The model to be updated to include IE in BB alongside EC. Short term.
3. Acquisition of confirmatory data on IE to compare statistically with model predicted values. It is understood that SWS intend to implement this step using the EDM to predict IE in the bathing zone(s). Medium term
4. Expand the modelling effort to cover the other sources of FIOs to the coastal zone from farming, the human population including sewage flows and wildlife. If these sources prove trivial SWS needs to have the empirical evidence to prove this judgement. Long term
5. Validation of the utility of the modelling and prediction efforts in the SWS region needs to be reviewed by the environmental and public health communities, the latter within LAs and NHS, and the former with the EA. Long term.

It is understood that SWS are about to implement the modelling of IE within BB as well as the use of percentile values as triggers for warnings.

Introduction

The job of the independent panel of experts (#4) was to review the present situation and make recommendations designed to improve accuracy, user trust and confidence in the public health predictions provided or implied by the (BB) system in use by SWS Ltd. This is a report of expert #1 (Professor David Kay) who addresses the first area of science defined by SWS Ltd, namely 'Water Quality'. By way of background, he led the UK team which produced the epidemiological data on which the first WHO Guidelines on Safe Recreational Water Environments (GSREW) (2003) were based. These were later adopted by the EU for the BWD (2006) which is still in force within the EU but under active review for the development of a revised (BWD). DK leads the science team, appointed by WHO, to manage the EU request for guidance from WHO on this revision of the BWD (2006).

Context

Some key points on the difficulties of measuring, forecasting and predicting water quality, in relation to Beachbuoy are presented below. All of these points should be taken within the context of what BB is and is not currently modelling. It is understood that SWS recognise that in BB they are only modelling the impact of the operation of their overflows (as measured by data derived from event duration monitors (EDMs)), and they are not intended, i.e. by SWS Ltd, to provide general advice on whether beach users should bathe or not (although this position taken by SWS Ltd may be lost on the bather community who will follow the health risk assessment which are implicit in WHO and EU microbial standards and designed to safeguard bather health). However, the points below should be taken into consideration in future updates of the modelling. It is also understood that SWS are about to implement the modelling of IE within BB as well as the use of percentile values as triggers for warnings.

1. Beachbuoy assumes that the Event Duration Monitoring (EDM) component of faecal indicator organism (FIO) concentrations at multiple compliance points can be modelled (i.e. predicted by hydrodynamic modelling). Previous work by DK's team suggests this may not be possible if past compliance data is used and not dedicated enhanced precision FIO quantification. The poor precision of compliance FIO concentrations (Table 1 below see also Figure 1) suggests this may be difficult as it will reduce the explained variance of such models. Further understanding as to why there is this poor precision is an active area of research. Enhanced precision of the FIO concentrations and dedicated measurement using such enhancement has proven successful in other projects where statistical multivariate models have produced explained variances over 80% at UK bathing waters seeking to enact the WHO Annapolis Protocol (1999) to underpin 'prediction and discounting' systems suggested in the WHO GSRWE (2003) and incorporated by the EU in the BWD (2006) (See Figures 1 and 2 below). Such dedicated sampling may prove useful for model construction, but it will be intensive and hence expensive. The team developing this predictive modelling have commonly collected enhanced precision samples for IE at half hourly intervals for 12 hours per bathing day on 60 bathing days per study (i.e. with QA samples approximately 1600 samples are analysed for the dependent variable with potential predictors including antecedent incident radiation, river and sewerage flows to the bathing water, tidal state in the period prior to sample collection and any other potential predictors considered explanatory at the site). Importantly, at other UK sites, modelled by water companies and regulators, a full range of FIO sources have been included in models: e.g. livestock farming, street runoff from urban areas, avian and other animal (e.g. seals) sources on the inter-tidal areas or in adjacent land draining to the bathing water. The measurement and inclusion of other sources should be built into the modelling systems seeking to address the EDM component alone. This data acquisition is normally called quantitative microbial source apportionment (QMSA) and it is considered by the present author as an essential step prior to modelling with EDM based data. Further information on the sampling is provided in the appendix.
2. This type of broader empirical sampling and analysis has in past studies offered reliable models which 'may' also be able to predict the EDM (i.e. stormflow) component of FIOs at a number of compliance points impacted by water company assets but it would be sensible to extend this approach (i.e. QMSA) to the SWS impacts at modelled DSPs and, if possible, build in the livestock, wildlife and other FIO impacts at any modelled sites.
3. Assuming such high explained variance models (i.e. perhaps over 80% explained variance in regulatory FIOs including IE as seen elsewhere) can be calibrated and, following robust peer review, such models may be considered as proven suitable for accurately predicting the FIO concentrations at compliance sites alleviating the need for data collection after the first year of the investigation. This will be challenging given: (i) the high within-day variability (i.e. 100 to 10,000 fold every day) uncovered at all UK sites examined to date and (ii) the effect of the sampling position on the tidal sampling transect which can produce an 'excellent' EU grading for the lower quartile of samples along the transect and an EU grading of 'poor' (i.e. EU Fail) for the quartile of samples taken from the upper transect nearest to the high water mark. This UK sampling activity and related

observations derives from EU and UK Agency (e.g. Natural Resources Wales) funding which has not yet been subjected to proper peer review in the scientific journals. However, to provide early exposure to these data SWS has received a copy of the latest study reported (i.e. in 2023) for Nolton Haven bathing water in Pembrokeshire which was funded by the EU Ireland-Wales programme. The spatial and temporal patterns outlined above have been evident at all 7 UK bathing waters so examined.

4 If this is the case, then the use of water quality (e.g. IE models) may be fruitful. For example, with appropriate calculation regarding the log_{10} standard deviation and log_{10} mean of the observed or possibly predicted FIO concentration sequences could be used to predict red days when GI illness of >10% in the bather cohort would be expected, leading to RED period warnings to the bather cohort.

5 If this process was considered 'credible' to the public, regulators and public health professionals, it could furnish a useful means of giving warning to the public and driving the 'prediction and discounting' provision recommended by WHO and adopted by the EU in the BWD (2006). This process can also be very useful in enhancing bathing beach compliance. This was seen at the first Welsh site so modelled (Cemaes Bathing Water in North Wales) which was a Poor (i.e. non-compliant) bathing water at the time of sampling in 2017 but moved to an Excellent grading in 2021 following the application of prediction and discounting as recommended by WHO and allowed in the EU BWD (2006).

6 However, this process needs professional planning and proper funding and will not be achieved using existing regulatory compliance data in the view of the expert advisor on Water Quality (i.e. DK).

Review Questions

Questions posed of the **Water Quality Expert** in the invitation letter of 10th February 2023 from Dr Nick Mills.

Human Health Implications

(NB this cannot be addressed credibly without IE measurements or accurate predictions in the exposure area with enhanced precision enumerations of the IE cfu/100ml).

Question 1 - Does Beachbuoy (BB) comply with present UK Government H&S legislation?
This is difficult to assess with certainty, perhaps the most relevant legislation is the Bathing Water Directive (2006). From a public health perspective, design of the Bathing Water Directive is based on UK epidemiology and approved by the World Health Organisation. The Bathing Water Directive defines 'Fail' or 'Poor' water quality as having a >10% risk of GI in the bather cohort and the Good condition on 5% risk of gastrointestinal (GI) illness risk (as recommended by WHO (2003)). However, in marine waters, this is predicted by IE **not** *E. coli* which does not seem to be modelled by the present incarnation of BB although the prediction of IE by BB is envisaged by the SWS team leading this initiative. The BB system is only designed to model counts derived from storm flow inputs to the bathing zone. However**,** SWS do acknowledge that there are other FIO fluxes to the bathing zones from treated effluents, livestock farming areas industrial effluents and dredge spoils. The papers by Kay *et al*. (1994 and 2004), Pruss (1998) and WHO (2003) explain how these studies were

used to develop the water quality criteria for marine waters outlined in Kay *et al*. (1994 and 2004a): and WHO GSRWE (2003) and later for German fresh waters by Weidenmann *et al*. (2006). It is understood that SWS are about to implement the modelling of IE (alongside EC) within BB as well as the use of percentile values as triggers alongside upper percentile values for warnings.

Question 2 - Identify all circumstances where BB users are not receiving red warnings when they should be. **Is this a problem for BB users?** In order to fully answer this question it is most important to see sufficient enumerations of the IE concentrations at marine bathing sites (measured with enhanced precision (i.e. not 'compliance' samples which are enumerated with poor precision at regulated UK bathing waters)) and calculate 95%ile compliance values at these bather-exposure sites. Currently this data is not available to answer this question fully. My concern expressed in point 1 above (in this Section of my report) might be taken to imply a systematic underestimate of risk because only the storm data is being predicted by the EDM data recorded and used for prediction? The WHO (2003) water quality guidelines listed above really makes measurement of IE in the bathing sites essential as only IE is correlated with health effects in marine waters. It is understood that SWS recognise that in BB they are only modelling the impact of the operation of their overflows, and they are not providing general advice on whether beach users should bathe or not.

Question 3 - Identify ALL Circumstances where BB users are incorrectly receiving RED warnings whilst there is no real threat. Is this a problem for BB users? As with question 2 above, in order to fully answer this question, it is important to see sufficient IE data (e.g. intensive sampling over the bathing water season) measured with enhanced precision. Due to the very high imprecision in FIO enumerations (as in regulatory compliance samples) enhanced precision through new acquisition of IE data, at the regulated bathing waters, is essential if this assessment is to retain scientific credibility.

Question 5 - Identify ALL undocumented threats to bathing waters examples to include:

- Lavant (Chichester Harbour),

- Eastney Long Sea Outfall (several bathing waters in Eastern Solent),

- Budds Farm (Chichester Harbour intermixing with Langstone Harbour),

- CSOs in the tidal River Medina up to Newport impacting Cowes/East Cowes and Gurnard beaches.

Are these a problem for BB users?

Given that IE is the only FIO to indicate health-based threats, its omission from the current BB monitoring system (where enhanced precision would be possible and is essential) makes this assessment difficult. Imprecision in regulatory compliance samples at bathing waters makes it difficult to undertake a scientifically credible and evidence-based assessment Table 1). Further advice from the modelling expert should be taken in response to this answer.

Question 6 - Identify cumulative threats from discharges within harbours/rivers/estuaries/etc. where ALL Blue Flag beaches are unexpectedly affected e.g. West Wittering (from Chichester Harbour outfalls) and Hayling Beachlands (from Langstone Harbour Outfalls). Are these a problem for BB users? From a bathing water quality perspective, the cumulative impacts would come from many different sources of FIOs (not just storm overflows predicted by EDMs). Again this would need model validation against the FIO parameter IE which does not seem to have been done (but is planned) and must involve enhanced precision enumeration of the IE parameter. All relevant FIOs have multiple sources in addition to EDM storm flows: e.g. (i) land surface fluxes from livestock discharged via rivers; (ii) avian and other animals (e.g. donkeys and seals) on the intertidal areas; (iii) treated effluents, especially at times of high flow when plant retention times may reduce; and (iv) effluents from boat traffic with informal effluent disposal facilities. It is recommended that modelling is updated to take into account the numerous sources of FIOs in bathing waters, which can have counter-intuitive cumulative effects, and that SWS are about to implement the modelling of IE (alongside EC) within BB. Further advice from the modelling expert should be taken in response to this answer.

Question 7 - Identify ALL outfalls, anywhere on the Southern Water patch, that have yet to be linked as a threat to bathing waters. The most recent example is Peel Common affecting Portsmouth (modified in 2021). Peel Common has been operational for decades. Are these problematic for BB users? Model predictions for IE at bathing sites would be needed to start delivery of this component and it would require wider data on worst case scenarios that only the modelling expert(s) could provide. Disinfection of effluents can be effective but the presence of this treatment step and its effectiveness would need well designed sampling programmes to acquire real-world and representative (i.e. credible) data which are an essential first step. It is understood that SWS are constantly reviewing and updating which fluxes of FIOs have the potential to impact bathing waters and are going to be including IE (alongside EC) within the modelling.

Question 8 - Is the upper limit of 500 cfu/100ml (NB the 500/100ml figure is not a 'limit value' it is an upper percentile DK) a reasonable for Escherichia coli (EC) when most of the 83 bathing waters show EA testing well under 100 cfu/100ml during the bathing season. Southern Water says "in our area, 80 out of 84 bathing waters are rated excellent or good, with none rated poor". Should the limit be reduced to say 250? The assumption in this question that you can define a limit value from a percentile value is simply wrong. It is important to recognise that the BWD (2006 page 46 of 64) does not specify 'limit values it does specify a 90%ile value of 500 cfu/100ml for (*E. coli*.) This is not an upper limit value (or single sample threshold), rather it is a 90%ile value, Depending on the $\log_{10}$ standard deviation and geometric mean of the samples collected at the bathing water the $\log_{10}$ mean value needed to achieve the 90%ile standard may be quite low, certainly much less than 500 cfu/100ml (see EU BWD (2006) Page 48 of 64). BB would have to generate long sequences of predicted IE values to allow this prediction run to produce a sufficient 'n' value of perhaps weekly model predictions. A value for 'n' suggested by WHO is a minimum of 100 samples used for the required upper percentile limit values indication 10% risk of gastroenteritis. I note the 'fail' percentile may only rarely be exceeded given the number of good quality bathing waters in the SWS region. Recent intensive sampling and analysis by CREH suggests that the likely GM value for IE to produce am EU BWD compliant bathing water is in the range 33/100ml (Nolton Haven) to 39/100ml (Swansea bathing water) These were outcomes of the EU funded Acclimatize and Smart Coasts projects and the Nolton Haven report has been sent to SWS. It is understood that SWS are about to implement the modelling of IE (alongside EC) within BB as well as the use of percentile values as triggers alongside maximum values for warnings.

Question 9 - Should the pathogen Intestinal enterococci (IE) be modelled in BB given EA sampling routinely shows IE significantly higher than EC (i.e. composite modelling) treated and storm vol. microbial parameter predicted by BB. Given the epidemiology used in standards design by the WHO and EU for marine waters (WHO GSRWE (2003) EU BWD (2006)). BB should be developed to predict IE in marine bathing waters as per the bathing waters under consideration in SWS. I understand that the recommendation to predict IE has been accepted by SWS. It is worth noting that IE is more correctly described as a Faecal

Indicator Organism (FIO) rather than a pathogen**.** It is understood that SWS are about to implement the modelling of IE (alongside EC) within BB as well as the use of percentile values as triggers alongside maximum values for warnings.

Question 10 - Propose how BB could distinguish between discharges involving rainfall and discharges of raw undiluted sewage caused by infrastructure failure. Typically these are "disguised"/"camouflaged" as stormwater discharges e.g. Event id 638885 (Bexhill). Maybe these should attract black or skull and crossbones icons? Improved monitoring is needed to understand the sources. The sources of effluent in discharges from the sewerage system and other inputs will generally not be quantified by standard FIO analyses some distance from the input flux but, rather, they can be quantified by phage tracing (i.e. with harmless viruses) tracing as is approved by the Marine Management Organisation (MMO). A well-designed phage and sampling study could afford this type of information on relevant contributions from different assets or contaminated areas. It is understood that SWS are working on distinguishing infrastructure failures within BB.

Question 11 - Consider Beachbuoy could be extended to cover all shellfish water and bathing water points from Bracklesham Bay in the east to Totland Bay in the west would therefore provide the level of coverage appropriate to the leisure water users of the Solent. For the reasons outlined above, I could not recommend the spatial extension of the present system at this time. The central problem with BB is not its spatial coverage but, rather, its methodology which measures the wrong microbial parameter for marine bathing waters as outlined above. As noted in question 9 above in this section, I understand that the recommendation to predict IE has been accepted by SWS. Additionally different standards are used for shellfish waters.

<u>**Automatic Review Process**</u>

Question 1 - Is the use of single "pixel" (just a few square metres on the ground) automatic "sampling" reasonable on a multi-km long beach particularly considering the juxtaposition of the "pixel" with outfall threats. (e.g. Eastney) Carefully planned spatial sampling (not modelling) would be essential in making this judgement of whether information from a small pixel surrounding an automatic monitoring point or modelled elevation in IE cfu/100ml was sufficient to define health risks for a multi-km stretch of bathing waters. It is understood that SWS are reviewing the process for identifying the extent of the bathing water areas.

Question 2 - Is the use of 1, 3 & 12 hour tidal assessments reasonable given so many discharges are well in excess of 12 hours in duration and frequently multiple hundreds of minutes in duration. All in the context of T90=40 hours (i.e. 3 tidal cycles) T_{90} values are highly dynamic in the marine environment due to diurnal effects of UV irradiance and the dynamic nature of entrained turbidity in the vicinity of the bathing areas. In my view, the chosen T_{90} values need empirical validation by laboratory and/or field (i.e. in situ) experiments (see Kay et al. (2004b) below. It is understood that SWS will use a variable T_{90} in the updated model.

Question 3 - Is it reasonable for the "initial" impact/no-impact assessment to stick with the event for its lifetime of tens or even hundreds of hours. Does the impact/no-impact assessment get routinely recalculated. There should be real-time event monitoring in my view, but this would require real-time monitoring data and model runs. BB updates every hour with EDM. Further advice from the software and systems expert should be taken in response to this answer.

General modelling

Question 3 - Reassess all outfall threats to bathing waters should Automatic Review Process scope #4 (above) should parameter modification that extends the reach of outfall pollution be required. This should include all outfalls irrespective of being 10km distant. I have been informed that the 10km distance has been revised and all outfalls which have the potential to impact are considered regardless of distance. Further advice from the modelling expert should be taken in response to this answer.

Question 4 - Would both volumetric and duration data be more helpful to BB users. Volumetric discharge data is far more informative than time (because of significant outfall diameter variations) The level of risk is after all directly proportional to the volume of sewage effluent not its duration. I am not really sure how volumetric data could be communicated to the public (if this was just EDM information it would potentially miss a great deal of explanation of other pollution sources and of health risk as stated above).

Question 5 - Should the cumulative effects of multiple outfall threats from single and/or multiple bathing waters be modelled. Currently the impact of each discrete discharge from each and every outfall on each bathing waters are considered entirely in isolation. There is significant oversight here causing significant RED flag suppression (eg Cowes/Gurnard area). Yes if only to prove such effects from other pollution sources were minimal (if indeed they were thought to be minimal). It is understood that SWS plan to provide cumulative impacts from releases in the future.

Question 6 - Could any discharge events, at any time, be masking or camouflaging other discharges irrespective of status. Of course, unless this has been tested with phage tracer studies, which are approved by MMO, and can quantify effluent dilution approaching 10^{15}, and provide information on different sources of pollution. Further advice from the software and system expert should be taken in response to this answer.

Question 7 - Is there a problem with modelling discharge inputs into harbour/river/estuary confined bodies of water. *E. coli* longevity (i.e. T_{90} values will vary they are highly dynamic: see Kay et al (2005) below), dispersion and advection is going to be different in confined water spaces as compared with the open sea. Is this more concentrated material from a confined body of water considered in the modelling from a limits perspective? (e.g. a discharge into Langstone Harbour will come back when the tide turns and affect a bathing water like Eastney in less than 12 hours when initially no impact). NB *E. coli* is irrelevant for any health risk evaluations in marine waters. This approach could be deployed to address such situations under different tidal conditions. I have no expert view on how this could be modelled but the MMO approved phage tracers have been deployed to inform the modelling process for UK water companies. However, very different microbial decay rates may be experienced in a turbid harbour environment within a stream-dominated estuarial system. It is understood that SWS will use a variable T_{90} in the updated model.

Question 8 - How would real time satellite tidal/cloud data and other real-time data sources improve BB accuracy and levels of user trust. Copenhagen's well respected and trusted system uses real time data, is this considered best practice? Real-time data could only improve the modelling effort in my non-expert view. It is understood that SWS plan to change to a system of using more real-time data in the future, ideally using modelling of each release as it occurs with appropriate and sufficient calibration data.

Question 9 - Are there any missing BB features from the reviewer's perspective. It should be modelling IE concentrations with a high level of field data collection to be used for model verification and calibration. It is understood that SWS plan to incorporate IE into the modelling (alongside EC) in the model update.

Question 10 - Consider how closely the software modelling tools used map to the unique tidal environment of the Solent over a rolling period of at least 14 days, understanding the applicability of the models to the local conditions within the Solent system and capturing the change in effect across the tidal cycle from neaps to springs. I would need to review empirically gathered marine and local T_{90} data to make this judgement. However T_{90} is highly dynamic, see Kay *et al*. (2004b) below, and varies through the day in response to solar irradiance and is affected by changes in nearshore turbidity which is often impacted by sediments washed into nearshore zones. Further advice from the modelling expert should be taken in response to this answer.

Question 11 - Focus on the decision process behind the recently adopted category of non-impacting discharges. Given the cyclical movement of water within the Solent over many tidal cycles, it is difficult to understand how a decision that a discharge is 'non-impacting' can be made. It would be helpful if the review could report on the level of confidence that could be applied to the output. MIKE21 is a long established and respected suite, but it is important to assess the accuracy of its models as used within the unique Solent environment What is the empirical evidence, for and against, this assumption of cyclical effects within the Solent, what is its observed and measured periodicity and does this affect water quality within the Solent? EDM data alone are not enough to investigate this potential problem. It is certainly the case that FIO inputs to bathing waters is impacted by urban runoff, livestock farming, sewage treated effluents, stormflows and avian and intertidal defecation by avians and other species. Further advice from the modelling expert should be taken in response to this answer.

Question 12 - The report should assess whether the modelling adequately covers the various tidal flows and back eddies throughout the Solent and through each tidal cycle when assessing the level of impact over 24 hour and 72 hour time frames. As a non-modeller, I cannot make authoritative judgement on this matter it will depend also on the availability of precise temporal water quality data of high spatial resolution. Further advice from the modelling expert should be taken in response to this answer.

Question 13 - Review whether the volumetric loadings and conversion from duration applied in the model are appropriate representation. Volumetric loadings and conversion from duration: again, this a question for the modeller I do not have expertise in this area. Assumptions and predictions of FIOs on discharge dynamics and peaks to the coastal zone can only be fully addressed by well-designed sampling programmes focused, as a minimum on the local sewerage system. Further advice from the modelling expert should be taken in response to this answer.

Documentation

Question 1 - Is current supplementary BB information in the public domain misleading or inaccurate. This needs to be corrected. I have read the descriptions of Beachbuoy on the Southern Water www site accessed at https://www.southernwater.co.uk/water-for-life/beachbuoy/information. The statements made there are, in my view, correct and balanced, indeed the specific criticisms of the overall project are made possible given the openness and candour with which elements such as (i) the prediction of EC rather than IE; (ii) the lack of confirmatory sampling and enhanced precision enumeration (of IE) to validate the SWS predictions in particular. If the recommendations coming out of the water quality review are acted upon, then documentation and statements on the site can be updated. This candour augers well for the development and improvement of Beachbuoy into the future.

Discussion

The Independent Review 'Scope' was defined by SWS in their Document dated February 2023 and its objective was defined to deliver near-real-time data to water users delivered by consistent, reliable and credible near-real-time warnings of potential water quality impacts from storm overflow releases. Importantly this letter dated 10th Feb 2023 states on Page 1 that:

> *'Beachbuoy is a web-based tool developed by Southern Water that provides near real time information about storm release activity near coastal bathing waters in the SW region.'*

If this is a correct statement, it clearly implies that only the storm system is modelled and all resultant management and water quality effects are only determined by this flux which could be measured by an EDM system.

This WHO report and standards were later adopted by the EU forming the scientific basis of the Bathing Water Directive (2006). This close WHO/EU collaboration has continued to the present, evinced by the WHO consultations with the EU in 2018. The UK epidemiology was originally used by WHO and EU as a basis for water quality standards because of its protocol design (i.e. based on randomised controlled trials at 4 UK bathing waters (Pruss (1998)) and the strong relationship linking intestinal enterococci (IE) concentrations in the bathing zone to reported rates of gastroenteritis amongst the bather cohort (Kay *et al.*, 1994). The design of the WHO Guidelines in 2003 was later published by Kay *et al*. (2004). The WHO Guidelines (2003) defined upper 95 percentile (%ile) values for only 'intestinal enterococci' which were related to observed rates of gastroenteritis experienced by the bather cohort of:

WHO (2003)

<1% GI illness 95th percentile IE <40/100ml

1-5% GI Illness 95th percentile IE <200/100ml

5-10% GI Illness 95th percentile IE <500/100ml

>10% GI Illness 95th percentile IE >500/100ml

WHO (2003) Table 4.7 Page 70

The WHO have, to date, only suggested these water quality standards based on 95 %ile values for IE. The original research which underpins this approach was based on epidemiological studies in UK saline (i.e. marine) bathing waters (published in the Lancet and Water Research: see (Kay *et al*., 1994 and 2004) but the EU has parallel *E. coli* standards for both marine and fresh water systems and both 95%ile and 90%ile values are suggested by the EU for both water types (in the 2018 report to the EU by CREH, this duality in percentile use (i.e. 90%ile and 95%ile) was advised against as potentially confusing). The WHO science team acted as advisers to the EU for the design of bathing water quality standards during the EU Directive's more recent revision in 2018.

Thus, it is feasible to relate water quality (expressed as a statistic (e.g. 95%ile in the case of WHO (2003 Page 70)) describing the probability Density Function of IE in marine waters) to % rates of excess gastroenteritis in the bather cohort. This might practically be best delivered using the upper 95th %ile values (i.e. not the EC standard as defined in the EU Bathing Water Directive (2006)) which are associated with 'Poor' water quality (defined as >10% risk of GI illness). The use of EC in this regard is questionable as it is not related to any GI level in the UK epidemiological research used by WHO (2003).

Therefore, key recommendations from this review are the use of IE and percentile values in the modelling. It is understood that SWS are about to implement the modelling of IE (alongside EC) within BB as well as the use of percentile values as triggers alongside maximum values for warnings.

If this 10% GI illness threshold is agreed as the RED warning level for marine waters, then Beachbuoy predictions of a 95%ile value could be a practical way to proceed. However, calculation of this threshold for IE would require information on the $\log_{10}$ geometric mean of the sequence of IE values /100ml predicted or observed at the site and the $\log_{10}$ standard deviation of the sequence of IE values /100ml predicted or observed at the site. The required calculation is described in the Bathing Water Directive (2006: Page 48 of 64). In Kay *et al.* (2004 see Pages 1301-2), a large multi-site EU data set (i.e. using 11,000 bathing sites and 121,000 IE enumerations) was used to define the observed $\log_{10}$ standard deviation for IE as 0.8103 and this value was used in the derivation of the numerical 95%ile values for IE used by the EU. Given its use for the design of the WHO and EU water quality standards now in force, this approach could be used here in calculating IE 95%ile values for the BB sites in the SWS region.

Therefore, a key recommendation from this review is further detailed sampling at bathing water sites using enhanced precision.

Recommendations in order of priorities

The recommendations which have come out of the independent water quality review of Beachbuoy are provided below.

1. Updating of the modelling to incorporate percentile values from the as triggers for the BB warnings. Short term.
2. The model to be updated to include IE in BB alongside EC. Short term.
3. Acquisition of confirmatory data on IE to compare statistically with model predicted values. It is understood that SWS intend to implement this step using the EDM to predict IE in the bathing zone (if possible). Medium term
4. Expand the modelling effort to cover the other sources of FIOs to the coastal zone from farming the human population including sewage flows and wildlife. If these sources prove trivial SWS need to have the empirical evidence to prove this judgement. Long term
5. Validation of the utility of the modelling and prediction efforts in the SWS region need to be reviewed by the environmental and public health communities, the latter within LAs and NHS, and the former with the EA. Long term

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Appendix

Further information on the proposed sampling that could be undertaken as part of Beachbuoy are provided below.

Option 1 One way forward in the present project

If it was decided to present actual GI levels based on the predictive power of IE to predict GI levels as suggested by the original UK RCTs. This could be delivered by acquisition of multiple samples, with enhanced enumeration precision at the bathing water DSPs of interest. This sampling and analysis could overcome the imprecision in UK 'compliance' samples. The 'enhanced precision' IE data could potentially be linked to EDM model predictions for the same locations (although it may be prudent to extend these predictions beyond the EDM contribution to FIOs at the DSPs of interest). The sampling with enhanced precision has at other sites involved half-hourly samples taken at each location for 60 bathing days in the 20 week bathing season. Enhanced precision for the 25 IE samples/day has been achieved by: (i) not having all samples diluted by a 10 fold dilution before analysis and (ii) triplicate filtration of all samples (see Table 1 for error bars on the present enumeration of FIOs) . This is expensive but important. This protocol has been accomplished at 7 Welsh sites with EU and NRW funding as part of an approach designed to improve the predictive power of statistical (i.e. multiple regression) models used in a 'prediction and discounting' framework as recommended by WHO (2003) and incorporated by the EU in BWD (2006) (see model results for Swansea DSP in Figure 2 below). This allows the discounting (non-use in later percentile calculations) of any elevated FIO concentrations from the, WHO recommended 95%ile calculations (NB no EC-GI relationships were found in the UK RCTs which formed the basis of WHO (2003) and BWD (2006) water quality recommendations. Such discounting is only allowed if the potentially bathing public have been given warning of the predicted elevations in FIO concentrations before they decide whether they and/or their family should enter the water on that particular day. Given that the laboratory enumerations of IE commonly take 72 hours, this discounting and provision of 'informed choice' operative within the bathing day can only be delivered by the type of modelling and prediction now possible at the 5 of the 7 Welsh sites sampled. Models with high predictive power have been delivered at 4 of the 5 EU funded sites (i.e. exceeding 80% explained variance). Two additional sites (funded by the Welsh Government and managed by Natural Resources Wales) are currently being sampled during the 2023 bathing season (i.e. making 7 Welsh sites available for modelling by 2024). We have sought to test the predictive power of traditional hydrodynamic modelling at one site (Swansea Bay see Figure 1)

Using the enhanced precision sampling undertaken along the sampling transect as ground truth data predicted by a hydrodynamic model calibrated for the site with the enhanced FIO (IE) enumerations as the dependent variable. This analysis uncovered a low explained variance (see Figure 1 below) for the hydrodynamic model in predicting the enhanced enumeration of these individual (i.e. spot) samples along the DSP of less than 0.1%. This testing and analysis is difficult and costly involving intensive sampling and multiple model runs for a single site, but it does suggest that model predictions of FIO concentrations, let alone EDM contributions to FIO concentrations at a compliance site, should be treated with some caution. If the combined EDM (and other FIO source) models results and intensive sampling at multiple sites is analysed after the first season of sampling and previously agreed high explained variance (e.g. >75%) between the model predictions and enhanced precision samples is proven empirically, then use of model predictions for additional locations may be accepted by the wider science community, but this must be pre-discussed and agreed by the relevant regulatory water quality and public health agencies (e.g. EA, DEFRA, local CEHO, NHS (Colindale and local officers) BFI, SAS, local citizen science groups, etc.

Option 2

Given agreement of the agencies above (as a minimum) the project management team may wish (with their partners) to drop the sampling and analysis if it is agreed that the EDM data has a high explained variance with the sampled data in Option 1. If it does not, I would strongly recommend dropping this, EDM driven, modelling as a predictive tool in any future investigations. Figure 2 shows a plot of predicted FIO concentrations with enhanced precision samples at the DSP in Swansea Bay.

Estimated count and 95% confidence intervals for the number of organisms in a 100 ml sample, where, after dilution, a subsample is examined

Organisms observed in the subsample	10-fold dilution		100-fold dilution	
	EC	CI	EC	CI
10	100	50-180	1000	480-1830
50	500	380-650	5000	3750-6640
100	1000	820-1200	10000	8190-12200

EC = estimated count.
CI = 95% confidence interval.

Table 1 Confidence intervals on bacterial enumerations (EC) with different dilution factors

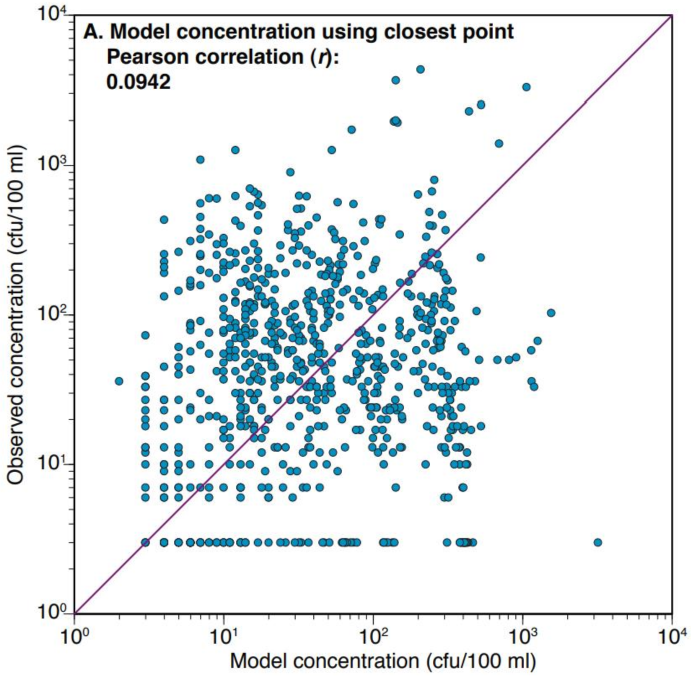

Figure 1 Hydrodynamic modelled concentrations of IE along the DSP transect in Swansea Bay (x-axis) plotted against observed concentrations of IE (y-axis) using enhanced precision for this parameter)

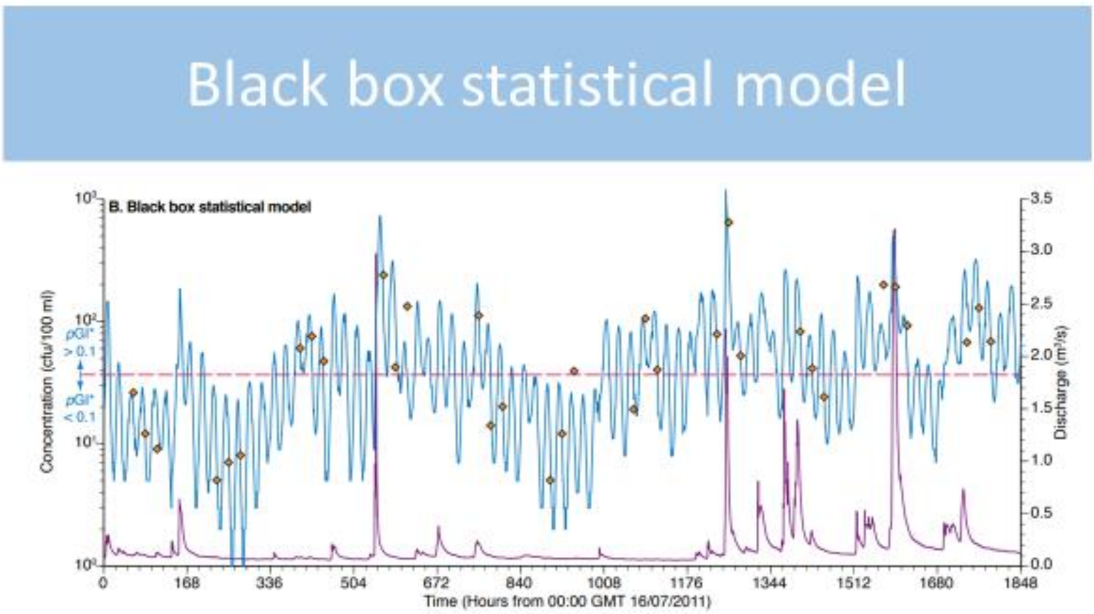

Figure 2 Multiple regression predictions (blue line) with geometric mean calculations (orange diamonds for the 2011 bathing season at the Swansea DSP. Note the capacity of the model to predict elevations in gastroenteritis over 10% which might be a suitable red-flag condition for IE where ‘discounting’ could raise levels of compliance against the EU BWD (2006).