MODELLING REQUIREMENTS TO MEET AN AVERAGE OF 3 SPILLS PER BATHING SEASON

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Background

In response to an EU Bathing Water Directive, North West Water launched an ambitious clean-up initiative titled 'Sea Change', a £500 million programme of work aimed at improving the quality of discharges to the North West coastal waters. The objective was to assist the Environment Agency in delivering the necessary Bathing Waters quality standards.

Sea Change included a diverse array of projects, including new wastewater treatment works, pumping stations and major sewerage schemes from Southport to Silloth near the Scottish Border.

The prime focus of work along the Fylde Coast included :-

- A 14km interceptor tunnel along the seafront from Blackpool's Central Pier to Fleetwood to collect and transport flows to Fleetwood WwTW.
- A new WwTW at Fleetwood, capable of treating 2200l/s.
- An additional stage of treatment at the Clifton Marsh WwTW, which serves the Preston and South Fylde areas.

Although each scheme was completed on time during the summer of 1996 and achieved their requirements in terms of discharge consents and spill frequency, the resulting improvements to the Bathing Waters were not sufficient to meet the required quality standard. This indicates the complexity of the many inputs and processes that effect bathing water quality. This Sea Change programme as undertaken along the Fylde Coast had been based on the results of the best network modelling software that was available at the time, predominantly WASSP.

As a result of the bathing water quality failures in 1997, NWW working under the direction of the EA, undertook a fast-track programme of further investment. The main thrust of these projects is to further reduce storm discharges to an average of three per Bathing Season per outfall and to provide further treatment (UV) at some of the existing WwTW's.

This programme of work commenced in February 1998 and will be completed by the summer of 1999. This paper will focus on the modelling methodology applied to the Fylde region, although the same strategy was applied to all five major schemes.

The Fylde area is shown in Figure 1:

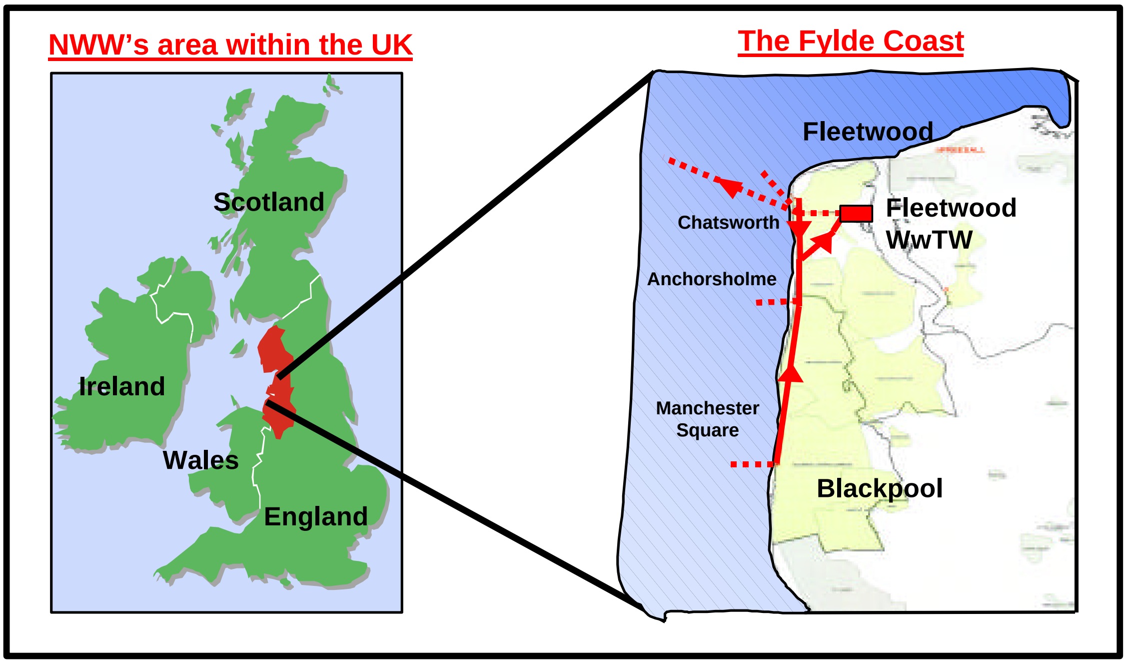

Figure 1 : *The Fylde Area within the North West of England*

Modelling Methodology

The start of this work in February 1998 was fortuitous because it aligned with the conclusions of a joint research project '*Continuous Simulation Methods for Designing Detention Tanks*" undertaken by WRc on behalf of NWW and other water companies. The significant political pressure imposed by the UK Government as a direct consequence of the 1997 Bathing Water failures lead to a prompt decision to apply these advanced Continuous Simulation modelling techniques as opposed to more traditional single-storm event methods.

To ensure the required timescales were achieved, it was necessary to commence the design process immediately. To enable this, initial estimates for the additional storage capacities were required. Consequently, results generated by unverified models, and in some cases no models at all (preliminarily estimates for the basic underlying network characteristics were made ie Area, PIMP, DWF etc) were fed into the design process. As the models were refined, new storage volumes were generated with increasing levels of confidence. The Project design team had to exercise a high degree of flexibility with this approach, with fundamental design criteria often changing on a weekly basis.

The adopted methodology was as follows:-

a) Build and verify detailed HydroWorks models for each individual sub-catchment

b) Build SIMPOL models for each of the catchments and calibrate against the corresponding HydroWorks models

c) Combine the individual SIMPOL catchment models to create a single SIMPOL model for each scheme : Verify against real-site data from SCADA systems

d) Run historical rainfall data though the SIMPOL models (Eg. Fylde - 24 years at hourly intervals)

e) Add additional storage to the model and re-run until the required number of spills is achieved

f) Combine the individual HydroWorks models and add the RTC rules for the existing system and verify against real-site data from SCADA systems

g) Add the additional storage (previously determined by SIMPOL) to the HydroWorks models at the appropriate locations

h) Evaluate and test alternative control strategies utilising HydroWorks Real-time Control (RTC)

i) Construct a detailed SIMULINK model of the proposed systems to allow detailed controller tuning and optimisation

j) Code the Programmable Logic Controllers (PLC) directly from the SIMULINK model

When the scheme has been commissioned, it is proposed to carry out a detailed post completion appraisal by :-

- Installing additional flow monitors and rain gauges for an agreed period of time
- Check the model predictions with the actual operation of the system

The following sections describe the methodology in further detail:

a) Build and verify detailed HydroWorks models for each individual sub-catchments

Some of the catchments had existing models while others had none at all. The existing models resided in a combination of formats, including WASSP, Wallrus and HydroWorks. Each model was initially assessed against the following criteria: date originally built, accuracy of verification, alterations to the sewer network since construction, ease of conversion to HydroWorks and overall confidence.

The limitations of the historical software lead to a lack of definition within the majority of the catchment models. To compound the situation, many of the sewer networks have been significantly modified since the work was undertaken and the WASSP software superseded several times. This lead to an early decision to build new detailed HydroWorks models for each catchment within the scheme.

As previously discussed, when a sufficient minimal data-set became available from the HydroWorks models, work commenced on the construction and calibration of corresponding SIMPOL models to allow the design team to commence work.

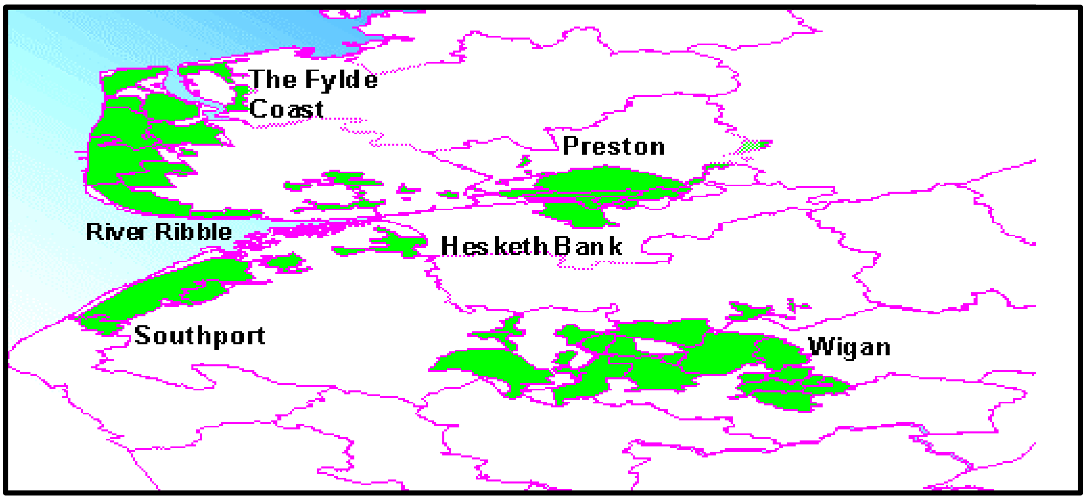

Figure 2 : *Scope of 3 spills per Bathing Season Projects*

In addition to the data required for this verification exercise, other key information was required including:

- *Long term rainfall data over large areas*

  This was required for the SIMPOL models (described within the next section) and also to investigate the impact of spatial effects over the catchments

This involved sourcing data from The Met Office, EA, Local Authorities and educational establishments

- *Data on the operation of the existing assets, pumping stations, WwTW and the feeder trunk sewers*

  This data was used for the verification of the SIMPOL models and the HydroWorks RTC models.

  The existing SCADA systems required alteration to ensure that all the required assets were not only being monitored but logged at on a continuous basis (on the Fylde system this equated to 23 pumps, 3 flow monitors, 8 depth monitors and 29 penstocks)

- *Details of the DWF and its makeup*

  This data was particularly important. The flows were measured at several points throughout the system and then collated and analysed with the population, rainfall and trade effluent data.

In excess of £0.7M was expended on flow surveys, data logging / acquisition

b) Build SIMPOL models for each of the catchments and calibrate against the HydroWorks models

As previously discussed, it was decided to use the latest continuous simulation techniques. Each catchment was emulated within the SIMPOL environment and calibrated against the corresponding HydroWorks. Very close correlation was achieved, typically +/- 1%. Figure 3 shows the typical correlation :-

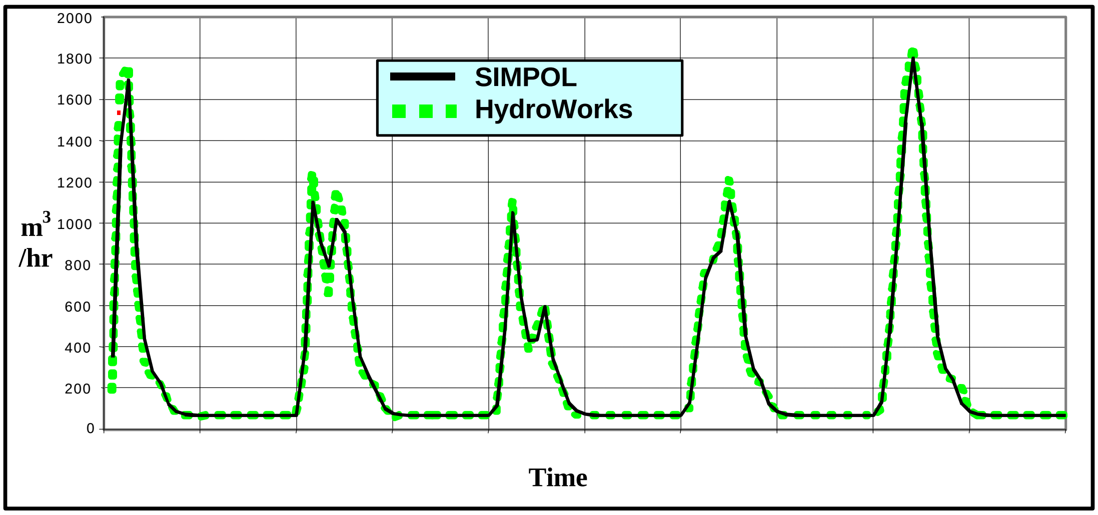

Figure 3 : *SIMPOL Vs HydroWorks Correlation*

c) Combine the individual SIMPOL catchment models to create a single SIMPOL model for each scheme. Verify against real-site data from SCADA systems

The appropriate individual SIMPOL models were then combined to create an overall SIMPOL model representing the entire catchment of each WwTW. The control rules that govern the underlying scheme were also emulated as accurately as possible within the SIMPOL environment.

Figure 4 illustrates the conceptualisation applied to the Fylde tunnel scheme:-

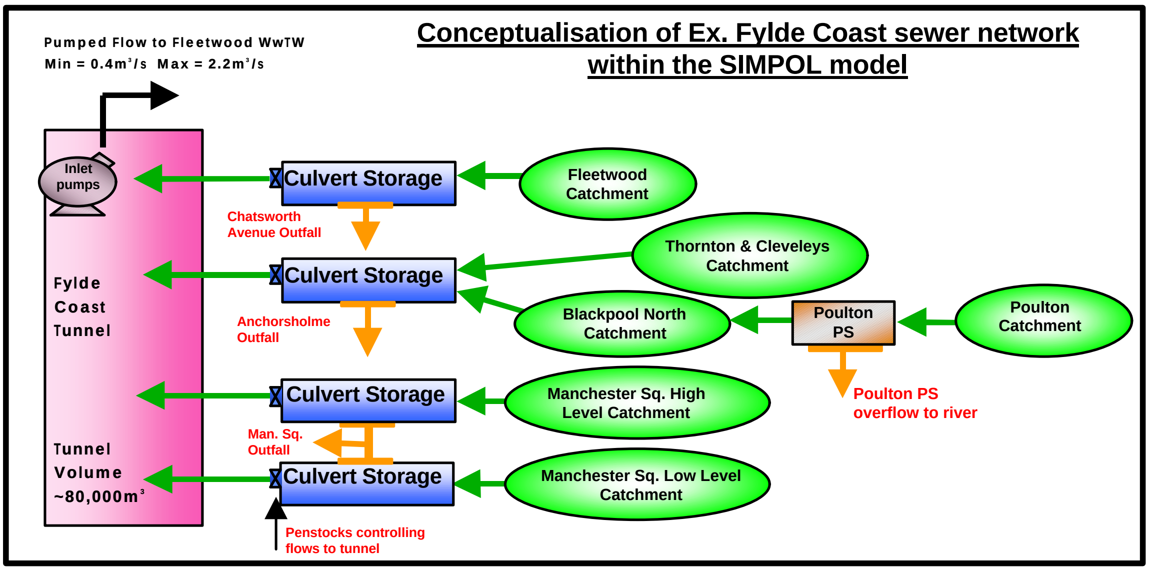

Figure 4 : *The Fylde Scheme SIMPOL Conceptualisation*

These models were then calibrated against real site data, obtained from both flow survey data and information from the SCADA system. Particular attention was paid to obtaining good volumetric matches.

Figure 5 shows the very close correlation achieved :-

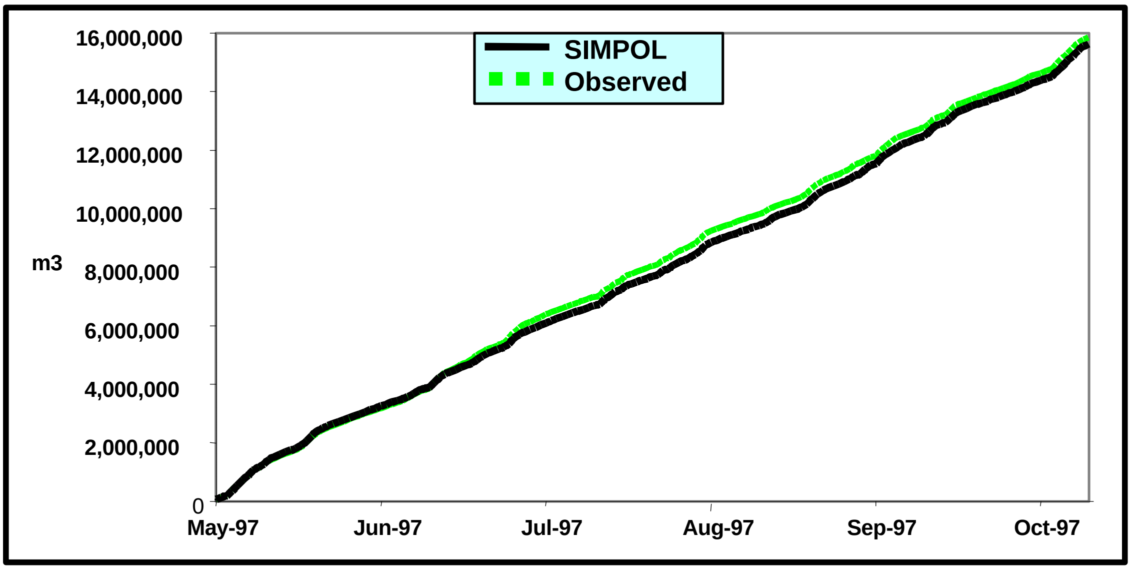

Figure 5 : *The Cumulative volume received at Fleetwood WwTW during the 1997 Bathing Season*

Advanced wetness and infiltration algorithms were also developed to improve the base-flow matches. Traditional techniques do not accurately predict the tail at the end of a storm event, tending to under-predict run-off. In reality, as the ground becomes saturated towards the end of a storm, additional run-off is generated. When sizing additional storage, it was of vital important to accurately model this effect. If the models used under-predicted run-off, the additional storage would be under-sized.

Figure 6 shows the closeness of the fits achieved.

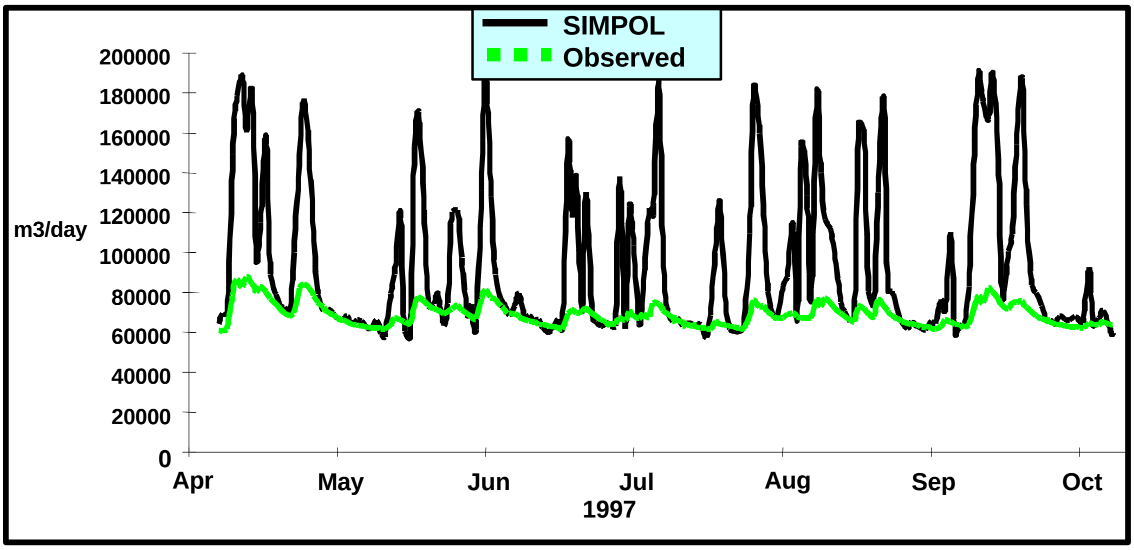

Figure 6 : *The SIMPOL model predictions of Base Flow against actual observed data*

Figure 7 shows the closeness of other fits achieved. Observed tunnel level at the Fleetwood shaft and actual pumped flows to treatment are compared directly against SIMPOL predictions.

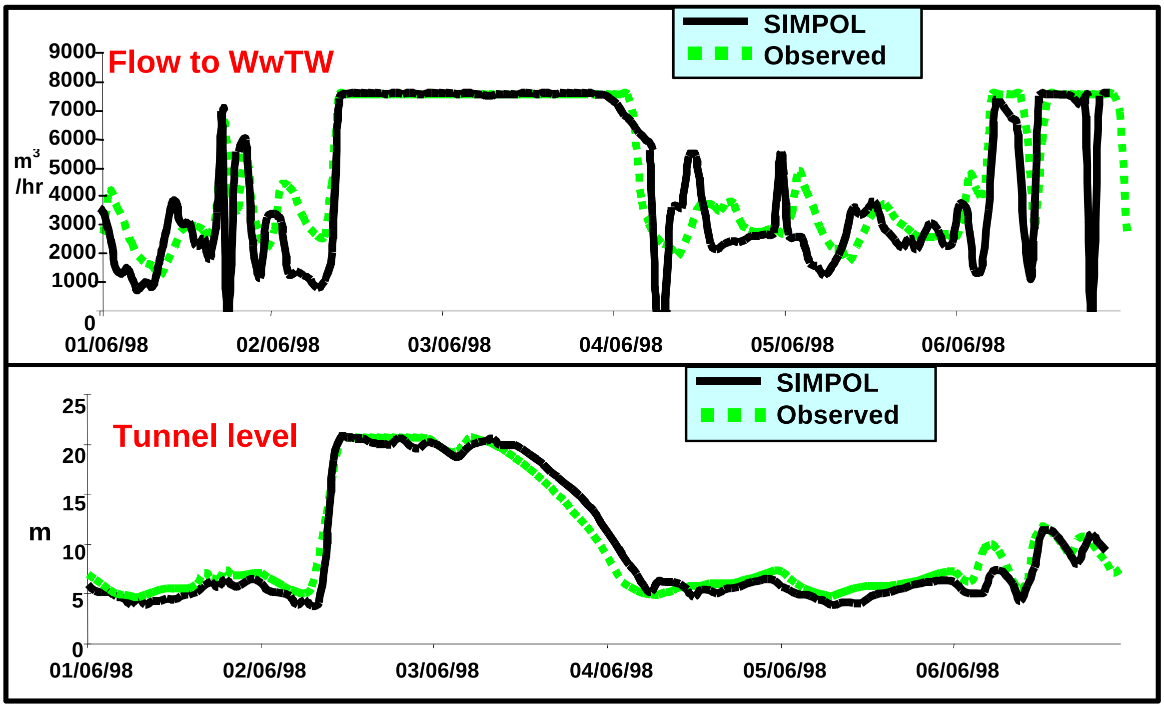

Figure 7 : *The SIMPOL model predictions against actual observed data*

d)&e) Run historical rainfall data though the SIMPOL models and add additional storage to the model and re-run until the required number of spills is achieved

Having developed a SIMPOL model that satisfactorily represented the existing scheme, the next phase was to modify this baseline model to reflect all known future changes to the network and scheme in general. Additional storage already identified, such as for the Urban Pollution Management work (UPM), was added to the model.

Historical rainfall data was then used to simulate a long-term, continuos period of rainfall. For the Fylde, 24 years of data measured at Blackpool Airport (at hourly intervals) was available, in other areas STORMPAC generated rainfall was used. An iteration process was then performed to determine the additional storage required, and at which location, to achieve the designated average 3 spills / Bathing Season / outfall.

f) Combine the individual HydroWorks models and add the RTC rules for the existing system and verify against real-site data from SCADA systems

SIMPOL was the correct environment for establishing the additional storage requirements. However, it was recognised that simplifications had to be made in terms of the control strategy that controlled the scheme. Having determined the additional storage, the next phase was to revert back to HydroWorks with the Real-time Control functionality to explore and assess alternative control strategies. The first step here was to develop a HydroWorks Model that closely resembled the scheme as it is at present. This provided confidence that the baseline model was accurate.

g)&h) Add the additional storage to the HydroWorks models at the appropriate locations, evaluate and test alternative control strategies

The next step was to integrate the new storage elements and then use the model as a platform on which to test, evaluate and optimise alternative control schemes. One of the lessons learnt from previous schemes was that the control systems that govern them are often over complicated and difficult to fully understand and alter. Therefore the intention was to keep the new control system as simple as possible.

g) Construct a detailed SIMULINK model of the proposed systems to allow detailed controller tuning and optimisation

When the overall, conceptual control strategy was agreed, a specialist control systems modelling environment (SIMULINK) was used to develop the detailed control algorithms. This software was used on the previous Fylde Coast scheme however, its full potential has been realised on this project.

h) Code the Programmable Logic Controllers (PLC) directly from the SIMULINK model

These will enable accurate flow charting prior to PLC software development. A real-time, bi-direction interface between SIMULINK and the actual PLC's will allow full dynamic testing of the software prior to commissioning.

The Modelling Results

For the Fylde Coast scheme, an additional 90,000m^3 of storage was identified to achieve the 3 spills per bathing season criteria. This compares with 80,000 m^3 for the existing tunnel and approximately 20,000 m^3 within the sewer networks. 60,000 m^3 , in the form of 2 tanks, is currently being constructed within the sewer network at Bloomfield Road, Blackpool. The remaining 30,000m^3 , also in the form of 2 tanks, is being constructed at Fleetwood WwTW and will be hydraulically linked to the existing tunnel.

As initial estimates for the storage volumes became apparent, concerns relating to the location of the tank(s) rapidly emerged. These would be some of the largest storage tanks in Europe, and yet they needed to be located within a totally urban environment.

A number of potential options and configurations were explored. The final choice of location was based any many factors, the prime ones being :- construction costs, impact on the local community, controllability for a given partition of storage at different sites, available access for construction, ease of connection to the existing sewer system and underlying ground conditions.

Figure 8 illustrates the selected location of the storage:-

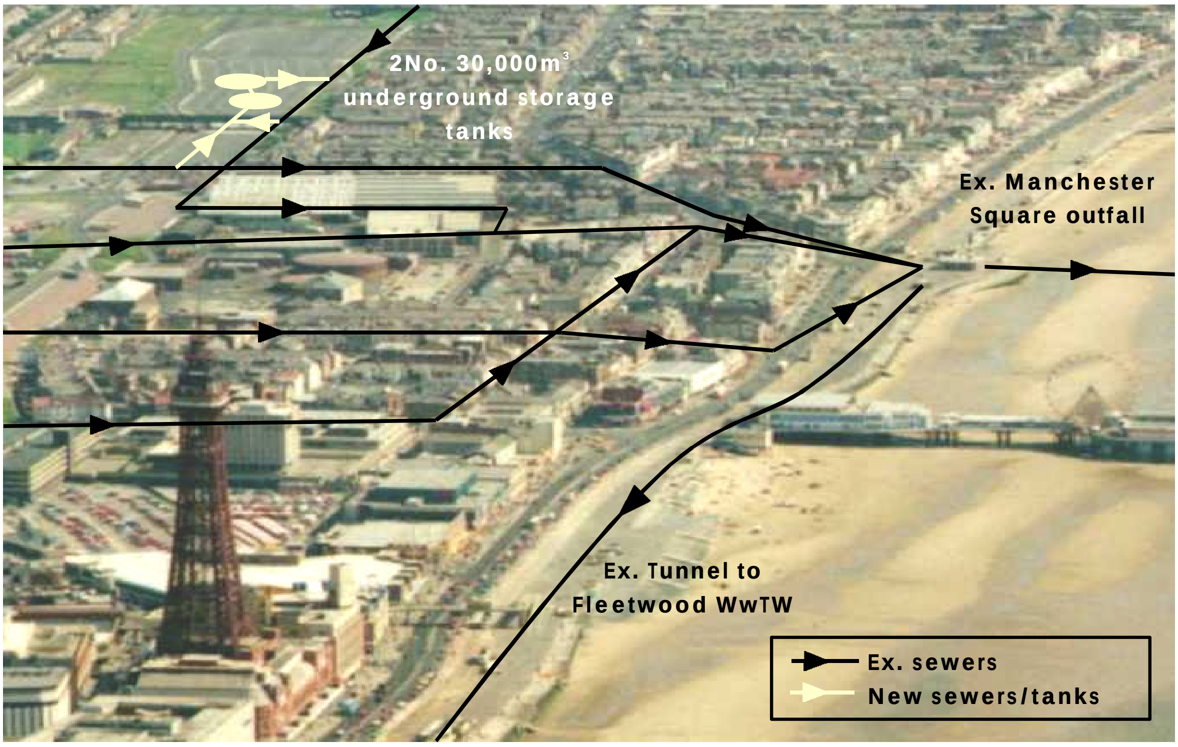

Figure 8 : *Aerial View of the Blackpool end of the Fylde Coast Tunnel*

Work was also undertaken using the models to assess the impact on operating costs and maintenance regimes at Fleetwood WwTW, given the additional flows that would now require treatment. Refurbishment of the existing outfall pumping stations at Manchester Square and Anchorsholme was also influenced by the modelling work in terms of screening and pump capacities.

The Challenges

General

As previously mentioned, some of the existing catchments initially had either ill-defined HydroWorks models or none at all. The necessary Model Verification Process involved the installation of over 400 flow sensors within a 6-week time period, and the instigation of many SCADA points throughout the region. The initial match between actual spill events and SIMPOL's predictions was deemed unacceptable. Leading-edge work was performed to improve the predictions, including :- enhanced control emulation, improved representation of catchment/tunnel interaction, inclusion of more advanced wetness/infiltration algorithms, assessment of the effects of spatial variation of rainfall and execution of full volumetric flow surveys with high-resolution SCADA data.

As previously stated, in order to meet the required timescales initial estimates had to be made at an early stage regarding storage volumes. The main way to ensure compliance with the target dates was to run the major activities in parallel.

Figure 9 below shows the overall programme :-

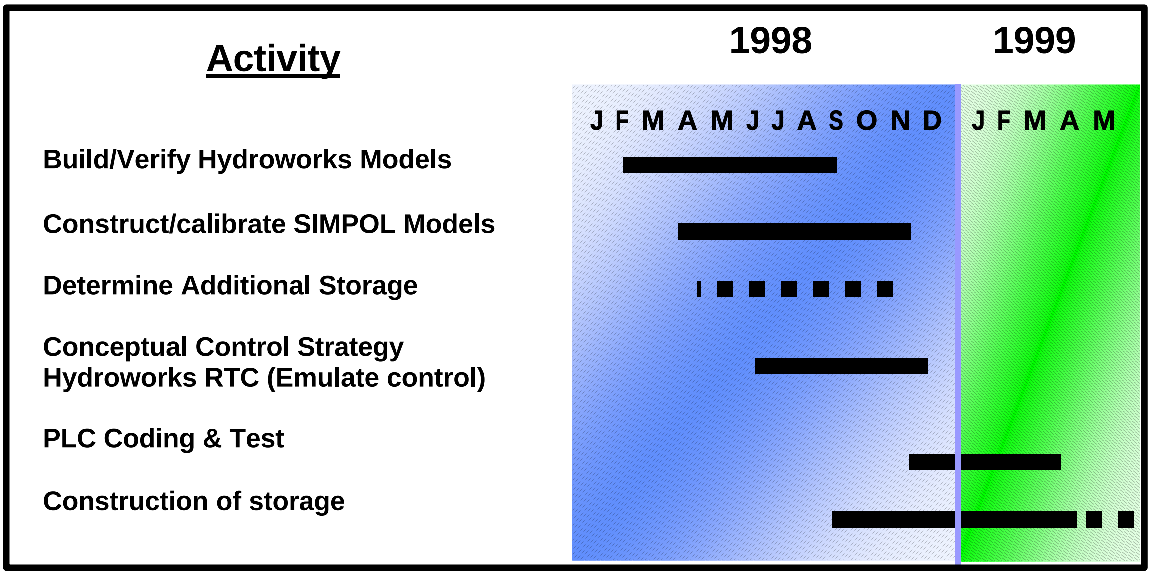

Figure 9 : *The Modelling, Engineering Design and Construction Programme*

Base Flow Representation

A consequence of using Continuous Simulation was the need to accurately understand and determine the individual components of flow and, in particular, the baseflow components. This is because the extra volume of storage can only be emptied in the gap between the baseflow and the maximum rate of flow through the WwTW.

Figure 10 shows the constituent parts of the total flow hydrograph :-

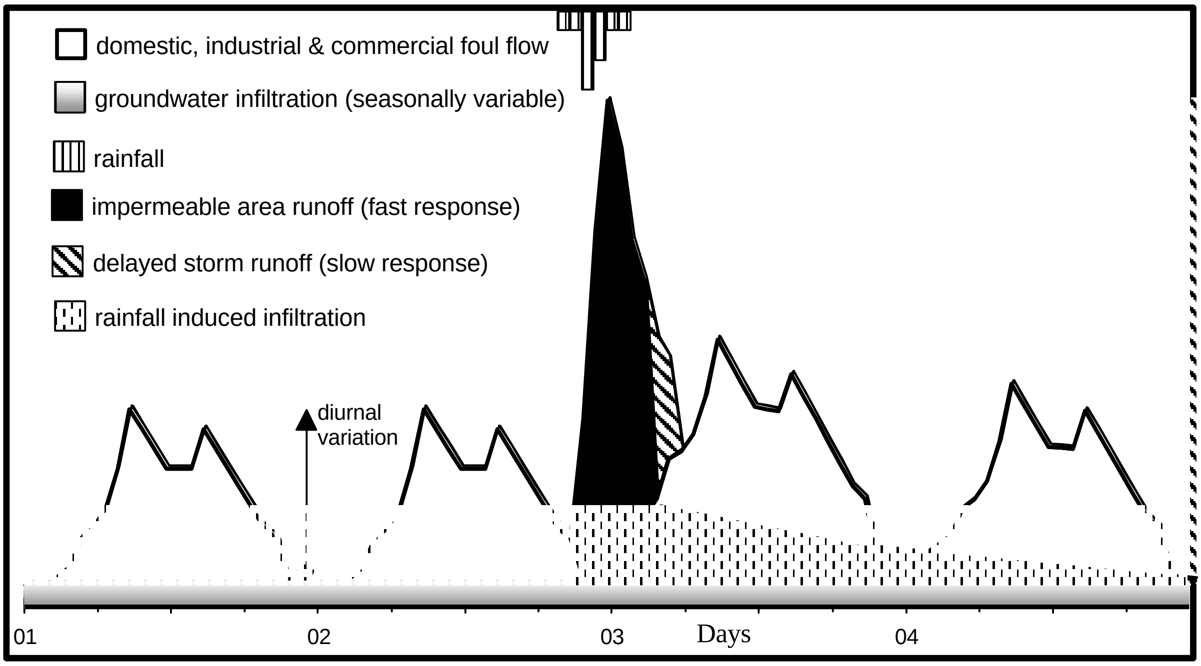

Figure 10 : *The individual flow components*

Each of the above flow components was represented in the SIMPOL model. The runoff components were calibrated against HydroWorks and the other components against SCADA data over 1997/1998. As the HydroWorks model building and verification progressed towards conclusion, more data became available from the flow surveys and the SCADA system enabling accurate calibration of the SIMPOL models. The accuracy of the fits from this work provided further evidence that the adopted approach was valid.

Spatial Effects

There were concerns relating to the potential impact of spatial variation on the spill frequency at each outfall. A spill occurring more frequently at one particular outfall compared to the others would imply that the storage capacities associated with that outfall had not been fully utilised. The EA expressed a view that they would ideally expect to see all three outfalls spilling simultaneously. They were informed that it would not be possible to guarantee that this would occur due to the location and connectivity of the various storage elements. However, NWW assured the EA that as far as possible all the storage in each catchment would be fully utilised before a spill occurred at any of the outfalls.

The first step was to establish if any spatial variation actually existed. To achieve this, long term data from as many gauges as possible was collated. This proved to be a some what fruitless task as the only available long term source of data was from Blackpool Airport and 18 months of data from the recently installed rain gauge at Fleetwood WwTW. This data was not detailed or long enough for any consistent variations to be found. However, it provided sufficient information to calibrate a spatial-temporal rainfall model, which was used to generate long timeseries of rainfall data. Using these series with the SIMPOL model gave confidence that the proposed solution was not particularly sensitive to spatial rainfall effects.

The orientation of the catchment also has an effect. The catchment is oriented North-South, with the prevailing wind direction being west to south west so there is little temporal variation when frontal rainfall hits the catchment.

A more critical situation occurs during localised storms moving slowly over each catchment. The worst case being a localised storm moving north to south across the whole catchment. It is theoretically possible that while the storm is centred over Fleetwood the run off generated would entirely fill the tunnel. Then as the storm moved south the flows from Anchorsholme would not be able to enter the tunnel and would spill immediately. Manchester Square is slightly different in that it has $60,000m^3$ of storage in the sewer network to fill before a spill occurs.

The small amount of analysis that was possible, due to limited amount of long term data, determined that while is was a possibility it was unlikely to occur on a frequent basis.

Conclusions

It was recognised at the outset that conventional modelling techniques (using single storm events) would have led to an incorrect assessment of storage volumes.

It was also clear that a radically different approach was required to meet the very tight timescales.

NWW, Bechtel and WRc have exploited the latest modelling software environments (SIMPOL continuous simulation version, HydroWorks RTC & SIMULINK) and applied leading-edge techniques to enhance and improve this technology.

The application of this novel methodology was applied to a major, fast track design and construction programme and was essential to meet the very tight timescales.

A close working relationship was deemed to be essential between those actually doing the work (NWW, Bechtel, WRc) and those expected to approve it (NWW, EA). This involved regular briefings and dissemination of information.

The Environment Agency has supported the approach taken throughout and is keen to learn from our experiences.

DISCUSSION

Question Sheila Sowerby Environment Agency
In some of the plots you mentioned a different rainfall runoff relationship. What consideration being given to reducing infiltration. Is it a company view only to look at short term goals.

Answer

None , the scheme was entirely focussed on the storage provision due to the time scales. I cannot give the company view.

Question Ed Bramely Yorkshire Water

What work has been done to look at what caused the failures ?

Answer

Nobody fully understands the complex relationships. The work was agreed between NWW and the EA. The current work focuses entirely on the storm discharges. Further investigations are under way by both NWW and the EA in order to get a better understanding of this complex situation.

Question Richard Kellagher HR Wallingford
What was the original design based on , rather than 3 spills per annum.

Answer

The original design was to achieve 10 to 12 spills per bathing season which was subsequently changed to 3 by the EA. All the assets constructed as part of the original design are meeting the consent standards set by the EA.

Question David Searby Wessex Water
How long will it take to empty the 170,000 m^3

Answer
It will take approximately 24 hours to empty the storage assuming no inflow. However , with normal DWF this would exceed 36 hours.