Barry Bathing Waters Strategy

Coastal Modelling as an Integrated Design Tool

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Introduction

A principal focus of the AMP3 Wastewater Improvement Programme in South East Wales is the achievement of compliance with the Guideline Standards of the EU Bathing Water Directive at the three designated bathing waters at Barry. This is a task that is both large and complex. The highly developed nature of the area, which includes the whole Cardiff conurbation, together with the extreme tidal conditions in the Severn Estuary mean that numerous major continuous urban wastewater discharges and several hundred combined sewer overflows (CSOs) in addition to many more naturally occurring inputs have the potential to impact upon the Barry bathing waters. It was in recognition of the these issues that AMEC, who is Dwr Cymru Welsh Water's Capital Alliance Partner in South East Wales responsible for delivery of the capital programme, conceived of, and created, the Virtual Design House (*'The Welsh Water Capital Alliance 'Virtual Design House'; Mike Jones (AMEC),* WaPUG Presentation Nov 2002).

The Virtual Design House (VDH) comprises the amalgamated resources of four consultants in South Wales (Arup, Black & Veatch Consulting, Hyder Consulting and Montgomery Watson Harza), AMEC, Black and Veatch Contracting and United Utilities Operational Services. The VDH can also call upon the international resources and expertise of these global organisations as-and-when required.

A cornerstone of the strategy for addressing the issues associated with the Barry bathing waters was the construction of a detailed two dimensional hydrodynamic and dispersion model of the Bristol Channel and Severn Estuary. It is the way in which this model has been developed and used by the VDH that constitutes the subject matter of this paper.

Location

Barry is located on the Welsh coast of the Bristol Channel, approximately 8km SW of Cardiff (Figure 1). It is a popular holiday destination and has three designated Bathing Waters at Jackson Bay, Whitmore Bay and Cold Knap (Figure 1). Sewage effluent from the largest urban concentrations in Wales (PE Cardiff 890,000, Cog Moors 350,000, Nash 160,000) enters the Bristol Channel between Newport and Cardiff, either directly from WwTWs and CSOs or via river inputs (Figure 1). 94 UIDs were identified as requiring improvement in Barry and Cardiff during AMP3, of which 34 are in year 5 and 60 were part of the outline determination for year 6 (Mar-Dec 2005).

Improvements within the Barry and Western Cardiff catchments, culminating in the commissioning of the Cog Moors WwTW in 1997, have brought about consistent compliance with the BWD Mandatory Standards at all three Bathing Waters. Further improvements to the Cardiff, Western Valley and Rhymney Valley discharges, culminating in full commissioning of the Cardiff WwTW in 2002 have brought about further improvements in Bathing Water Quality. In 2002, which was a particularly dry summer, the Whitmore Bay and Cold Knap Bathing Waters achieved a Guideline Pass.

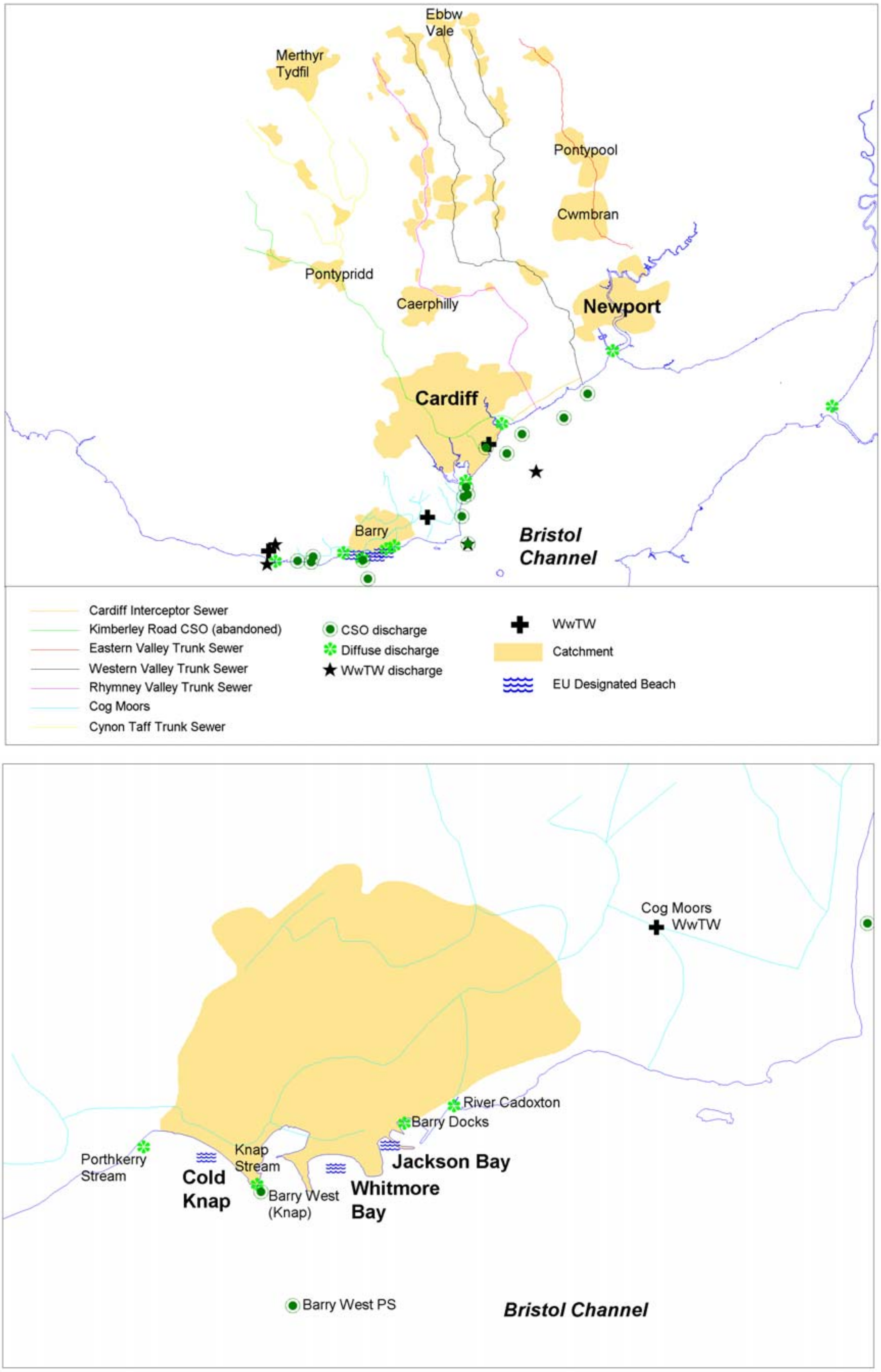

Figure 1 Location Map, Catchments and Inputs to Bristol Channel

Methodology

Aims and Objectives

The coastal model was commissioned to provide a means of integrating output from catchment models and determining the impacts of these discharges on the Bathing Waters at Barry. The model is used to determine present impacts under both dry weather (continuous impacts) and storm (intermittent impacts) conditions. The impacts of each discharge can be assessed in order to determine its significance and provide an assessment of where improvements are required together with an indication of the potential scope of such improvements. The model is then used to test design solutions during optioneering. The integrated use of the coastal and catchment models allows individual catchment solutions to be developed within an overall strategy that should ensure delivery of a total design solution that incorporates all potential impacts on the Barry Bathing Waters.

Coastal Model

The coastal model has been constructed using the Delft3D software system. The model domain is approximately 90km long, extending from the Severn Bridge at Beachley to Porthcawl in the west. A curvilinear grid is used to give higher model resolution in key areas and provide a good fit of grid to coastline and bathymetry. Grid resolution varies from 30m around Cardiff and Barry to 200m to the south and west of the study area. Data used in model construction, calibration and verification have been derived from a number of historical data sources and site specific surveys.

The model consists of two components; a hydrodynamic model to represent water movement under tidal and meteorological forcing conditions, and a particle tracking model to represent the dispersion and decay of bacteria. The hydrodynamic model was calibrated and verified against water level, current velocity and drogue data from historical and specifically commissioned surveys. The particle tracking (dispersion) model was initially calibrated and verified against dye release surveys, with further verification against historical bathing water sample data from a number of locations. Calibration produced a generally high level of fit and was within acceptable tolerance. The final model has been independently reviewed in order to provide an additional level of confidence in its fitness for use.

Compliance Assessment Tool

It was recognised at an early stage in the project that, while the coastal model provides an accurate tool for assessing the fate of discharge effluent, the large number of outfalls, environmental scenarios and design options would require an unacceptable time to run through the model. What was required was a tool that retained the capabilities and accuracy of the coastal model, but provides fast and efficient input of scenario data and output of results. A subsidiary tool, the Beach Compliance Assessment Tool was therefore developed. This tool is similar to a number of existing systems and uses superposition of coastal model output data to determine the effects of multiple discharges.

The basic theory behind the Tool is relatively simple, although construction is rather more complex. The key stages are:

1. Applications of the coastal model are undertaken for each input source using a 'unit pollutograph'. The unit pollutograph defines a constant, continuous load equivalent to a 1 cumec discharge with a concentration of $1x10^7$ fc/100ml faecal coliforms.
2. To take account the effects of tidal phase, the model is run for a series of discrete discharges released approximately every hour over a complete tidal cycle. Each run simulates a number of days in order to allow the model to reach equilibrium.
3. Results from each discharge are output for a series of points along the coast. Output files (Unit Pollutograph Response Time Series) are stored in a database.

4 To determine the actual impact of any given discharge, each Response Time Series in the database is multiplied by the ratio of the average hourly discharge load to the unit load. The modified Response Time Series are then added together for each monitoring point to determine the overall impact on the receiving water. To assess the impact from continuous inputs, e.g. WwTW and background river loads the 13 unit pollutograph responses are cycled continuously through the run to obtain the total impact concentration.

The methodology is shown schematically in Figure 3. The runs are repeated for each discharge under a representative range of environmental conditions, e.g. tide and wind to create a large Unit Pollutograph Response Time Series database. The present database contains approximately 1100 response time series allowing a wide range of conditions and locations to be assessed.

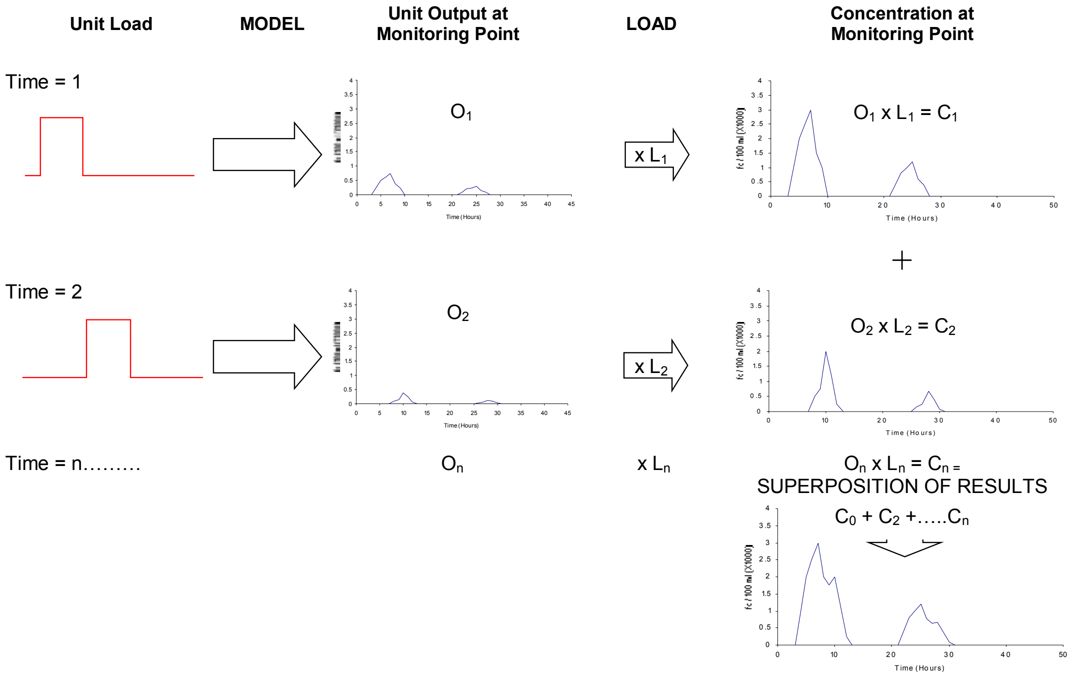

Figure 3 Basic Concept of Unit Pollutograph Approach

For application purposes, the Beach Compliance Assessment Tool contains a simple Graphical User Interface (GUI) to allow selection of input options and scenarios together with the appropriate loading profile for each discharge. A summary of results is output for each Bathing Water as time series plots and peak concentration. Loading profiles can then be modified to test the effects of input variables (e.g. phasing of discharges) and options for storage and / or treatment developed by the VDH design team.

Supporting Models and Surveys

The coastal model is supported by a number of additional data collection and modelling exercises. Surveys include coastal bathymetric and hydrographic surveys, beach WQ sampling, WwTW, sewer and river loading surveys (under dry and storm conditions) and asset surveys to define the location and condition of outfalls.

In the Case of the Barry East catchment an additional river model has been developed using DHI's Mike11 software. This model includes the CSO discharges to the Cadoxton River in order to provide accurate predictions of the river loads to the coast near Barry during storm events. A built-in hydrological model is used to determine river flows and concentrations and to assess the effects of dilution and time of travel.

The integration of the urban wastewater system, river and coastal models is illustrated in Figure 4.

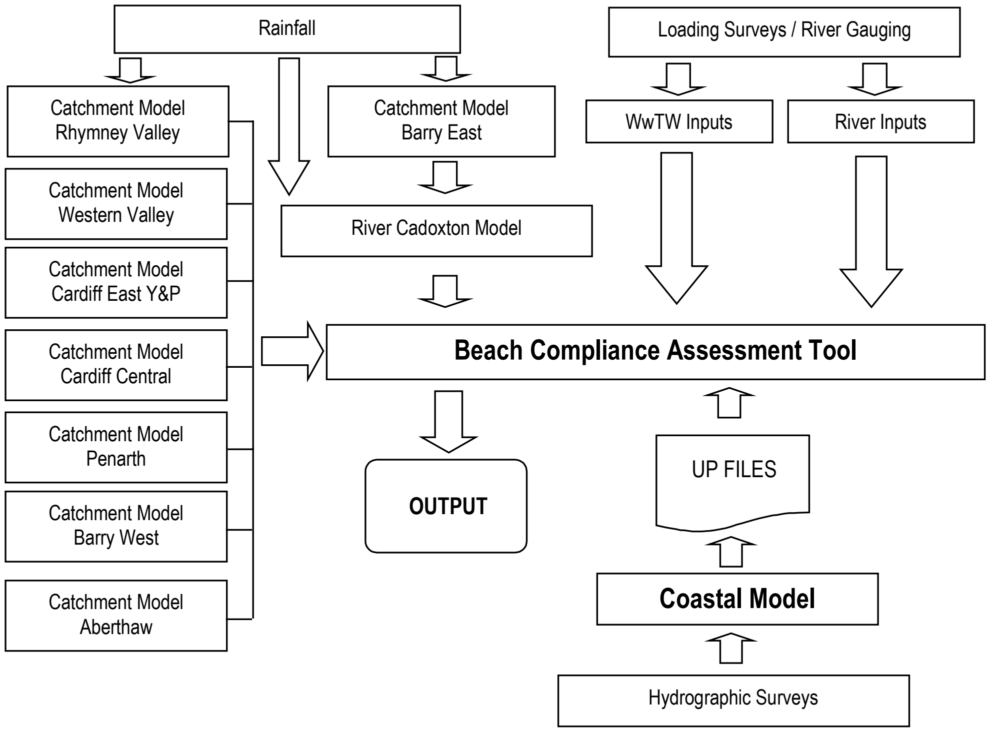

Figure 4 Model Inputs and Integration

Applications

Application of the Coastal model and Beach Compliance Assessment Tool has been divided into 3 key phases.

Sensitivity Applications - After initial calibration and verification, applications were undertaken for a range of conditions to assess the sensitivity of the model to key parameters, e.g. wind, tide, decay, load.

Baseline Applications – The Tool was applied to normal dry weather loads from WwTWs and rivers to determine a current baseline condition and to test Bathing Water Compliance under such conditions. Results from this exercise were compared with Beach Sampling data from 2000, 2001 and 2002 to ensure that the model replicated the range of concentrations measured at the Bathing Waters and adjacent coastal locations. Recent changes in the discharge from Cardiff, Western Valley and Rhymney Valley outfalls allowed a more rigorous assessment of sensitivity to be undertaken, accounting for changes in environmental conditions and discharge loads.

Combined with the sensitivity analysis, these applications provided valuable information on the current compliance level, the available assimilation capacity of the receiving waters under storm conditions and potential benefits of improvements at WwTWs. Figure 5 presents an example of combined results from the Baseline Applications phase.

The blue symbols represent beach sample data from 1995 to 2002 (Bathing Seasons). The red box represents the range of concentrations predicted by the Tool for a number of environmental scenarios and fixed WwTW discharge loads from 1DWF to FFT. The green boxes present similar results with WwTW discharges described by diurnal loading profiles. The effects of ongoing improvements at WwTWs since 2000 can clearly be seen in both the sample data and model results. The effects of commissioning the Cog Moors WwTW can also be seen in the sample data after 1997.

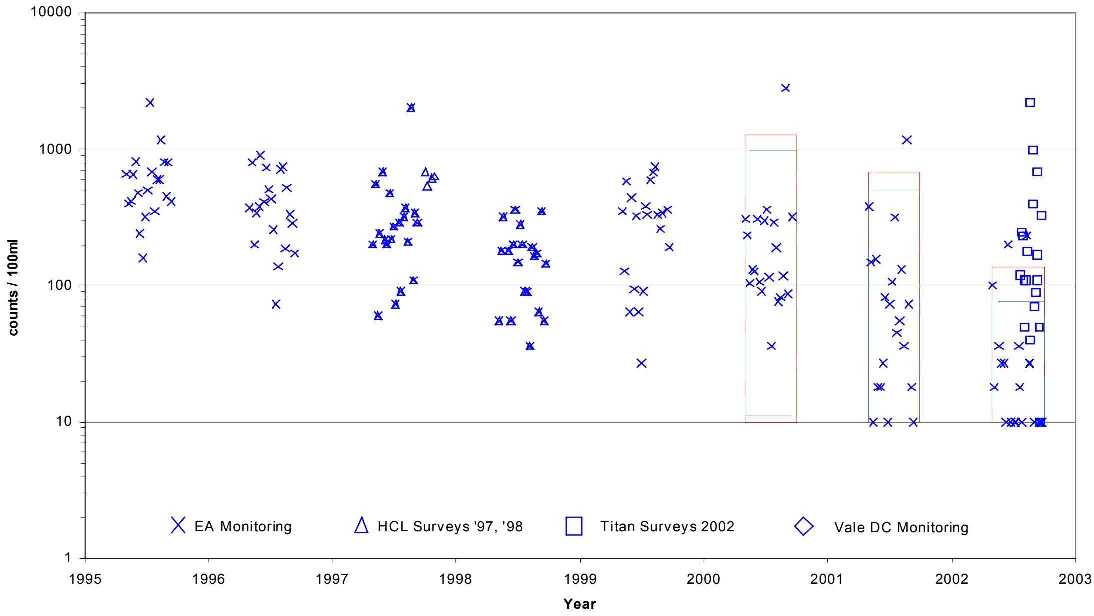

Figure 5 Comparison of Baseline Model Output with Beach Sampling Data – Whitmore Bay (fc/100ml)

Preliminary Storm Impacts Assessment – The Beach Compliance Assessment Tool was applied to a representative storm spill event for each catchment. The 31st largest spill event for each urban drainage system, was selected as a representative event as this is the first significant storm above the normally permitted 3 spills per Bathing Season. The basic approach adopted is summarised in Figure 6.

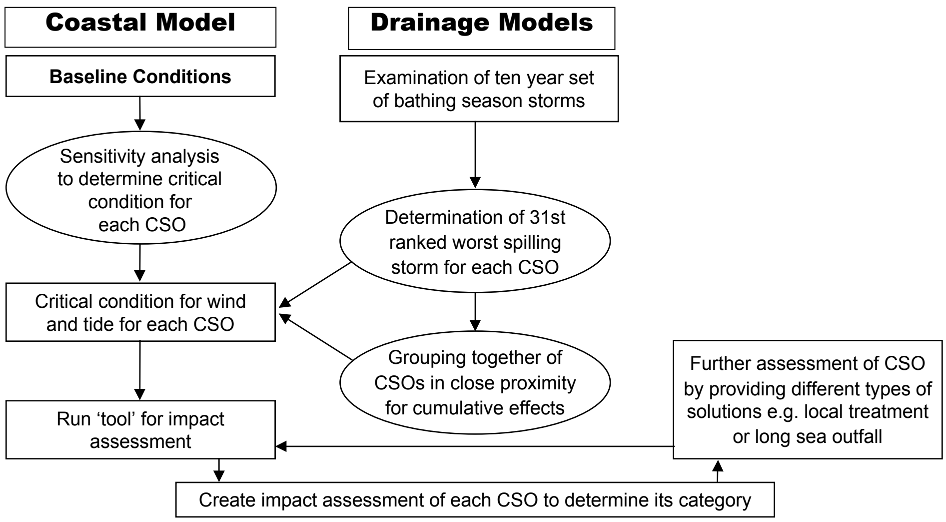

Figure 6 Storm Impact Assessment

Results from the Tool provide the relative magnitude of impact from CSOs and rivers and allowed each storm input to be categorised as either:

Non-Significant – i.e. those discharges that either individually or when combined do not cause a breach of the threshold value for the Guideline Bathing Water Standard under any of the conditions modelled. Non Significant discharges will require solutions to meet relevant local standards for screening, spill frequency (amenity value), pass forward flow (Formula 'A') and emergency provision (standby generator, telemetry or storage). Discharges to rivers will also need to meet local water quality drivers while those to tidal waters will require an outfall to Mean Low Water Spring.

Significant– i.e. those discharges that either individually or when combined are likely to cause a breach of the threshold value for the Guideline Bathing Water Standard under some or all conditions modelled. In addition to local drivers, Significant discharges will require improvement to achieve 3 spills per Bathing Season. Where CSOs are in close proximity to Bathing Waters this may require aggregation.

Intermediate - i.e. those discharges that either individually or when combined may cause a breach of the threshold value for the Guideline Bathing Water Standard under certain conditions of wind and tide. These discharges will require further assessment in order to either re-classify them as Significant or Non-Significant or to develop solutions such that their impact on the Bathing Beaches is reduced to an appropriate level. Such solutions are likely to require the outfall to achieve a 95% level of confidence of compliance with the Guideline Standard through such measures as reduced spill frequency, increased pass forward flow, local treatment, extended outfall etc.

At this stage, it is not proposed to adopt a full water quality approach to determine whether outfalls will cause Guideline Bathing Water non-compliance. The Environment Agency is not in favour of such an approach because, at the low Guideline concentration (100 fc/100ml), the accuracy of the model can be limited by factors that cannot be fully predicted or accounted for (e.g. natural fluctuations in load from rivers, decay rate, wind patterns, patchiness of bacteria distribution). Such factors bring with them an inherent risk of non-compliance that cannot be readily quantified. Given such risks it was felt, by DCWW and the VDH that a design based upon the use of the model to determine an appropriate spill frequency will provide a lower level of risk to DCWW, should the Bathing Waters fail to comply with the Guideline standards.

An example of initial results from this exercise is provided in Figure 7. The figure plots the peak storm concentration at the Whitmore Bay Bathing Water for a spring and neap tide under a southwesterly wind for a number of CSO discharges.

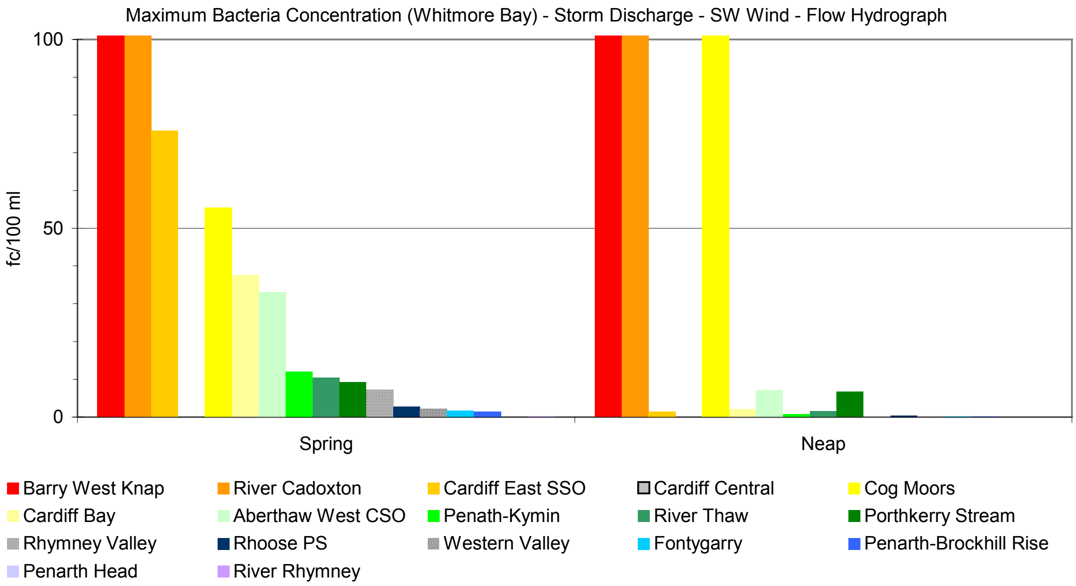

Figure 7 Whitmore Bay Peak CSO Impacts (fc/100ml) – Storm 31, SW Wind

Although individual classification of discharges has yet to be fully ratified with the Environment Agency, the initial classification has allowed a significant number of AMP3 outputs to be progressed. It has also allowed preliminary strategy development for the larger catchment, which also includes consideration of future requirements (AMP4 and beyond).

From Figure 7 it can be seen that discharges from Barry West (Knap) and the Cadoxton River (Barry East) each contribute concentrations in excess of 100 fc/100ml and would therefore be classified as Significant impacts. The development of an overall strategy for the Barry catchment will now be developed based on a 3 Spills aggregate solution.

The discharges from Cardiff East, Cardiff Bay, Cog Moors and Aberthaw are classed as Intermediate and require further investigation. Of particular note is the variation in impact of these discharges with tide, similar variation is seen as a result of variations in wind condition and discharge / tidal phasing. Solution development for these catchments will require more detailed assessment if cost effective designs are to be delivered. The size of the Cardiff East catchment presents a particular challenge and the use of storage alone is unlikely to be cost effective or feasible. For these catchments, a number of approaches for the assessment of impacts and delivery of solutions are currently being developed in consultation with the Environment Agency

The remaining CSOs have been provisionally classified as Non-Significant and, hence, will require local solutions. This has allowed a significant number of these AMP3 outputs to be brought forward in the programme, providing a more balanced distribution of year 5 outputs into years 4 and 5, and also the potential to advance year 6 works if the outline AMP3 determination is ratified by OfWat.

Summary

1. A detailed 2 dimensional coastal model of the Severn Estuary and Bristol Channel has been constructed to assess the impacts of domestic effluent discharges upon the Bathing Waters at Barry.

2. The model forms an integral part of the Barry Bathing Waters Strategy developed by the AMEC Virtual Design House under the Welsh Water Capital Alliance.

3. These Bathing Waters currently achieve compliance with the Mandatory Standards under the Bathing Waters Directive and are close to Guideline Standards. A primary aim of the Barry Bathing Waters Strategy is to achieve reliable and robust compliance with the Guideline Standards.

4. A Beach Assessment Compliance Tool has been developed to improve the efficiency of the modelling process. The Tool uses the established principal of superposition of impact responses. This Tool has dramatically reduced model application time and allows rapid testing of impacts and the effects of design options.

5. The model has been extensively verified and subjected to independent review. A range of supplementary studies and surveys were commissioned to support the modelling exercise.

6. The model includes inputs from more than eight large urban catchments serving a significant proportion of the population of Wales.

7. Individual catchment inputs and solutions are provided by the VDH members. Output form the model is fed back to the VDH as part of the design and optioneering process.

8. The model has been applied to baseline dry weather and storm conditions to identify and quantify key impacts. These have been categorised as Significant, Non-Significant and Intermediate and appropriate drivers and standards applied.

9. Further modelling is to be undertaken for the Intermediate discharges in order to develop appropriate drivers and standards.

10. This process has allowed a significant number of AMP3 deliverables to be brought forward and allowed strategies to be developed for the individual catchments. These strategies will support planning and design under AMP3 and beyond.

Acknowledgements

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