How to build the biggest hydraulic model in the world

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1. Introduction

As the Sewerage Management Plan (SMP) consultants for the Minworth catchment, RPS was set the task of creating a single working hydraulic sewer model for the entire catchment for Severn Trent Water (STW). The Minworth SMP catchment contains the majority of Birmingham, England's second biggest city, as well as most of Wolverhampton, Walsall, Sutton Coldfield and parts of Solihull. As of today the Minworth model contains approximately 135,000 nodes which make it one of the biggest hydraulic models of its kind based on node count. The model has a total sewer length of 6,670 km, which includes all of the surface water system for the catchment and covers a total area of 44,750 hectares and a population of circa 1.5 million people.

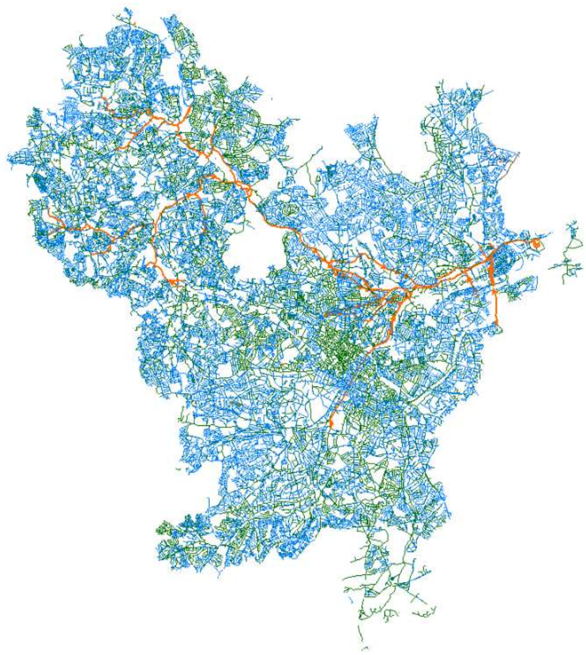

Figure 1.1 Minworth Catchment (Black Country Trunk Sewer shown in orange)

Due to the size of the catchment, the area was originally split into 53 drainage area studies which were undertaken during AMP 3 and AMP 4. This means that there was already a wealth of data that could be used to help create an all-encompassing Minworth model. This included over 1,000 DAP flow monitors and hundreds of asset surveys. In addition, as part of this project 64 strategic flow monitors were installed along with 80 rain gauges, of which 13 are still installed. Over the years many schemes have been completed, which meant there were lots of As—Built drawings and scheme models which could be used. Within RPS there are a number of senior employees that have a vast experience of working in the catchment. In addition RPS have been working on the Minworth SMP for over six years now and the Minworth SMP team have developed very good relationships with a vast amount of key stakeholders to the catchment.

With all this information collated in one place it enabled a great starting point when looking to build one of the biggest hydraulic models in the world.

2. Model Development

2.1 Sub Area Models

The Minworth SMP catchment at the beginning of the AMP5 model upgrade process was divided into seven sub areas in order to allow allocation of resources to ensure completion for the end of AMP5. The seven sub areas (see Table 2.1) were defined based on suitable hydraulic points and therefore not equal in size or complexity. Flows around these hydraulic break points were checked on completion of the combination of the sub area models.

Table 2.1 Summary of Sub Areas

Sub Area Ref	Location	Size (ha)	Size (population)
A	Rea Main	6,664	252,964
B	Oldbury and Tipton	6,257	222,612
C	Walsall and Ladymoor	7,454	270,644
D	Perry Barr and Great Barr	3,975	92,293
E	Central	7,132	374,124
F	Sutton Boldmere and Yardley Tyburn	5,914	98,616
G	Cole Valley	7,099	262,701

The AMP5 model upgrade process included:

- Updated the model to the latest version of modelling software (CS 10.5 for Sub Area A, CS 11.5 for Sub Area B, CS 13.5 for Sub Area C, D, E, F and G)
- Checked the landline to OS Matermap positional accuracy
- Ensured the associated modelling files (contributing area, non-domestic flow, domestic flow and land use) comply with the current specification
- Updated the runoff model to the AMP5 standard runoff profiles
- Checked that the following the model parameters are suitable against the AMP5 specification: headloss, storage compensation, flood modelling, infiltration
- Reflagged the models to the latest specification and based on the data source
- Reviewed the previous verification following model updates made as part of AMP5 model upgrade process and where necessary make adjustments to the model

All of the activities above are typical for SMP updates however the scale of the activities due to the size of Minworth means that these updates can take a large amount of time. For instance, Sub Area E contained 4,000 junction manholes which took just under 4 weeks to assess.

The proposed SMP phased programmed was outlined in *The Minworth SMP – Initial Steps* (Bailey AD, 2011) and is shown below in Figure 2.1.

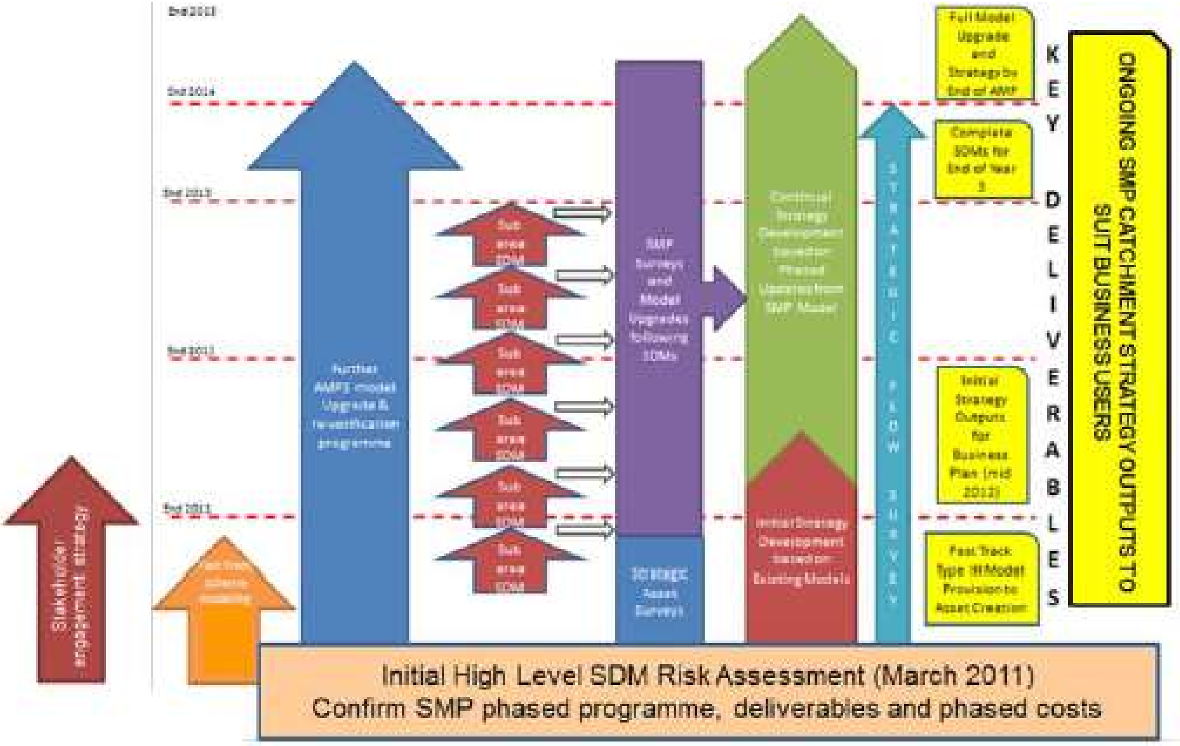

Figure 2.1 from The Minworth SMP – Initial Steps (Bailey AD, 2011)

The model discussed in this paper is the final Minworth SMP model following the addition of the Sub Area model upgrades. This section will detail the model combination process and any issues associated with this process.

The original plan was to undertake each of the seven sub area model upgrades sequentially. The first two sub areas (A and B) were undertaken following this approach. During a meeting in 2013 the Client PM decided to change tack and to undertake the remaining five sub area model upgrades at the same time rather than staggering the remaining five sub area model upgrades as shown in Figure 2.1.

After the first two model upgrades a number of lessons were learnt and procedures put into place. For instance, extensive internal model audit were undertake at each major model stage rather than just at the completion so as to reduce stability issues.

2.2 Surface Water Model Build

Historically, pre AMP5 in Severn Trent Water, the public surface water sewers had only been modelled in areas with drivers such as flooding or where CSOs discharge to them. In the Minworth catchment in particular only 48% of the surface water system had been modelled prior to AMP5.

The Minworth catchment contains circa 4,000 dual manholes and, therefore, the Asset Creation Design team requested that the surface water system be modelled for the entire catchment. This was to enable full catchment assessments on the dual manholes in the catchment. The SMP Client PM agreed to this request as it was evident that the benefits of having the entire sewer catchment model would be appreciated in the wider business.

The surface water sewer model was constructed using sewer records. In order to make the model a manageable task the activities were split into the same areas as the AMP5 model upgrade sub areas. A large team of modellers (approximately six modellers over six months) was resourced to undertake this major model build activity.

Following the completion of this model build exercise, the surface water sewer was added to the relevant Sub Area model. This ensured that the connectivity of the two models was completed by the modeller with the greatest catchment knowledge.

Stability tests were then undertaken on these sub area models as it is often found that the surface water sewers are most prone to stability issues.

2.3 Addition of Developments and Capital Projects

The AMP5 sub area models had a base model age of the DAP flow survey (between 2001 and 2010) therefore it was necessary to add in the capital project and developments that have been completed since the base model age in order to produce a Current As-Built model.

These additions were undertaken within the individual model areas to best utilise the catchment knowledge from the sub area modellers.

2.4 Model Combination

Each sub area model was considered complete and ready for combination when the following activities were complete:

- Converted to AMP5 specification
- Addition of surface water model build
- Addition of developments and capital project to give a model age of 2015
- Stability Checks undertaken

From the initial model review, as part of the Minworth Scoping Report, through to having the sub areas ready took approximately four and a half years.

Following the addition of the surface water model and the other model addition this led to the potential fully combined model node count to exceed 100,000. At the time the existing software was capped to 100,000 nodes. Therefore, it was necessary to consult with Innovyze in order to make changes to the software to allow for a model of a node size bigger than 100,000. As a result Innovyze expanded the node limit on their ICM 5.5 software.

As each of the sub area models had been constructed in CS 13.5 it was necessary to convert each of the models to ICM 5.5. The necessary stability checks were undertaken during their conversions.

The model combination was undertaken with accordance to Severn Trent's *Procedure 253 -Combining Model* which is based upon the work undertaken of *Application of a model combination methodology to the Northern Tame catchment* (Milner S, Margetts J & Austin H, 2007). The basis for this is that model checks are undertaken on the model when it is in its own model space, when it is in the combined model space but not connected up and once it is connected up in the combined model space.

There were a number of processes and checks that were put in place as it is a complex and large scale model. This includes having a log for profile numbers for both wastewater and trade profiles – with the number of models and number of modellers working on the models it made the chance of duplication in unique ids less and make the combination of the model more straight forward. Extensive checks were also undertaken on Pipe Shapes, Head Discharges, RTC, User Defined Defaults, Duplicates, Runoff Surfaces and Land Uses.

After each sub area combination each of the outfalls in the model was checked to ensure that any connections between the sub areas were not missed.

The final model contains over 135,000 nodes and is a good physical representation of the foul and surface water network upstream of Minworth STW. The only network that is missing is ex-section 24 sewers, sewers less than 100mm diameter and culverted watercourses. It should be noted that, to date, the majority of the surface water sewers are not verified for the catchment.

2.5 Rainfall Application

As the Minworth catchment is so large. at over 44,750 hectares, it is difficult to know how best to apply rainfall across the catchment. It is standardised practice for design rainfall application to be applied globally across the whole model. However, as seen from rainfall review, this is not reflective of reality of a catchment the scale of Minworth due to spatial rainfall. Therefore, standard design rainfall application may give an over prediction of trunk sewer flows and therefore an over prediction of predicted sewer flooding and CSO spills. Tests were undertaken in order to understand how spatially varying design rainfall application affected the predicted trunk sewer flows, sewer flooding and CSO spills. A test was done where design rainfall was first applied to the entire model and then seven more simulations in which rainfall was applied to only a single sub area within the Minworth model. Comparing the results from these tests showed that the increased trunk sewer levels had a small impact on sewer flooding. This is due to the CSOs located on the trunk sewers across the catchment and as a result an increase in CSO spills is seen on the trunk sewers when rainfall is applied to the entire catchment compared to when rainfall is applied to just a single sub area. As there was only a small increase in flood risk as a result of applying rainfall to the entire catchment, it was agreed with STW that for the purposes of the SMP live outputs, applying rainfall to the entire catchment would be acceptable. This gives a reasonable balance with over predicting CSO spills in design rainfall with only marginal impact on flood risk. It was also agreed to create a “fuzzy zone” around the areas which see an increased flood risk, due to higher trunk sewer flows, so that the user knows that results from these areas should be used with caution. For detailed design purposes on a catchment level it is also recommended that further investigation is undertaken.

Another question which arises regarding rainfall application is whether or not applying one storm to the entire catchment at the same time is the “worst case scenario”. Can a storm which moves across the catchment, result in greater trunk sewer flows? Further investigation is required in order to understand this. The advantage of having such a large model is that it is a great model use for research into modelled rainfall application.

2.6 Issues

Due to the size and complexity of the modelling in Minworth there were a number of issues that were found in the combination process.

The existing software at the time was restricted by a node limit of 100,000. Therefore it was necessary to do most of the model updates on a sub area basis and await the software update by

Innovyze to expand their node limit to accommodate the “new” Minworth model node size. This meant having to convert the model to a new version of the software. There can be small variations between the various software updates which can lead to changes in the model results. Therefore, simply due to the size of the network, lots of checks had to be taken on the model to ensure that the model results had not changed significantly based on both combination of the models and converting to a new version of modelling software.

A regular problem for the modelling team was the restriction of 2GB on the Infoworks CS Jet Model Database size. This meant that for the first sub area, Sub Area A, eighteen jet databases were required for all of the modelling activities undertaken in this sub area alone. In order to resolve this issue an SQL server was used from 2013 onwards. This allowed a team of over ten modellers to store all modelling activities in Minworth in one place without the regular need to archive old databases. Prior to the model combination in ICM in 2015 the SQL server for Minworth was 150GB in size and therefore without this there would have been approximately 75 Jet databases which would have been more difficult to manage.

Due to the size of the model, simulation times and the file size of the simulation files can be large. When undertaking full design suite simulations it required some planning and preparation. One DWF design simulation takes approximately 2 hours. A week long verification event can take approximately 10 hours to simulate and has a file size of 80GB. To undertake the full design suite simulations it took four computers approximately a month to complete. This also takes into account resolving model instabilities and network dropouts. It is necessary with models the size of Minworth to make sure there is sufficient hard drive space to store the simulation runs and that there is sufficient resilience within the IT systems so that there is no disruption to the simulations.

Drain down times in a catchment the size of Minworth are large. However, using a large lag time on model simulations further lengthen overall simulation times and increases file sizes. In order to keep simulation times and file sizes reasonable the lag time for Minworth was kept to 2,000 minutes for the SMP outputs. A lag time of 2,000 minutes for some areas of the Minworth catchment does not reflect sewer flows returning to DWF conditions, which again need to be reflected in assessing the model output.

Due to large presence of surface water sewers in the model, and the fact that the majority of the surface water sewer flows have not been verified, model instabilities often occur. Pink simulations tended to occur in one out of seven simulations on the Minworth model prior to improvements to the model. Changes (see below) have been made to the model in order to improve model stability, some of them suggested by Innvoyze and based on experience with the model. It should be noted that changes to headlosses should be considered at the initial model build stage and not after verification as it was found to cause large changes in depths in both the trunk sewer and local network.

- Headloss type to NONE if the gradient is over 0.1m

- Ensure that junction headlosses have been properly calculated

- Ensure that all head manholes have an upstream subcatchment

- Replace small lengths of sewers with modelled orifices

- Sufficiently sized dummy network

- Set tolerance in Sim Parameters as per Innovyze's recommendations

- Undertake diagnostics on simulations with stability issues by checking the log results for locations where large iterations have occurred

The Minworth model simulation issues have vastly improved following the stability changes undertaken and the team are more experienced in undertaking the necessary diagnostics to assess and resolve instability issues.

3. Model Outputs and Uses

The advantage of looking at the Minworth model as a fully combined model is that the trunk sewer flows are fully represented rather than represented using level or inflow files. It also means that risk can be assessed on a whole catchment basis and flows directly into Minworth STW can be understood.

The main advantage of the Minworth Model is that the surface water system is fully modelled and therefore assessment can be undertaken on the surface water system that were not previously possible. This is particular pertinent following the 2010 Pitt Report where there has been a drive for Water Companies, such as STW and Lead Local Flood Authorities (LLFA) to work closely to understand all flood risk. In the majority of cases this is when there are complex relationship between surface water sewer, small watercourses and major rivers. The Minworth SMP Model results have been used by Severn Trent to help understand the root cause of flooding and supplied to LLFAs in areas where they are multiple flooding sources.

3.1 SMP Outputs

The current available outputs that have been produced for the Minworth catchment using the full Minworth catchment model:

- Severn Trent 2B Flood Risk Layers and assessment – thematic map using model surcharge levels and LiDAR
- Severn Trent 2C Flood Risk Layers – flood map using model surcharge levels and then maps the potential overland routes
- PONDSIM - flood map using model surcharge levels and then maps the potential overland routes
- CSO analysis – assessment against consent and Formula A
- PS Analysis – assessment against pump starts and the impact of growth on the asset
- Ancillary analysis – assessment of storage utilisation etc.
- Headroom analysis – assessment of surcharge levels, self-cleansing velocity assessment
- Carbon and Energy assessment - assessment of the power use of non infra assets

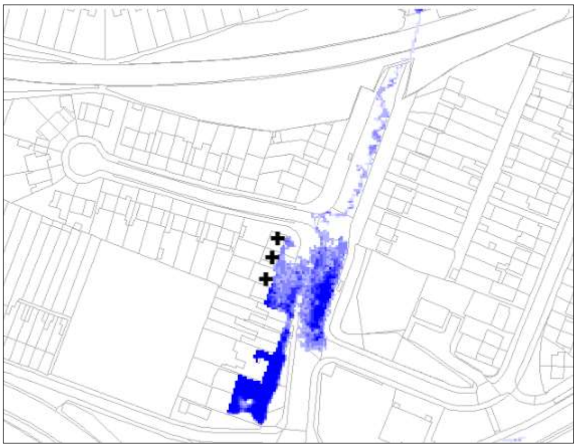

Figure 3.1.1 Example of PONDSIM Output

3.2 Strategy Development

The purpose of Sewerage Management Plans is to assess and evaluate risk, propose risk interventions and devise a strategy to mitigate risk in the catchment.

Utilising the Minworth SMP model results as well as consultation with a vast number of stakeholders the strategy for the Minworth SMP is currently being developed. One element of the strategy that is being developed at present is separation in the highly paved of Birmingham City Centre in order to reduce runoff to the combined system in this area. Another looks to understand all storage tanks within the catchment and their downstream control settings to understand whether adjustments on the controls could lead to better optimisation of storage to reduce flood risk in the catchment.

3.3 RTC Project

The Minworth SMP team are currently working on a project that is looking to utilise real time controlled penstocks on the major trunk sewers in the catchment of Minworth. The feasibility required for this project would not be possible if the entire catchment was not modelled as a whole. Not only the boundary conditions on the trunk sewer assets are better understood, but it is a requirement to understand the flows to Minworth STW. One of the aims of this project is to utilise storage capacity in the sewer network to control flows to Minworth STW in order to reduce energy use and cost.

4. Assisting the Wider Water Company Business

Due to the extensive catchment knowledge and experience within the Minworth SMP team many areas of the Severn Trent business approach the team as the first port of call for any root cause analysis or catchment requests.

4.1 June 2016 Flooding Analysis

In June 2016, Birmingham and the surrounding areas were hit with several large rainfall events. In some areas the events were recorded as over 1 in 100 return period storm events. 13 rain gauges are installed across the catchment, and it was therefore possible to retrieve details of the storms across the catchment and determine their return period. The availability of the Minworth Current As Built meant that the observed data from the rain gauges could be used to simulate the rainfall on the model. The model results data could be used to help inform STW whether or not areas reported to have flooded have done so due to hydraulic incapacity of the system. If an area had been reported to flood but was not predicted to flood in the model, it may indicate that the reported flooding was a result of pluvial or fluvial flooding. A good example of this is Pershore Road. Flooding was reported here, however the model did not predict flooding of the scale reported. A closer look at the river banks after the flooding showed that the river had overtopped its banks, which was understood by Severn Trent Water to be the cause of the flooding. This storm also enabled the testing of newly installed 250m^3 shaft tank on Pershore Road, which was yet to experience a storm event of this magnitude. The model suggested that the shaft tank did not fill even half of the tank; however telemetry data suggested that the tank was fully utilised. This gave STW Asset Creation a better understanding of how their asset was performing as the combination of model results and telemetry indicated that extra flow was discharging into the combined system and filling the tank. Evidence from a site visit suggested the source of this extra flow was from the watercourse overtopping its bank. STW Asset Creation informed Birmingham City Council and the Environment Agency so that all parties can work collaboratively to reduce all flood risk in the area.

The data from this storm also helped to develop future schemes by testing them in extreme rainfall events. On the 8th and 16th June a hotel in Great Barr flooded where there is already an ongoing scheme. Currently the combined system serving this hotel is pumped to another catchment. A proposed solution to this flooding problem is to abandon the pumping station and gravitate the flows directly to the nearby trunk sewer. As a complete Minworth model is available, with reasonable confidence in trunk sewer flows the proposed solution was simulated using observed rainfall data. This allows the Client to test their solution to a realistic large impact event. This will help STW Asset Creation to refine the solution for exceedance events.

Although the 13 rain gauges across the catchment were able to give a reasonable representation of the large storms, there is still a risk that smaller variations in rainfall were not captured by these rain gauges due to the large catchment size. A review of whether the 13 rain gauges are sufficient to capture spatial rainfall is recommended but will need balancing with budget. A few weeks after the June 2016 storm events 1km radar rainfall data was provided for the entire catchment for the 8th and 16th June. This data was then also used to simulate rainfall on the Minworth model. This gave more confidence in regards to variability in rainfall from the previous example as the density of data points is greater. Using the available radar data resulted in more predicted flooding nodes across the catchment as the spatial variation in rainfall is more accurately recorded compared to the availability of rain gauges. However, care should be used due to the expected peak intensity and total rainfall issues that are known to be associated with using radar rainfall. Results from both radar rainfall and observed rain gauges were used by STW and Birmingham City Council to help inform whether reported floodings were due to hydraulic incapacity. This helps STW and Birmingham City Council decide any proposed mitigation either local level or major capital project.

Research is currently being undertaken by RPS staff on the effect of spatial variation of rainfall on sewer models due to the availability of radar rainfall and over four years of observed rain gauge from 13 rain gauges across the catchment. This means the Minworth model is a valuable tool for their research.

4.2 Root Cause Analysis

Another example of root cause analysis that the Minworth SMP team have assisted Severn Trent Water with is for a pollution incident in a golf course in Sandwell. Service Delivery contacted the Minworth SMP team for assistance in understanding CSO spills to the golf course following a pollution incident. The Minworth SMP undertook upstream traces in the Minworth model of each of the four outfalls located in the golf course and no overflows were found. Based on the SMP team's catchment knowledge the team identified the area as a known dual manhole area. The SMP team produced a plan detailing where the eight known dual manholes were located but also indicated to Service Delivery that there may be further unmapped dual manholes in the area too.

5. What Next?

Now that a complete Minworth sewer network model is available, it provides a vital tool to STW for understanding root cause. The future is looking for how the model can be utilised further to predict risk before it happens and make current root cause analysis more efficient.

There has been a keen interest as part of the Birmingham Surface Water Management Plan (SWMP) to develop a "whole truth" model for understanding flood risk. This would be a model that contained all sewers (foul and surface water), culverted and small watercourses, major rivers and the interaction between all three. In addition, in particular known flooding areas it may also be prudent to undertake 2D modelling to fully understand the flood mechanism and route. The development of a "whole truth" model will require relevant funding and support from all stakeholders: STW, Birmingham City Council and the Environment Agency. Historically it has not been undertaken due to differing modelling software being required for sewers and rivers. However, now with the development of integrated catchment modelling software, models of this type can be produced. Based on the work undertaken for the root cause analysis for the June 2016 events having a tool like this would have been invaluable.

The Minworth SMP team are currently undertaking five dual manhole projects to ascertain whether it is suitable to seal specified dual manhole without causing flood risk to the catchment. Once these five projects are completed a dual manhole procedure will be developed for use across the entire STW region to stipulate the necessary assessment required to inform the decision on whether it is safe to seal a specified dual manhole. The Minworth model will be used to develop and test this procedure due to the complete modelling of both the combined and surface water system and the knowledge of the modellers within the team. Dual manholes along with misconnections are one of the major risks of pollution to the Minworth catchment.

In addition the SMP team are also undertaking Water Framework Directive (WFD) Intermittent discharge assessments on five river reach catchments that fall within the Minworth SMP. This will require less model build activities than other catchments due to the work undertaken to maintain the CAB model including the modelled surface water sewers. The WFD assessments will build on the existing model and add confidence in surface water flows in these five areas.

There is a move in the water industry for the Water Companies to have Smart Networks where incidents are prevented before they occur. The Minworth catchment has complex network of sewers, a high population density and proportionally high number of incidents compared to other catchments. This makes the Minworth catchment a prime catchment for Smart Networks. The Minworth model has been trailed for forecasting operational issues using ICM Live previously. However, it could also be used to forecast hydraulic flooding and better understand incoming flows to Minworth STW. The Minworth model with its coverage and the lessons learnt from the previous trial would be a good candidate for further use as a forecast tool.

References

The Minworth SMP – The Initial Steps, Andrew Bailey, 2011

Application of a Model Combination Methodology to the Northern Tame Catchment - Hannah Austin, Steve Milner and Jamie Margetts, 2007

Use of Monitoring Equipment to Proactively Manage the Waste Water Network, James Mason, 2016