Newcastle Bathing Water Study – A Case Study for the Revised Bathing Water Directive

I .T. Clifforde[1]*, S. Quinn[2], P. Martin[1] and M. Magill[3]

[1] *Black & Veatch, Grosvenor House, 69 London Road, Redhill, Surrey, RH1 1LQ, England, UK.*
[2] *Black & Veatch, Beechill House, Beechill Road, Belfast BT8 7RP Northern Ireland UK.*
[3] *Northern Ireland Water, 34 College Street, Belfast, BT1 6DR Northern Ireland UK.*

**Corresponding author, e-mail cliffordei@bv.com*

ABSTRACT
The paper describes a study undertaken to determine the causes of historic failures of the bathing water standards in Dundrum Bay, Northern Ireland and to plan cost effective upgrading measures for the urban drainage system of the town of Newcastle such that the requirements of both the current and Revised Bathing Water Directives would be met. A comprehensive impact assessment approach was adopted, the results of which were unexpected in that the primary cause of historical failures was found not to be the intermittent combined sewer overflow discharges as had been supposed. Instead, the secondary treated effluent from the town's treatment works was demonstrated to be the cause. The study demonstrated that compliance with current standards could only be achieved by enhancing the treated effluent quality or discharge location. Moderate additional in-system storage to reduce the frequency and volume of the intermittent discharges would also "future proof" the scheme by ensuring compliance with the more stringent standards of the Revised Directive.

KEYWORDS
Bathing Water Directive; revised Bathing Water Directive; marine compliance assessment; urban drainage system optimisation.

INTRODUCTION

This study was undertaken by Black & Veatch for DRD Water Service (now Northern Ireland Water Ltd.) to investigate the causes of failures of the bathing water standards at three designated bathing waters in Dundrum Bay, County Down. The paper describes the existing drainage system, the problems experienced in the bathing waters and the study methodology, before going on to present and discuss the results. The results identified an unexpected cause for the bathing water compliance problems experienced in the area. The study goes on to look at issues associated with compliance with the requirements of the Revised Bathing Water Directive (2006/7/EC).

CATCHMENT DESCRIPTION & EXISTING SYSTEM PERFORMANCE

The town of Newcastle is one of the most popular and attractive holiday resorts in Northern Ireland, located on the shores of Dundrum Bay at the foot of the Mountains of Mourne (see Figure 1).

Photograph reproduced by permission of K McGrady

Figure 1: Newcastle and Dundrum Bay from Mountains of Mourne

The town of Newcastle has a winter population of approximately 8,500 which rises to 12,000 during the summer holiday season. The Rivers Shimna and Glen, flow through the town and discharge into Dundrum Bay. The town is served by a predominantly combined sewer system which includes a total of 25 combined sewer overflows (CSOs) and emergency overflows (EOs). The majority of the CSOs spill relatively frequently either to the rivers or directly to Dundrum Bay. Base flows in the sewer system pass to a secondary treatment plant located at the southern end of the town. The works has a compact footprint and is fully enclosed. Treated effluent from the works is discharged via a short sea outfall extending approximately 300m from the shoreline. Figure 2 illustrates the geographical arrangement of the catchment and the major discharge locations.

There are three designated bathing waters within Dundrum Bay. The Bay is a relatively shallow water body with a large inter-tidal area. Tidal currents are generally slack with wind induced currents dominating water movements in the area.

A Drainage Area Planning (DAP) study was undertaken for the Newcastle urban drainage system between 2003 and 2005 to address the issues of frequent CSO operation and other known operational and asset condition shortcomings within the sewer network. The designated bathing waters within Dundrum Bay were known to fail Bathing Water Directive (BWD) Guideline Standards on a regular basis and rarely the Mandatory Standards. The DAP indicated that a volume of approximately 3,500 m^3 of in-sewer system storage would be required to achieve the default standard of 3 spills per bathing season from the aggregated Newcastle drainage system. Construction of so large a storage volume was considered to be unacceptably costly for a relatively small catchment. Moreover, finding a suitable site to build a tank of this volume within the confines of the urban area was difficult. Hence, an alternative approach to planning the investment needs for the network was proposed based on an impact assessment of the urban drainage system discharges on the marine environment.

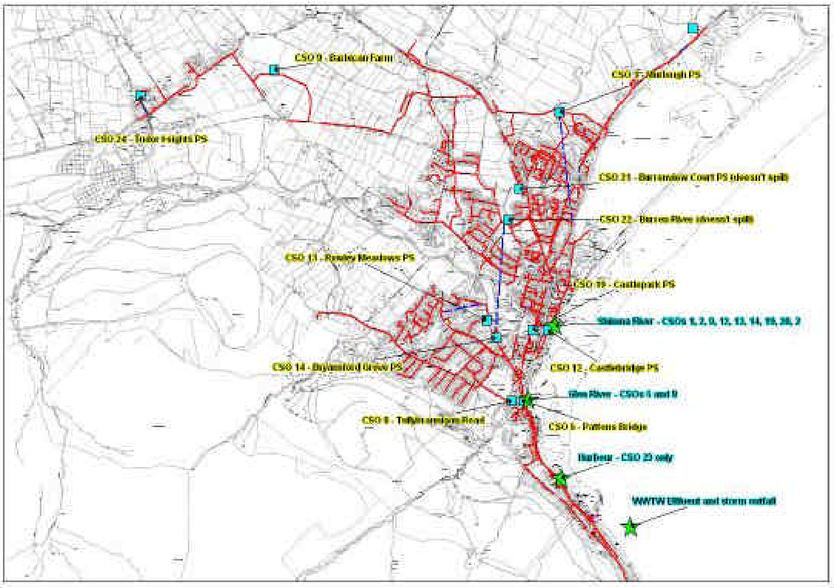

Figure 2: Newcastle Catchment and Major Discharges

STUDY OBJECTIVES & ENVIRONMENTAL STANDARDS

The objectives of the study were determined as follows:

- To evaluate the impact of current urban drainage system discharges relative to the standards of the current Bathing Water Directive (76/160/EEC).
- To identify appropriate and cost effective solutions to achieve robust compliance with these standards.
- To assess the current and upgraded system performance relative to the standards of the Revised Bathing Water Directive ((2006/7/EC).

The current Guideline Standard requires faecal coliform concentrations of less than 100 cfu/100ml for 80% of the bathing season. Taking into account the sampling regime used to monitor the bathing waters, this standard equates to a compliance figure of 89.6% of the bathing season on a continuous basis. The Mandatory Standard requires faecal coliform concentrations of less than 2000 cfu/100ml for 95% of the bathing season. This equates to a compliance figure of 98.2% of the bathing season on a continuous basis.

The Revised Bathing Water Directive came into force in March 2006 with a two year period to bring the necessary new laws and regulations into effect in the UK. The new Directive places tighter standards on bathing water quality using different microbiological indicators. The previous “Guideline” and “Mandatory” Standards are replaced by four new standards termed “Excellent”, “Good”, “Sufficient” and “Poor”. The microbiological parameters of total and faecal coliforms and faecal streptococci are replaced by intestinal enterococci and escherichia coli. The proposed standards specified under the new categories are stated in Table 1.

The change to these new standards is anticipated to occur within the operational lifetime of any improvements to the Newcastle urban drainage system. Hence, it was determined that any upgrading measures for the Newcastle urban drainage system should take account of the requirements of the new standards. Specifically it was proposed that any planned improvements should achieve compliance with the future “Excellent” standard.

Determinand	Excellent Quality (Standard should be met for 95% of the Bathing Season)	Good Quality (Standard should be met for 95% of the Bathing Season)	Sufficient Quality (Standard should be met for 90% of the Bathing Season
Intestinal Enterococci (cfu/100 ml)	100	200	185
Escherichia Coli (cfu/100 ml)	250	500	500

Table 1: Proposed Coastal Bathing Water Standards

MODELLING TOOLS & COMPLIANCE ASSESSMENT METHODOLOGY

A combination of tools is required for the purposes of any marine impact assessment study. The first is an urban drainage system model to quantify the discharges and loads emanating from the sewerage network and sewage treatment works. The second is a hydrodynamic and pollutant tracking model for the marine environment and finally a processing tool is required to assess the impact of the discharges in terms that are compatible with the environmental standards. The manner in which these tools were selected, constructed, made fit for purpose and then applied in the Newcastle study is described below.

Urban Drainage System Model
An InfoWorks CS model was constructed and verified for the Newcastle sewer system as part of the Drainage Area Planning study prior to commencement of this Bathing Water Study. The version of the model used for this study incorporated the majority of improvements that were planned in the sewer network as a result of the Drainage Area Plan, but not the major storage tank required to achieve 3 spills per bathing season. These improvements included the closure of the majority of the smaller combined sewer overflows and provision of several small local storage tanks.

This model was run with the rainfall events for 10 bathing seasons, producing representative hydrographs and bacteria load estimates for all the remaining CSOs and the effluent from the sewage treatment works. Bacteria discharge loads were estimated by the application of default average concentration values for untreated foul sewage, secondary treated effluent and storm sewage which were agreed in advance with the Environment & Heritage Service (EHS).

Marine Impact Model
The Resource Management Associates (RMA) suite of models was used for this study. Specifically, the marine hydrodynamics were modelled using RMA10 and the water quality was simulated using the particle tracking module RMATRK. The models constructed for the purposes of this study covered the whole Irish Sea, although the finite element grid employed by the models allowed for greater detail in the area of specific interest, Dundrum Bay.

Setting up and calibrating such models is complex and time consuming. For the purposes of this study, it was necessary to undertake field work to collect site specific data on tidal levels, bathymetry, currents (by meter and drogue), wind speed and direction and vertical salinity/dissolved oxygen/turbidity. These data, together with existing documentary data, were used to set up and calibrate initially the hydrodynamic model (RMA10) and subsequently the water quality model (RMATRK).

Marine Compliance Assessment Tool (MCAT)

Several seasons of water quality data are required to reliably assess compliance with the percentile based standards of the Bathing Water Directive. It is impractical to run the marine impact modelling tools in continuous mode for such long periods to directly generate the required data. It is necessary to employ a methodology whereby the impact of the drainage system discharges are evaluated in a representative manner without the need to run the marine models for every discrete event. The approach that was adopted for this study was the well proven technique in which the marine models are run for unit discharges from the various pollutant input sources (including the rivers as well as drainage system sources) for a number of scenarios taking into account the tidal cycle, winds and bacteria die off rates. This establishes the marine environment’s response to standard unit inputs under a wide range of conditions. These results can then be scaled up, extrapolated and sampled to provide a realistic representation of the responses for the whole time series of inputs over one or more bathing seasons.

The computing and data management resources demanded by this approach are still considerable, but they are manageable. The software used to facilitate this process was a Black & Veatch in-house tool MCAT (Marine Compliance Assessment Tool). The tool has the following features/capabilities:

- It receives input data from the urban drainage model in the form of time series of flow rates and bacteria concentrations for a sequence of bathing seasons.
- It receives input data from the marine model in the form of bacteria concentrations at a large number of locations (cells) in response to the unit discharge loads from the intermittent and continuous sources for a range of tidal stage releases, wind and tide conditions.
- It integrates the above datasets to generate information about the overall bacterial concentrations within the cells of the marine model over time for each tide (spring or neap), wind, and release tidal stage condition (12 tidal stages).
- A T_{90} bacteria die off rate is applied to the response files
- Water quality response files are generated based on the percentage occurrence of the specific environmental (tide, wind, release tidal stage) and spill condition
- The water quality response data are processed to evaluate compliance against specified criteria. In the case of this study, the criteria were periods of exceedence of concentration threshold values and peak concentration values relevant to the standards of the Bathing Water Directives.

Application Methodology

Having developed the above tools to the point where they were fit for the purposes of the study it was then necessary to formulate an application methodology that would generate results which would allow robust assessment of compliance (or otherwise) with the standards of the Directives. Essentially, this involved running the land-based (InfoWorks CS) model for a time series of rainfall events representative of 10 bathing seasons to generate representative data of the discharges and then using MCAT to integrate these inputs with the response files produced by running the marine models for a representative range of wind and tide conditions. Initially this procedure was carried out for the current situation (incorporating the network improvements proposed in the DAP). This was termed the baseline scenario. Further scenarios were then investigated incorporating potential enhancements to the urban drainage system. A series of sensitivity tests were also undertaken to confirm the reliability of the conclusions from the baseline and upgrade scenarios.

Running the InfoWorks model of the urban drainage system for 10 bathing seasons was straightforward as the model was relatively small and could be run in continuous mode for this period without excessive computer run time. Discharge results were generated at 8 specific locations as listed in Table 2, some of which are the aggregated results for several individual discharges.

Discharge Reference	Discharge Type
1	Storm Tank Newcastle WWTW
2	CSO at Harbour
3	All CSO's spilling into River Glen
4	All CSOs spilling into River Shimna
5	Anything above DWF to Flow to Full Treatment
6	Dry Weather Flow (DWF) from Newcastle WWTW
7	Background Concentration River Glen
8	Background Concentration River Shimna

Table 2: Urban Drainage System Discharges

In selecting the wind, tide, bacteria die-off and dispersion coefficients for the marine response aspect of the study, priority was given to the selection of not only realistic, representative values for the baseline simulation scenario, but also more conservative values for the sensitivity testing scenarios. Sensitivity testing was considered to be a necessary process due to the relatively high levels of uncertainty associated with several of the marine response parameters.

The marine models were run for each of these variables for unit discharges at each of the 8 locations for which inputs from the urban drainage system model were available. In each case the impact was modelled over a 5 day period.

Both the urban drainage system model outputs and the matrix of unit responses derived from the marine models were then input to MCAT which integrated the two input data sets to produce a time series of responses over each of the 10 bathing seasons for the various tidal states, wind conditions and times of discharges. Finally, the responses were sampled in a manner representative of the probability of the storm discharges relative to the specific tide and wind conditions. MCAT allows the results to be presented either for individual discharge locations or for the combined effect of all of the discharges. In each case, the results are presented as the duration for which a specified threshold value of bacteria concentration is exceeded, allowing ready comparison with the allowable percentile for the particular standard.

To simplify the scope of the Newcastle study, the only determinands modelled were Faecal Coliforms, when assessing compliance with the current Directive and Escherichia Coli for the revised Directive. The justification for this approach was that historical compliance data showed that past failures of the bathing waters had invariably been associated with Faecal Coliform concentrations. In the case of the revised Directive, the ratios between the default concentration values dictated that, if compliance was achieved for Escherichia Coli, then compliance with Intestinal Enterococci could be assumed to automatically follow.

RESULTS

It can be difficult to present the results for a study of this type in a readily accessible way, due to the large volumes of data involved. For the purposes of the Newcastle study, two primary modes of presentation were employed. The first was graphical plume diagram plots showing duration compliance contours throughout the study area. The second was histograms of impact at selected points in the study area broken down into the component contributions of each source. Examples of each form of presentation are provided in Figure 4. These examples relate to compliance with the Mandatory Standard of the current Directive for the baseline modelling scenario, i.e. for the existing system with limited network improvements. They show that the bathing water is compliant with this standard, as would be expected on the basis of historical sampling data. The plume diagram illustrates that the treated effluent plume has a significant local impact but that this does not extend into the bathing water. The histogram indicates that the most significant contributor to the impact within the bathing water was the combined sewer overflow in the harbour area, but that the impact was not sufficient to cause a failure of the standard.

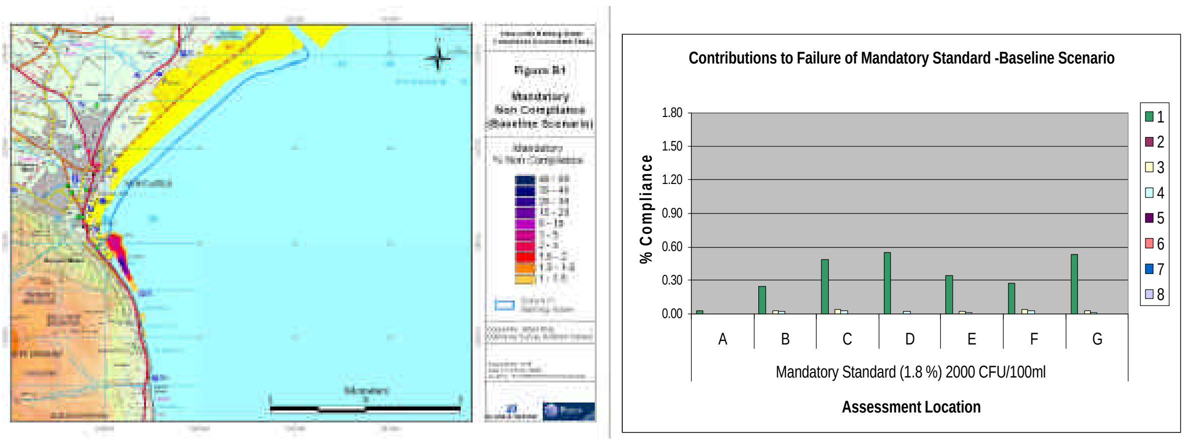

Figure 4: Compliance with BWD Mandatory Standard – Baseline Scenario

Similar results were produced for the Guideline Standard of the current Directive. These are presented in Figure 5. The situation they illustrate is very different. The plume diagram tallies with observed data in so much that it suggests widespread failure of the Guideline Standard both along the coast line and throughout the bathing water. This result is no surprise as the threshold value for the Guideline Standard is very much lower than for the Mandatory Standard. However, the histogram shows that the dominant cause of the failure is the impact of the dry weather flow discharges from the treated effluent outfall, as opposed to the intermittent discharges from any of the combined sewer overflows in the system, despite the fact that some of these overflows are simulated to operate in excess of 30 times per bathing season.

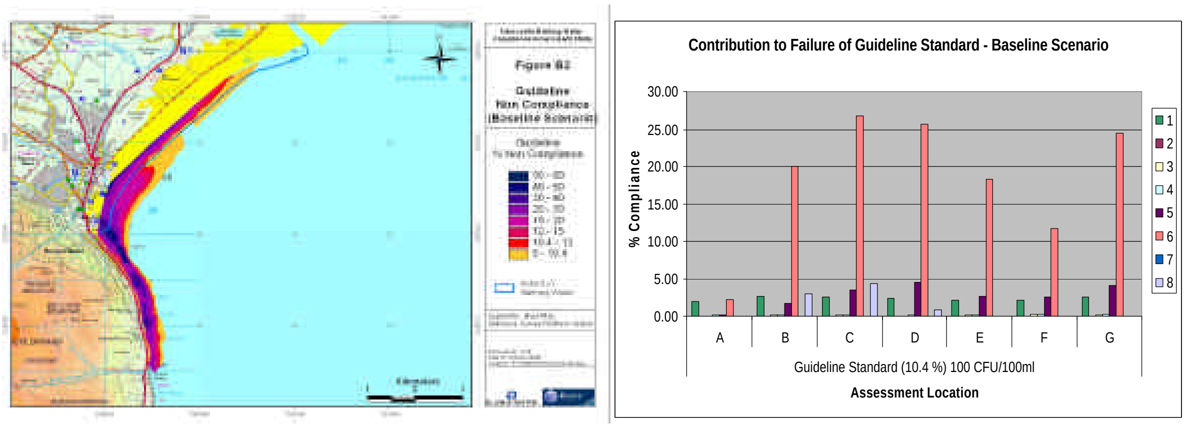

Figure 5: Compliance with BWD Guideline Standard – Baseline Scenario

The robustness of these overall results and conclusions was confirmed by the programme of sensitivity testing. The parameters varied during testing indicated that different aspects of the results varied to a greater or lesser extent for different parameters. For example, compliance with the Mandatory Standard was most affected by the rainfall patterns in the catchment, whereas compliance with the Guideline Standard was most dependent on the quality of the final effluent from the wastewater treatment works. However, the major conclusions still held good even when these parameters were varied to a degree that was up to the limit of realistic likelihood.

To further confirm that the continuous treated effluent discharge was indeed the principal cause of failure of the Guideline Standard, an upgrading scenario was modelled which limited combined sewer overflow spills to 3 times per bathing season. The results indicated significant improvement in respect of the Mandatory Standard, but little or no improvement in respect of compliance with the Guideline Standard. Consideration of the respective compliance percentiles for each of these standards readily explains why this should be the case.

Further consideration of system improvements was therefore directed towards the composition and location of the effluent discharge. Initial modelling had assumed a conservative concentration value of 1 x 10^6 cfu/100ml for the final effluent. Additional modelling was undertaken using a concentration of 5 x 10^4 cfu/100ml, considered to be a value representative of an effluent subject to tertiary treatment by ultraviolet irradiation. This work indicated that compliance with the Guideline Standard would be achieved throughout the bathing water by the provision of tertiary treatment. The only exception to this was a limited area close to the mouth of the Shimna River where the bacteria loads discharged by that river could cause localised failures. However, the bacteria concentration used for modelling of the river input were considered to be very conservative in respect of future conditions and the potential failures were not expected to occur in reality. Changing the location of the treated effluent outfall was also investigated in a limited manner in the study. Sufficient work was undertaken to demonstrate that compliance with the Guideline Standard could also be successfully achieved by moderate lengthening of the outfall, such that the effluent plume would not so readily impinge on the physical extent of the bathing water during periods of south east to north west coastal currents. At the time of writing, a comprehensive study to optimise the outfall location and hence allow a cost benefit analysis of the relative merits of tertiary treatment versus outfall extension has yet to be undertaken.

Having identified a potential solution that would ensure robust compliance with the current Bathing Water Directive, the study objectives dictated that the solution should be further investigated as to whether it would meet the future requirements of the Revised Bathing Water Directive. Whilst the standards for the Revised Directive are expressed in terms of different indicator organisms, the percentile basis of the standards is similar and hence the same modelling approach is appropriate. The percentile and threshold values need simply to be changed to suit the requirements of the Revised Directive.

The plume diagram in Figure 6 shows that there is limited failure of the "Excellent" standard along much of the coastline throughout the bathing water even when the effluent quality has been upgraded. However, the diagram also suggests that the effluent discharge may not be the primary cause. This view is confirmed by the histogram which identifies that it is intermittent storm discharges from the lower part of the sewer network that are the source of the problem, together with the discharges from the Shimna River (as already discussed).

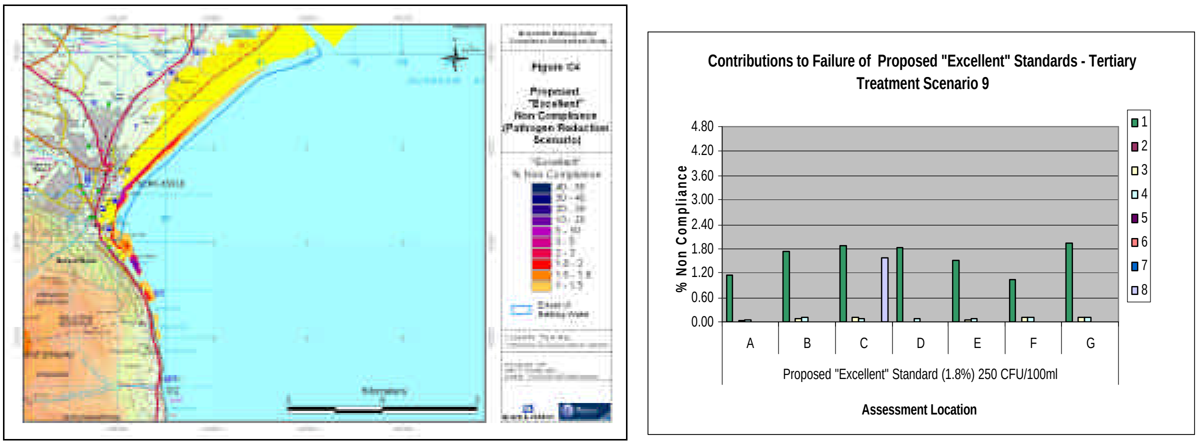

Figure 6: Compliance with revised BWD "Excellent" - Tertiary Treatment Upgrading Option

A further programme of sensitivity testing showed that the addition of 500m^3 of in-system storage reduced the impact of these intermittent discharges to the point where robust compliance with the "Excellent" standard was achieved. The marginal benefit of additional storage in excess of 500m^3 was shown to be much reduced as the frequency and volume of additional spill events captured was limited.

CONCLUSIONS

The major finding of this study is to show that the primary cause of historical failures of the bathing waters in Dundrum Bay was not the combined sewer overflow discharges as had been assumed. Instead the major cause was shown to be the impact of the treated effluent from the treatment works outfall. This conclusion was not anticipated at the start of the study.

The study has further demonstrated that the problem of compliance with the BWD Guideline Standard cannot be effectively addressed by improvements to the intermittent discharges alone. Changes to either the quality or the location of the continuous effluent discharge are essential to achieve this objective. Reduction in the frequency and volumes of spill flows has little or no effect on the compliance statistics for the Guideline standard.

The improvements proposed to achieve compliance with the requirements of the current BWD have also been shown to provide compliance with the Good standard of the Revised BWD. However, a limited amount of additional upgrading in the form of in-system storage to reduce intermittent spill frequencies and loads is required to achieve compliance with the Excellent standard of the Revised BWD. Nonetheless, the scale of this in-system storage is modest compared to that required to meet the default criteria of 3 spills per bathing season.

Hence, the study described in this paper can be considered a success for the following reasons:

- It showed that costly capital investment in providing large volumes of in-system storage is neither cost effective nor environmentally beneficial.
- It allows investment to be targeted in the area where it will achieve the desired end result, and
- It shows that limited and well defined additional works will allow the scheme to be "future proofed" by meeting the requirements of the Revised Bathing Water Directive.

ACKNOWLEDGEMENT

This paper was produced with the permission of the Directors of Black & Veatch and Northern Ireland Water. The views expressed in the paper are those of the authors and not necessarily those of Black & Veatch or Northern Ireland Water.