Better Targeting of Investment through Integrated Catchment Modelling

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1. Introduction

This paper describes work that MWH have undertaken recently in the field of Integrated Catchment Modelling for coastal, and inland water quality investigations. Integrated Catchment Modelling in this context is the linking of sewer, WwTW, river and coastal models to gain a better understanding of the interdependence of flow and quality between the different components of the system.

The paper presents case studies for unsatisfactory CSOs which highlight the potential savings in capital investment which can be made through adopting a more sophisticated approach where this is justified by the very high solution costs derived using simpler, more traditional methods.

We recognise that the time and cost of complex modelling studies needs to be justified in advance, and that many problems can be solved using simple models or in some cases without any model. However, it is apparent that in some cases the very significant savings, which can be demonstrated through an integrated modelling approach, do justify the additional time and cost entailed. In the examples below the savings generated are orders of magnitude greater than the costs of the investigation.

2. Background

The UPM Procedure is now well established in the UK as a planning methodology for solving intermittent discharge problems. A very large number of Unsatisfactory Intermittent Discharge (UID) schemes have been developed using it, and large sums of money have been allocated based on it. Given the huge investment that has been based on the UPM approach, it is worth reminding ourselves of the background to its development, and its key objectives.

The UPM Manual 2nd Edition contains the following definition:-

> *"Urban Pollution Management (UPM) is defined as the management of wastewater discharges from sewer and sewage treatment systems under wet weather conditions, such that the requirements of the receiving water are met in a* ***cost effective*** *way."*

It goes on to say:-

> *"Cost effective way: suggesting that the procedure leads to the identification of the* ***least cost solution*** *commensurate with meeting the needs of the environment."*

Cost effectiveness is therefore at its core. It is clear that the intent behind the development of UPM was to target effectively the huge investment necessary to achieve acceptable standards of water quality in our rivers, lakes and coastal waters and to comply with EU legislation in this area.

It is also worth noting that the UPM procedure makes allowance for a range of complexity and cost in terms of the study approach adopted. This can range from no modelling at all through simple models to highly complex and integrated modelling approaches. The intention is that the effort and cost of the investigation are commensurate with the expected cost of the solution required and particularly the savings that may be generated by a more detailed understanding of the problem.

If we look at the ways on which UPM has been applied in AMP3, it is interesting to test the actual application against the definitions quoted above. To what extent has cost-effectiveness been the main driving force, and how far have we as an industry gone to identify the least costs solution to a particular problem or set of problems?

Whilst there have undoubtedly been significant advances in modelling tools and methodologies which have led to an enhanced understanding of the impact of sewer discharges on receiving waters, there are many instances where the cost-effectiveness driver has not been the main consideration. For example: -

- A spill frequency approach to bathing waters is often applied, despite its in-built conservatism. In some cases this can lead to extremely onerous solutions, particularly when agglomeration over a wide are is required or in catchments which suffer from high levels of infiltration or inflow. Application of a spill frequency criterion to shellfish waters can be even more onerous due to the effect of winter infiltration levels and delayed runoff.

- Formula A is still often used as a minimum CSO setting, without necessarily considering the needs of the receiving water.

- At WwTWs, storm tank storage and FFT capacity is often based on population and dry weather flow multipliers without necessarily considering in detail the actual operation of tanks and the range of flows arriving at the works.

- Interdependence of flow and quality between the sewer network the WwTW and the receiving water is not routinely considered

- Optimisation of WwTW performance is not often considered as an option: compliance with the consent is often taken to be sufficient.

Of course consideration of risk, programme, political sensitivity and the need to satisfy the environmental regulator of the validity of the approach are all factors which need to be taken into account in this analysis. In the past, the speed with which computer simulations can be undertaken has limited the complexity of the analysis which is possible within reasonable time scales, although with the continuing increase in computer speeds this constraint diminishes year by year. The implications of adopting a sub-optimal approach can, however, be very significant in terms of cost, disruption and operability of the derived solutions.

On a positive note, there are of course many examples where the cost-benefit argument has been successfully applied and agreed with the regulators. It is the intention of this paper to focus on the positive steps we can take now, rather than to paint a negative picture of what has taken place in the past.

3. Case Study – Bathing Waters Compliance

One example of the benefits of using integrated models to derive a cost-effective solution for bathing waters compliance is the Whitburn and Ryhope Bathing Waters Study carried out by MWH and Metoc for Northumbrian Water Limited.

There are two EU designated bathing waters (Whitburn North and Whitburn South) located in the vicinity of Sunderland in Northeast England. Northumbrian Water Limited had an obligation within AMP3 to demonstrate that discharges for which they were responsible would not prejudice achievement of Guideline Standards for the designated beaches.

An earlier AMP1 scheme had been implemented utilising attenuation storage with a marine outfall to discharge CSO spills a suitable distance offshore so as to minimise risk to the bathing waters at Whitburn. This scheme had successfully delivered compliance with Mandatory Standards since its construction. The AMP3 study was commissioned by Northumbrian Water to assess what improvements would be necessary to achieve compliance with Guideline Bathing Water standards.

An existing model of the sewerage system was updated and reverified. A 10 year stochastic rainfall series was then applied to the model to obtain spill hydrographs for all the intermittent discharges in the vicinity of the bathing waters. The hydraulic model could have been used to develop a spill frequency solution for the catchment, however Northumbrian Water elected to use an impact assessment approach using a coastal dispersion model, and agreed this approach with the Environment Agency.

In addition to the CSO discharges, continuous discharge rates with appropriate bacterial concentrations for WwTW effluents were also applied as inputs to the coastal model. A "unit hydrograph" approach was applied to the coastal model to assess how bacterial loads from each discharge would move, disperse and decay within the coastal environment. From these coastal model runs the overall picture of cumulative impact from each discharge across the range of tidal and wind conditions could be built up by post-processing results using Metoc's in-house software.

The analysis showed that, with the improvements that had already taken place or were planned in the level of treatment for continuous discharges in the area, compliance with Guideline Standards could be achieved without additional work to CSO discharges.

The integrated modelling approach demonstrated that it was the continuous discharges which were most important in this case, and that the required bathing waters standards could be achieved solely through the upgrading of the treatment process at Hendon WwTW to full secondary treatment and UV. These improvements were already in effect or planned within the AMP3 period.

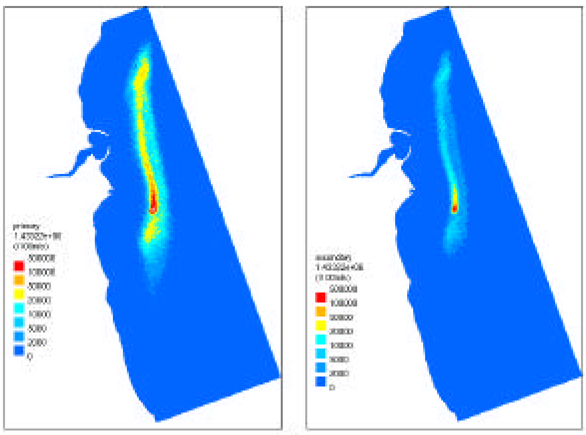
The benefits of using an impact assessment approach over a spill frequency approach at this location are clear, when the solution costs are compared. Applying a 3 spills per bathing season criterion to the discharge from the existing marine outfall would have required the provision of approximately thirty thousand cubic metres of additional storage, with an associated cost in the order of £15M.

Using an impact assessment approach resulted in a significant saving in terms of the capital costs of CSO improvements in the catchment, whilst confirming that planned investment in treatment processes was worthwhile. Savings in operating costs will also be made, as the pumping and treatment of additional storm flows was shown to be unnecessary. These savings are orders of magnitude greater than the costs of undertaking the sewer and coastal modelling studies.

The CSOs have been upgraded with screens to remove aesthetic pollution and both designated bathing waters have achieved Guideline Standards for the three bathing seasons since improvements to the WwTW were implemented.

Figure 1 The Whitburn and Ryhope Catchment

Figure 2 Northumbrian Coastal Modelling System



4. Pilot Study – Integrated Catchment Modelling for Inland Catchments

During 2003 MWH have undertaken a pilot study on a real river catchment to assess the potential benefits of an integrated modelling approach for inland water quality.

The objective of the pilot study was to estimate the size and cost of solutions required to meet river water quality standards using a detailed integrated modelling approach and compare the solutions with those estimated using current methodologies. The chosen modelling software was InfoWorks for the sewerage system, STOAT for the WwTW and Mike Basin for the river modelling. The basis of the modelling was to be continuous simulation of all three elements using long period rainfall generated using the STORMPAC software. It was felt that recent increases in computing power meant the use of continuous simulation was now a viable methodology.

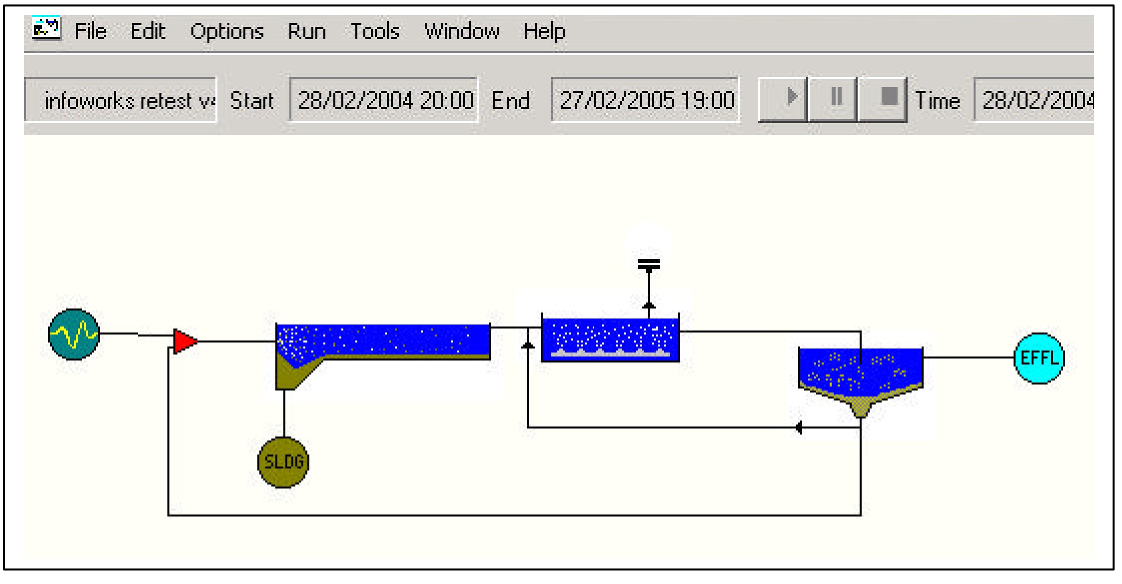
A trial catchment was selected which had existing models of the combined sewerage system and of the WwTW and for which river flow and rainfall data was available. This catchment had been subject to a conventional UPM analysis and significant storage requirements had been identified as necessary to achieve compliance with river quality standards.

The sewerage model had been developed in HydroWorks and had been verified using discrete rainfall events. The first stage was to confirm that it was possible to maintain the verification fits for both flow and quality when using continuous simulation in InfoWorks. This was done by creating a continuous RED file from the 4 months of flow survey data and applying it to the model. Comparison of the verification events with the continuous simulation showed the results to be very similar to those obtained originally from the discrete simulations.

Having confirmed that continuous simulation produced credible results the model was used to simulate the effects of a typical year's rainfall generated by STORMPAC. The results were used to generate continuous flow and quality hydrographs for CSO spills and WwTW inflows for input into the river and WwTW models. The advantages of using continuous simulation for the sewer model were felt to be twofold. Firstly each rainfall event would have the appropriate antecedent conditions and secondly the effects of the filling and emptying of in-system storage tanks, including the WwTW storm tanks, could be represented.

Figure 3 shows a representation of the model of the WwTW in the STOAT software.

Figure 3 STOAT representation of the WwTW



The WwTW consisted of primary sedimentation tanks, an activated sludge stage and final settling tanks. The inlet works, storm tanks and storm tank return flows were represented in the sewer model. The continuous flows to treatment, which were output from the sewer model, were used as input into the WwTW model. The statistics of the predicted effluent flows from the model were calculated and compared to statistics obtained from measured data from the plant. These are shown in Table 1.

Table 1 Comparison of Predicted and Measured Effluent Quality

	Model Prediction		Actual (2000)	
	Ave	95%ile	Ave	95%ile
BOD	4	6	4	8
SS	11	18	8	15
Ammonia	0.7	3	1	2.9

From this Table it can be seen there is good correlation between predicted and measured data which confirms that the model can reasonably predict the behaviour of the works during continuous simulation. The predicted continuous effluent data was used as input into the river model.

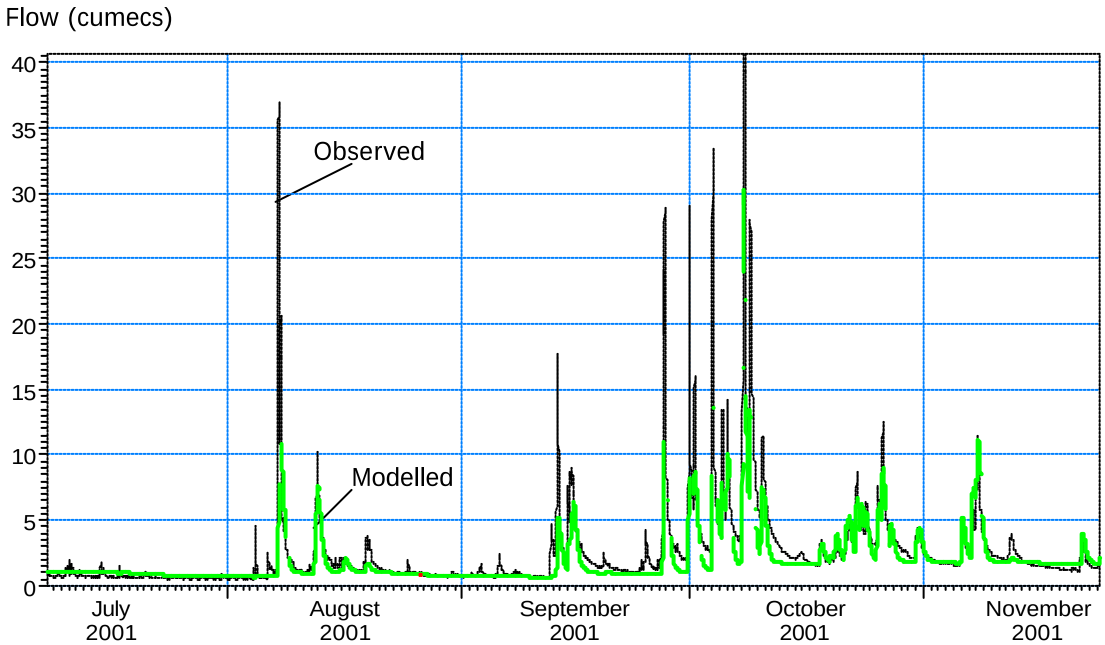
For the river modelling the chosen software was MIKE BASIN produced by the Danish Hydraulics Institute (DHI). MIKE BASIN was chosen because it offered rainfall runoff modelling, plus both point source inputs and a non-point source pollution model. It also contains a river quality model for DO, BOD, ammonia plus phosphorus, nitrate and coliforms. The level of modelling is sufficiently simplified that simulations of a period of a year only take a few minutes.

MIKE BASIN also contained routines to allow it to be run automatically so it could be interfaced with MWH in-house software tools for processing model outputs.

A model was developed for one subcatchment within the test catchment. The catchment area was calculated and checked against the Flood Estimation Handbook. The model simulated the main watercourses; these were fed by runoff and baseflows from the upstream catchments. The water quality in the rivers was modelled using the non-point source model. Continuous discharges were supplied from the WwTW model and intermittent discharges from CSOs from the InfoWorks model

A three-year record of simultaneous 15-minute resolution observed river flow and rainfall data was available for a site in the study catchment. This data was used to calibrate the rainfall runoff model. The calibration aimed to under estimate flow rather than over estimate to ensure that the results would be conservative. Flow balance was within 90-95% of the observed data set and the observed data tended to be peakier than the model predictions. Figure 4 shows a sample of the calibration fits obtained. Background water quality was simulated using the non-point source models in MIKE BASIN. As no data was available to accurately calibrate this model, estimated values were used and altered until the model predicted similar pollutant concentrations to observed summary statistics. This demonstrated that the model could be used to produce credible water quality simulations.

Figure 4 Comparison of modelled and observed flows.



Once calibrated the river model was used to simulate hourly rainfall data based on the same STORMPAC Series applied to the sewer model. The source inputs were produced from InfoWorks and Stoat simulations. These were processed into time-series files that could be read by MIKE BASIN, using MWH in-house software and a prototype post-processor routine in VB to automate the process.

The final step in the pilot study was to estimate solutions for the catchment to meet water quality standards and to compare these solutions to solutions derived using current methodologies. Solutions were derived for four scenarios based on the UPM high percentile standards which were currently being used to assess water quality in the catchment area. The number of hours that the water quality simulation failed the standards was calculated and if the standard was breached then storage was added to the intermittent discharges. The scenarios evaluated were as follows.

Run 1 – Correlated flow and quality

> The MIKE BASIN model was run at 1-hour time step to generate the river boundary flows and qualities, into which the intermittent discharges and WwTW inputs were added.

Run 2 – Correlated flow and uncorrelated quality

> This run was undertaken in order to identify the relative significance of quality correlation to results. This is similar to Run 1 except the river flow quality was assigned randomly rather than using the predicted quality from MIKE BASIN

Run 3 – Uncorrelated flow and correlated quality

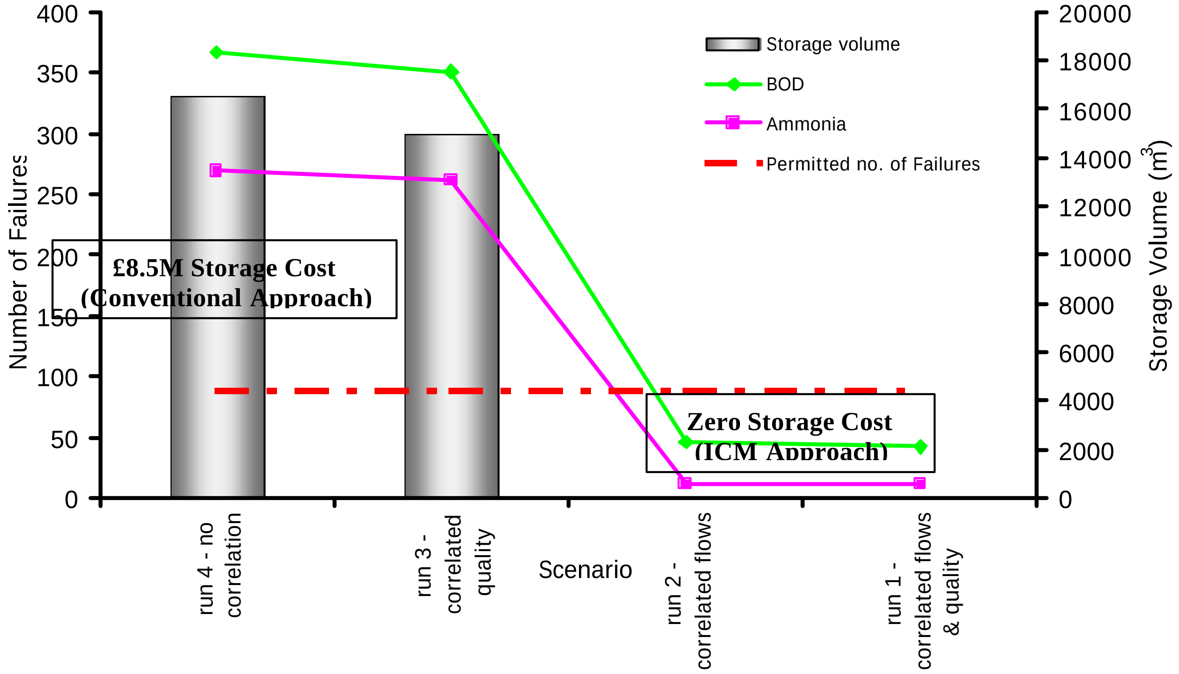
> This run was undertaken in order to confirm the relative significance of flow correlation to results. River flows were assigned to the CSO spills and WwTW discharges randomly based on the river flow statistics.

Run 4 – Uncorrelated flow and uncorrelated quality

> This approach mimics the way that impact analysis has typically been carried out using random flow and quality picks.

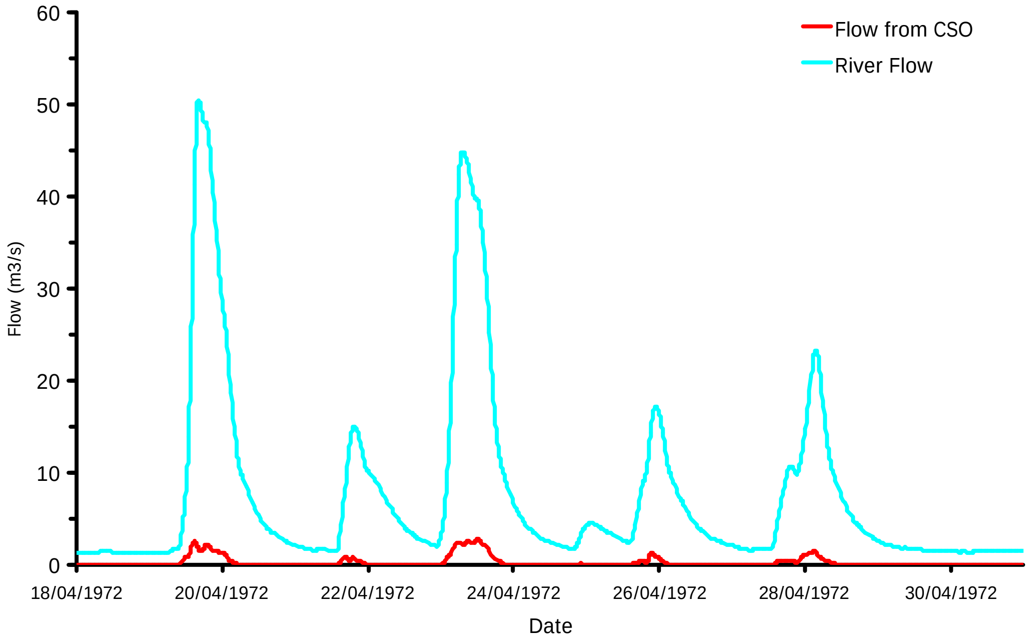
Figure 5 shows the results the correlation of flows had a significant effect on the required solutions. The left hand axis shows hours of failure per year for BOD and Ammonia, with the red dashed line showing the maximum hours of failure for the river to pass. The right hand axis shows the required storage volume to achieve a pass. The conventional approach demonstrated the need for around 17,000m^3 of storage, with an associated cost in the region of £8.5M. When the correlation of the flows and CSO spills was taken into account, the intermittent discharges did not breach water quality standards. The correlation of river flows with sewer and WwTW flows reduces that storage requirement to zero. Correlation of quality had a marginal beneficial impact over and above this.

Figure 5 Results of impact analysis for the different modelling scenarios



The reason for the dramatic reduction in failures, and hence solution costs, achieved using the integrated modelling approach was quite clear when the continuous river flows and CSOs spills were plotted together. Because the CSOs discharge to relatively small tributaries of a steep river catchment, the river had risen considerably by the time the CSOs spilled providing considerable dilution for the spills.

Figure 6 Simulated River Flows and CSO spills



5. Summary of Pilot Study Results

The pilot study has demonstrated clearly that the integration of existing tools for sewer, WwTW and river modelling is practical and achievable within a reasonable time scale and cost.

Linking output from these models allows a much more realistic assessment of water quality outcomes, particularly by allowing for the interdependence of flow and quality in the various components of the system.

This interdependence can be very significant in catchments where CSOs discharge to small tributaries, which can lead to extremely onerous solution requirements using a conventional approach.

The study has shown that using integrated models in this way can demonstrate huge savings when compared with the traditional approach, with the savings potentially outweighing study costs by several orders of magnitude.

6. Future Steps

Efforts should be made to identify those catchments where the benefits of integrated modelling are expected to be significant. This could be achieved through a high level scoping exercise, which would concentrate on catchments where large storage requirements are indicated by more traditional approaches. The basic data to do this in the form of river flows, rainfall, and sewer models is available in many of the catchments that could benefit from this approach.

It is necessary to get “buy-in” from all parties concerned to approach water quality improvements with value for money and sustainability as primary objectives. If this does not happen there is a real danger that investment will be misdirected on very expensive and potentially unworkable storage solutions which do not deliver the desired improvements.

The ICM approach could be extended to consider WwTW optimisation in order to develop optimised solutions for the network and WwTW together. It could also be extended to consider the effect of non-point source pollutants and to include a wider range of determinands such as nutrients and bacteria.

It could also be extended to explore the potential of closer integration of models - two-way interactions and hydraulic interaction between the sewer system and receiving waters

7. Conclusions

The investigations described above, which have been undertaken on live projects within AMP3 and using real catchment data for the pilot study, have shown that the integration of existing tools is feasible and that it can be carried out within a reasonable time scale and budget.

The modelling tools and methodologies described above are considered to be sufficiently robust to be adopted more widely within the industry than they have been to date.

We have demonstrated that an integrated modelling approach can deliver significant savings when compared with a more conventional approach. In some cases these savings can be several orders of magnitude greater than the costs of the study.

UPM has been a great asset to the UK water industry in providing a coherent framework for upgrading of intermittent sewer discharges. It is important that the industry as a whole remember that UPM offers a range of approaches from the simple to the very complex according to the individual needs of each catchment, and that its key objective is to identify least total cost solutions.

Whilst highly complex integrated modelling may not be justified in the majority of cases, it is important to identify those catchments where it can make a significant difference and apply it effectively to identify the most cost-effective solution.

In catchments where very expensive solutions have been derived using the standard approach adopted in AMP3, moving to a more integrated modelling approach could demonstrate real savings, and allow the investment necessary to deliver those solutions to be targeted more effectively elsewhere.

An integrated modelling approach may also provide the means to understand the potentially huge implications of the Water Framework Directive on the UK water industry.

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