A wastewater modelling strategy to investigate the impact of intermittent discharges on shellfisheries across East Anglia

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1 Introduction

Anglian Water had an AMP3 obligation to investigate the impact their discharges were having on designated shellfish waters. There are 23 such waters in the company's region. Most of these are in estuaries in Essex (Thames, Blackwater, Crouch, Roach), Norfolk and Lincolnshire (The Wash). The purpose was to define the scope for possible capital investment in AMP4 and beyond. This paper describes the **wastewater network modelling** that enabled others to quantify the impact of **intermittent discharges** on these shellfish waters. In particular it describes the use of a simplified modelling tool and approach which reduced the cost and duration of wastewater network modelling in previously un-modelled catchments.

To better explain the context of this programme of wastewater network modelling, the paper also describes some elements of the associated costal water quality modelling study undertaken for Anglian Water by Metoc Limited using the Anglian Coastal Modelling System (ACMS).

2 Shellfish Waters Directive

In 2001, the Environment Agency published its standard for Shellfish Water Quality. This resulted from the implementation of the European Union's Shellfish Waters Directive (79/923/EEC) by means of The Surface Waters (Shellfish)(Classification) Regulations 1997 SI No 1332 and The Surface Waters (Shellfish) Directions 1997. The Agency's Policy has two purposes, which are to meet :

- the UK's obligations in respect of the Shellfish Waters Directive (SWD); in particular the 'guideline' standard.

- Government's aspiration that all commercially harvested shellfish beds achieve at least Class B quality under the Shellfish Hygiene Directive (91/492/EEC)

The Policy allows two ways for the discharger to demonstrate compliance – either a maximum spill frequency, or a demonstration that water company point sources would not exceed a defined water quality standard. It is this second approach that Anglian Water selected, following the company's successful bathing water investment programme. Anglian Water believes that a modelled approach to coastal improvements is better for customers than improvements based on a 'one size fits all' spill frequency design standard.

The 'guideline' standard in the SWD is expressed as 300 faecal coliforms per 100ml of flesh and intervalvular liquid in 75% of shellfish samples. However the Agency points out that there was no research available at the time to use as a basis for setting either a water quality standard or operational standards to deliver the SWD's guideline standard.

Therefore the Agency used research by CEFAS (Centre for Environment, Fisheries and Aquaculture Science) to arrive at a water quality standard aimed at delivering the second stated purpose of their Policy; at least Class B under the Shellfish Hygiene Directive. The standard resulting from the research is 1,500 faecal coliforms per 100ml must be met for at least 97% of the time; and the Policy seeks to apply this across the whole extent of the designated Shellfish Water.

3 Screening for wastewater catchments which impact on shellfish waters

There are 1061 wastewater catchments which could potentially impact on shellfish waters in the region through a direct river to estuary pathway or by dispersion along the coastline. Each discharges to a receiving water body a continuous bacteriological load (reduced by sewage treatment processes) and an intermittent untreated bacteriological load through combined sewer overflows (CSOs), storm tanks and emergency overflows.

Metoc Limited devised and carried out a modelling study to determine which of these catchments were likely to have a significant impact on water quality in the designated shellfish waters around the coastline. Since little or no information was available on the quantities of untreated effluent discharged it was assumed for the purpose of screening that 25% of the bacteriological load generated in each catchment (6.5×10^{10} faecal coliforms per head per day) was discharged without treatment. Continuous discharges were assumed to discharge 10% of the total load following a 1 log reduction through treatment. Using a model of the river network, the ACMS where necessary, and conservative assumptions concerning decay rates and times of travel the most significant wastewater catchments where identified. The study concluded that 99.9% of the impact on shellfish waters originated from 68 wastewater catchments. Figure 1 shows the outcome of this analysis for the Essex sub-region. Catchments marked by red symbols were determined to have a significant impact on the shellfish waters (marked in pink). Orange and then green catchments show progressively less significant impacts.

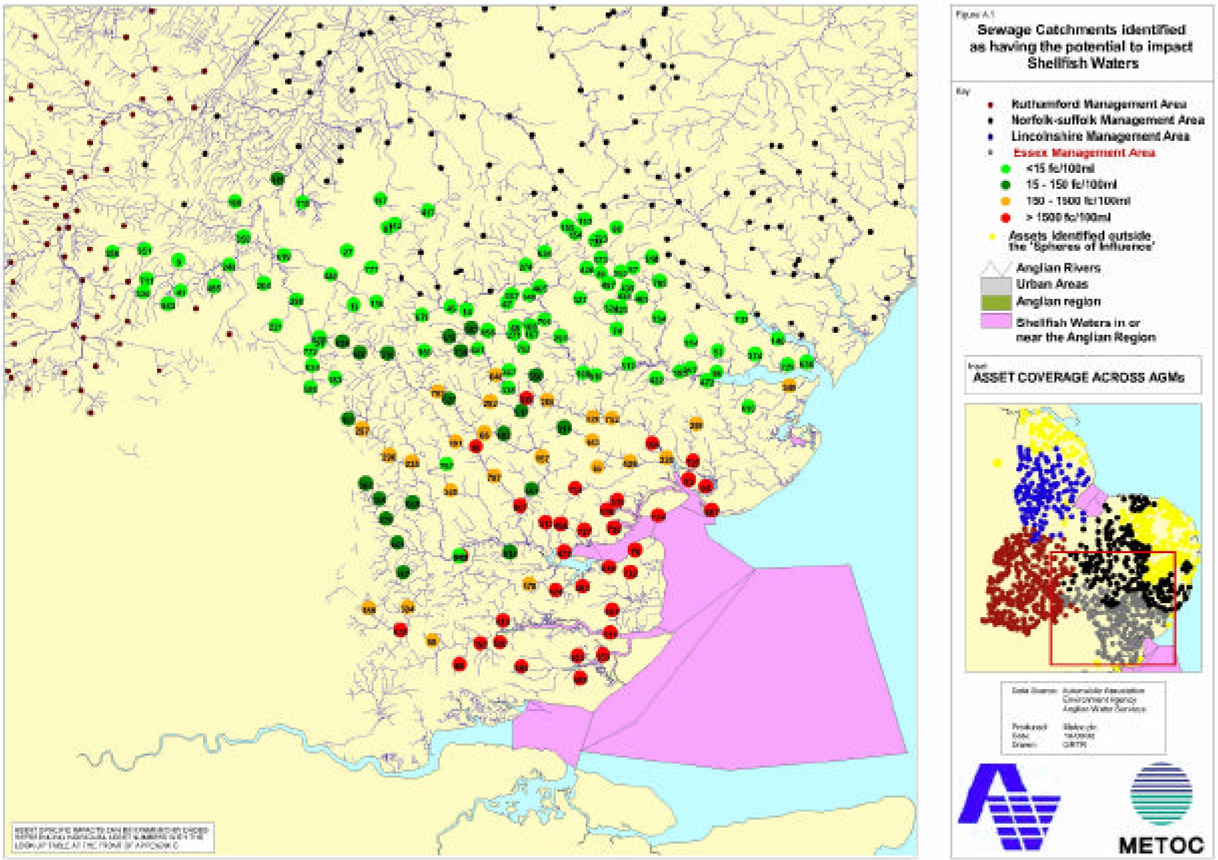

Figure 1

The screening exercise hence provided a list of catchments requiring further investigation; in particular, sewer network modelling to predict performance of intermittent discharges. It was recognised at an early stage that 'significant impact' status in the screening assessment was not necessarily an indication that capital investment intervention was warranted largely due to the understanding that actual impacts will be spatially and temporally discrete. The screening process simply determined which wastewater catchments warranted further investigation. In particular, a more realistic measure was required of the timing and location of intermittent discharges.

4 Wastewater network modelling

Halcrow were commissioned by Anglian Water to develop an approach to modelling the 68 'significant impact' wastewater catchments.

4.1 Wastewater model output requirements

For each intermittent discharge within the 'significant impact' catchments a 10 year long continuous hydrograph of spill flow was required for input to the ACMS. Bacteriological loadings were to be attributed to the spill flows prior to input to the ACMS and eventual determination of threshold – duration water quality data within the shellfish waters.

This requirement prompted a decision to adopt continuous simulation methods as a means of capturing all spills, particularly spills triggered by delayed emptying of off-line storm storage. Stormpac 3.0 was used to generate 3 representative rainfall time series for use in south Lincolnshire, north Norfolk and Essex. An analysis of historical rainfall data across East Anglia indicated that these series were sufficient to capture climatological differences across the region. It was important that hydraulic models that impacted on common shellfish waters were 'driven' by the same rainfall input time-series. This was to ensure that the timing of intermittent discharges was consistent across the sewer models. The availability of 'design' spatially variable rainfall time-series would have improved this aspect of the study. Assuming uniform rainfall across wide geographical areas was accepted as a conservative safeguard in the modelling approach.

4.2 Model availability

The target catchments contained a fairly typical mix of models and information and can be divided into four categories:

a. Catchment contains no intermittent discharges – no modelling required
b. Recently built & verified models in InfoWorks CS
c. Legacy HydroWorks, WALLRUS or WASSP models in need of up-dating to InfoWorks
d. Incomplete sewer records and no model

Figure 2 summarises the categorisation of the 68 'significant impact' wastewater catchments. This analysis showed that there was a substantial programme of modelling (34 catchments) required.

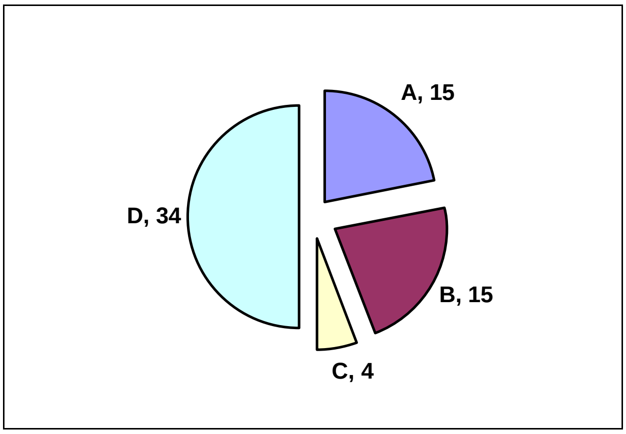

Figure 2

Modelling was able to commence immediately in the case of existing InfoWorks models. Although it was noted that many existing models did not extend to the STW or include storm tanks and associated intermittent discharges. Models were extended to include these assets as required. Continuous simulations were carried out making use of the InfoWorks feature, which permits fast time-stepping through dry periods. Even with this feature, some simulations in complex catchments took many days to run.

Legacy models were updated; again making sure that they were extended to include all intermittent discharges. They were also improved to include recent capital works and reflect recent population growth. In some circumstances re-verification was carried out.

In some cases where there was no model, other drivers in the catchment (e.g. DG5 properties or demand issues) warranted a traditional new model build to Drainage Area Plan standards. Although costly and time-consuming, this approach was justified in 6 catchments. There remained, therefore, 28 catchments requiring a fast, low cost, yet sufficiently accurate alternative to detailed model build and verification.

5 A simplified modelling approach

Halcrow were commissioned to consider the use of simplified modelling approaches to address the 28 un-modelled wastewater catchments in the region.

5.1 Simpol

First, Simpol (Version 2.0, as supplied with the UPM2 Manual) was considered. An advantage of Simpol was a degree of familiarity with the tool within Anglian Water and Halcrow and an acceptance by the Environment Agency for its use. However, a number of limitations of Simpol were insurmountable. The software did not allow continuous simulation and the export of long time series spill hydrographs. Simpol was also limited to the Wallingford runoff model and was therefore unable to represent increasing catchment wetness during storms. Direct comparison of model results and observed sewer flow data was also awkward and limited to fixed locations within the model.

5.2 STAVRoS

Because of these difficulties, an alternative approach was agreed whereby Anglian Water and Halcrow developed their own simplified modelling tool, tailored to meet the exact needs of this study yet also sufficiently flexible for a wider range of applications and further development. The outcome was a software application called STAVRoS (**S**pill **T**ime **A**nd **V**olume **R**un**o**ff **S**imulator). Anglian Water requested, and were subsequently awarded, Environment Agency acceptance of STAVRoS for use in a study of this type.

The key features of STAVRoS are as follows:

- Easy to use drag, drop & click interface.
- Reads *.red* format (300 second) sub-event rainfall files allowing continuous simulation
- Simulation at any timestep from 1 minute to 24 hour

- Includes a flexible results processing and viewing system permitting import of flow survey data and the export of results to ACMS and other systems
- Impermeable surface runoff generated using fixed runoff coefficient
- Permeable surface runoff generated using New UK Runoff model
- Diurnal foul flow profiles
- Monthly groundwater infiltration profiles
- RTC to mimic storm tank return philosophies
- Rapid simulation – typically 10 years in 5 minutes at a 1 hour timestep.

5.3 Using STAVRoS to build wastewater models

STAVRoS models were built for 28 catchments across the region. Figure 3 shows the location of STAVRoS models (in red) built in Essex. Larger towns generally had existing detailed models (in green), but smaller towns often located very close to shellfish waters required STAVRoS models.

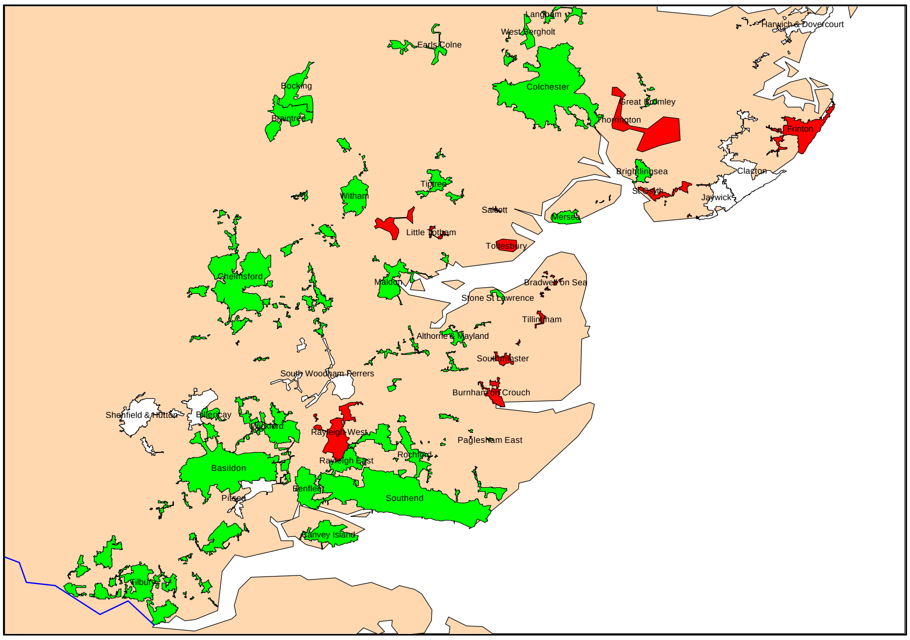

Figure 3

Successful development of STAVRoS models for catchments with discharges impacting on shellfish waters involved gathering together as much existing information as possible on the sewerage system in general and intermittent discharges in particular. The overriding philosophy was to collect the minimum amount of data necessary to address the model's needs. The model was designed to meet the minimum requirement of the end user – a representative 10 year spill hydrograph from each overflow. This 'lean' approach was designed to ensure a rapid and low cost outcome to the modelling programme.

Anglian Water were able to supply population data, sewer records (often incomplete), discharge consents (for CSOs and STWs), telemetry data (e.g. high level alarms and/or spill information) and a database of known intermittent discharges. These data were augmented by site visits and interviews with operational staff. Information was sometimes based solely on local myth and legend and along the lines of *"storm discharge typically operates 10-20 times per year."* Site visits frequently identified inconsistencies and inaccuracies in the supplied data and assisted with the understanding necessary to adequately model these catchments.

Once intermittent discharges had been identified, a low cost flow survey was commissioned for each catchment. The purpose of each flow survey was to simply characterise flow upstream and, if possible, downstream of known intermittent discharges. Sections of the sewer systems downstream of intermittent discharges were not monitored at all and not modelled either. Flow survey contractors assisted in determining the optimum location for flow monitors. Because sewer diameters were often small (150mm), good flow monitor location was crucial and the experience of flow survey contractors was much appreciated. Catchments typically required between 2 and 5 monitors and a single rain gauge. The flow surveys were monitored closely and quickly removed once 2-3 significant rainfall events had been captured which was sometimes after only 3-4 weeks. Equipment was rapidly re-deployed in adjacent catchments allowing for a large number of systems to be modelled quickly. In the whole simplified modelling programme 48 overflows were modelled using 24 rain gauges and 76 flow monitors. Many discharges were controlled by downstream pumping stations acting as throttles. Where no data were available on pump settings, drop tests were commissioned to confirm the pass forward throttle.

Models were assembled in STAVRoS and conceptualised to represent each intermittent discharge controlling a sub-catchment. Flow survey data were imported as continuous series and not sub-divided into traditional 'storm events'. Model calibration was approached in a pragmatic manner looking at the whole data survey period. Known parameters (e.g. population and trade flows) were entered and model simulation results compared against observed data. Early model builds were deployed with impermeable area survey (IAS) results but it was generally found that these inadequately reflected the actual mix of contributing permeable and impermeable surfaces in what were generally partially separate systems. Unknown parameters (e.g. infiltration %, permeable area and routing coefficients) were adjusted until a satisfactory match with observed data had been achieved. Goodness of fit was assessed through volume measures (automatically reported in STAVRoS), peak flows and the modeller's judgments on hydrograph shape. The modeller's judgment was also applied to ensure that sensible combinations of input parameters were used: it was accepted that resulting models were not 'verified' but 'calibrated'.

Using the New UK Runoff model was particularly useful in capturing the influence of catchment wetting through extended rain periods. Figure 4 shows good model calibration through a 2 day period which included multiple rainfall events and a gradually wetting catchment.

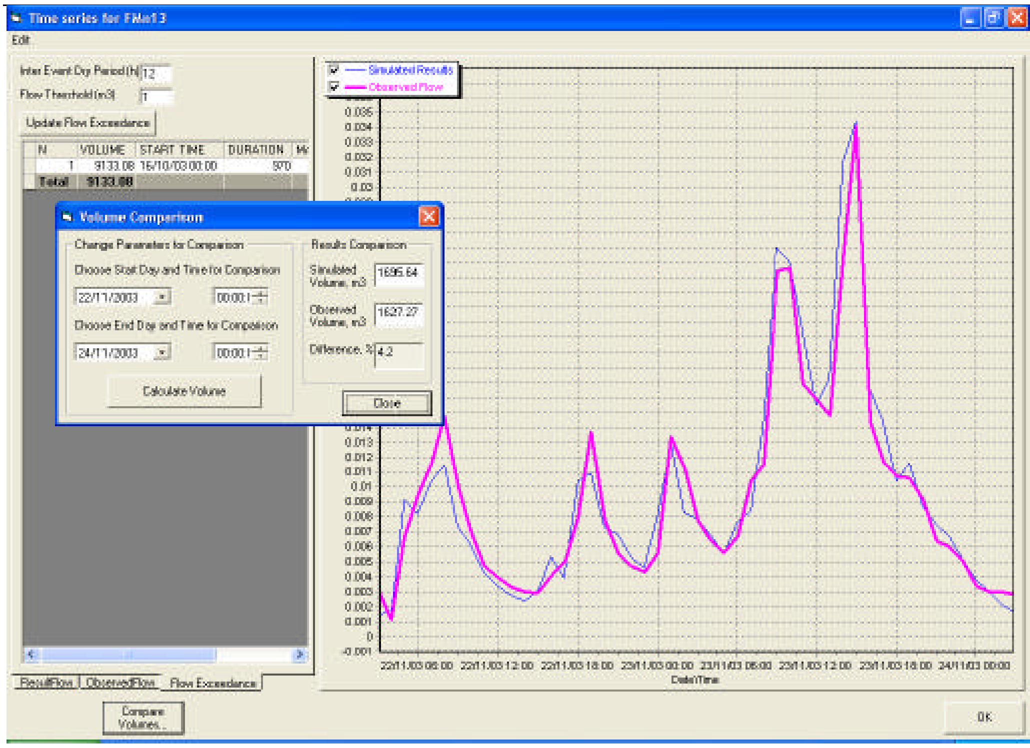

Figure 4

It was recognised, however, that it was easy to confuse permeable surface runoff with rainfall induced infiltration effects; with consequences for runoff volumes in the simulation of long rainfall time-series.

When the STAVRoS models had been calibrated (generally within WaPUG flow peak and volume criteria) they were amended to include time varying infiltration. Flow records from STWs were used to determine monthly variations in infiltration inputs and the seasonal pattern was replicated in STAVRoS. Though crude, this approach was simple to apply and captured the essence of reduced sewer capacity in winter months due to the influence of high water tables.

Long simulations were then carried out with Stormpac rainfall data to generate spill hydrographs. Rapid simulation and data processing permitted many model iterations to be carried out, testing any sensitivity to data inputs. Wherever possible, spill frequency results were validated against quantitative or qualitative data on actual asset performance. This information was sometimes available at larger storm tanks and formed part of the model validation evidence.

Figure 5 shows a typical 10 year storm tank spill hydrograph output from STAVRoS. These data were pre-formatted for direct input to the ACMS where they were combined with hydrographs from InfoWorks models and inputs describing STW effluents.

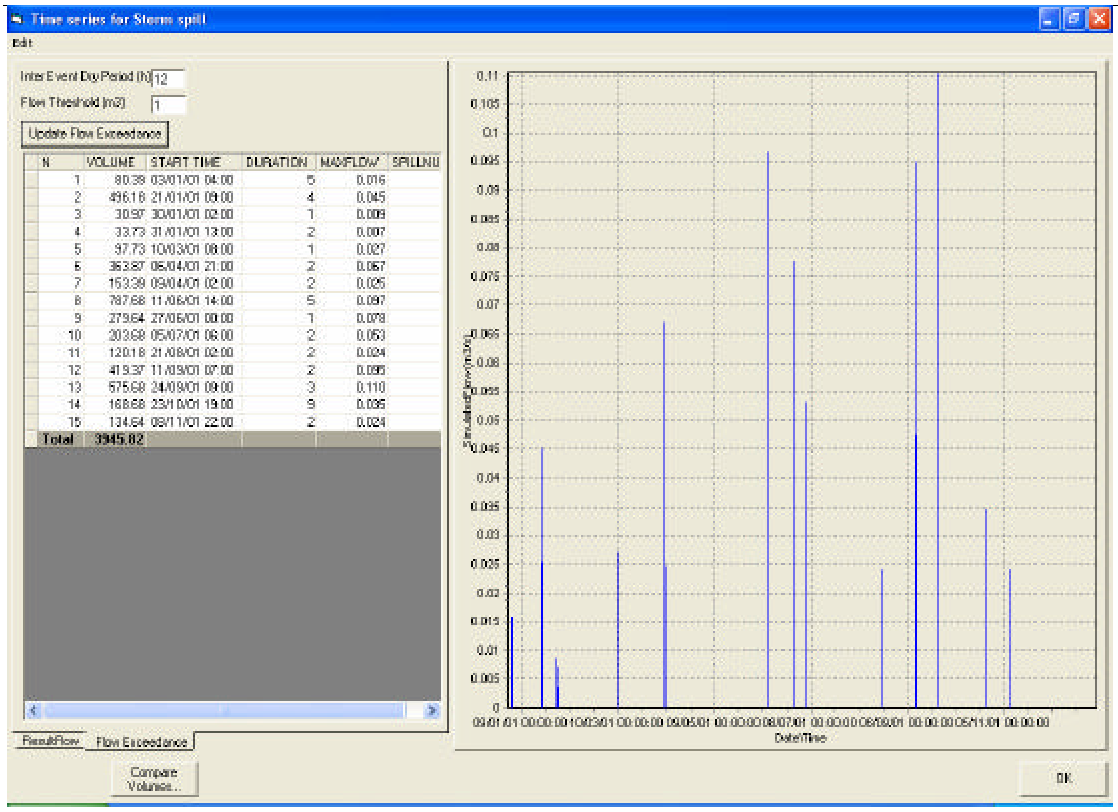

Figure 5

6 Shellfish water study outcome

There were three studies completed in time for Anglian Water's AMP4 business plan. These were aimed at estimating point source impact at Shellfish Harvesting Areas in the south east Wash, Roach estuary (south Essex) and Thames estuary (off Southend). The studies showed that impacts were within or near to the water quality standard stipulated in the Agency's policy, in which case there was a poor business case to seek to improve shellfish flesh quality through point source improvement.

The modelling identified those assets most likely to affect 'compliance' at key points in the coastal water, and therefore permitted the estimation of specific amelioration work, if the Regulator wished to recommend inclusion of improvement works in Anglian Water's investment programme. Ministers have since decided that improvement of Anglian Water's assets affecting shellfish water quality is not a business imperative in AMP4.

The study outcome has helped Anglian Water to understand which assets are likely to affect shellfish quality. This knowledge has contributed to the development of a coastal water quality management system whereby Anglian Water monitors rainfall and spill activity from assets now known to be critical to shellfish water quality. Significant discharges and rain gauges are linked through a comprehensive telemetry system so that performance can be closely monitored and operational problems quickly diagnosed and resolved. Increasing volumes of historical data captured by this telemetry system also allow further validation of detailed and simplified wastewater models.

7 Conclusions

The wastewater modelling strategy deployed by Anglian Water in this study has made best use of existing models, limited new detailed model builds to places where a multitude of drivers warranted the cost, and applied an innovative simplified modelling system (STAVRoS) elsewhere. STAVRoS proved to be an excellent tool to model these catchments and the manner in which it was used realised significant cost and time savings over traditional approaches. The 'lean' simplified modelling approach proved fit for purpose and should be considered elsewhere when strategic level sewer catchment information is required. Anglian Water and Halcrow have continued their development of STAVRoS as a tool for studying a range of wastewater planning issues. For example, it now includes a water quality modelling functionality for use in UPM studies and sewage treatment works design.

8 Acknowledgements

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