Understanding Region Wide Flood Risk

Presenters: Matthew Butterfield (RPS)

Authors: Matthew Butterfield (RPS), Ally Gorst (RPS), Jose Pereira (AWS)

1. Introduction

Whilst catchment wide risk approaches have been developed for many years, improvements in software and simulation times have allowed us to refine and enhance the process of catchment based risk assessments. A huge step forward in the understanding of catchment flood risk can now be achieved, from 'likelihood' alone to 'likelihood and consequence'. Holistic analysis allows us to gain a better understanding of future challenges and the prioritisation of interventions based on the needs of the water company and a whole life cost benefit.

On behalf of Anglian Water Services (AWS), RPS Group Ltd (RPS) were tasked with calculating a Region Wide Flood Risk for 5, 10, 15 and 25 year design horizons. To allow AWS to assess the prioritisation of catchments for PR19, the scope of the study required the calculation of flood risk, including pollution risk from overland flows, for all catchments in the AWS region for a variety of scenarios, to assess the impact of climate change, creep and growth on future catchment risk.

2. The Challenge

To gain an understanding of flood risk for the entire AWS region, totalling 1023 catchments, a balance must be struck between the extent of the assessment and the level of confidence given to the results. Catchment level results can be produced everywhere but on lower confidence models, or results from higher confidence models can be calculated and extrapolated for the remaining catchments. At the time of the study the AWS Integrated Urban Drainage (IUD) programme, which aims to produce 100% model coverage across the entire AWS region, was in its early stages. Therefore, the only available models were from previous DAP studies or modelling projects in high priority areas and most of the catchments were without a model at all. The final agreed approach was to use the best models available to create a good base for extrapolation. A total of 40 catchments, recently verified against short term flow surveys were assessed and these results were then extrapolated to other catchments based on standardised metrics to produce a region wide flood risk assessment.

The assessment has been split into three sections; modelling of overland flows, quantification of risk using existing cost models and extrapolation of costs to remaining catchments.

Modelling of overland flows was agreed to be undertaken in InfoWorks ICM. Existing 1D models were converted to 2D and a variety of scenarios were simulated. Including a Baseline assessment, scenarios for Creep, Climate Change rainfall, Growth and a Worst Case scenario (including creep, growth and climate change) were created for 5, 10, 15 and 25 year design horizons and a variety of return periods and storm durations were run through the models to calculate the likelihood of flooding.

Quantification of risk was undertaken using existing cost models to identify the consequence of flooding. The 2D results from ICM provide a depth of flooding which is converted to a cost based on land or building type. In addition to the flooding cost impact, pollution from overland flows was also considered.

Extrapolation of costs to the remaining catchments was finally undertaken. Trends between several catchment properties and the total cost impact were identified for the 40 assessed catchments. These results were then extrapolated to those catchments where an assessment was not undertaken, with more weighting given to superior trends, to produce a region wide flood risk assessment.

Further detail on the sections of the assessment are given below:

2.1 Modelling of Overland Flows

To assess the overland flood risk from the sewer network, a standardised methodology was required. The agreed approach included the conversion of existing high confidence 1D models, within ICM, to 2D models. Therefore, extensive testing was undertaken to test a number of 2D modelling attributes and their impact on model predictions to create a standardised, repeatable process. The final process was chosen to efficiently configure models to optimise simulation times against the quality of predictions with the data available.

The first step was to identify what data was available. The resolution of the DTM used to produce the 2D mesh for the catchment was found to have a huge impact on the flood risk results. The figure below shows the difference in the quality of modelled overland flows and the impact on the predicted risk when a reasonable confidence resolution of 1m/2m LiDAR is used to produce the 2D mesh compared to a low resolution 10m DTM. The 40 catchments to be assessed were all chosen because, as well as a fully verified model, they also had full coverage of 1m and 2m EA LiDAR data across the entire catchment allowing for reasonable confidence to be given to results.

Figure 1: shows the difference in the modelled overland flows and the impact on predicted risk when a 1m/2m DTM is used to produce a 2D mesh compared to when a 10m DTM is used.

The next testing that was performed was on the resolution of the 2D mesh parameters within ICM. Whilst a higher resolution mesh gives more confidence to the modelled overland flows, the more triangles included in the mesh has a marked increase in simulation times when compared to a lower resolution mesh. The following resolutions were tested:

- High resolution: Max triangle size= 25m^2, Minimum triangle size=5m^2.
- Medium resolution: Max triangle size= 50m^2, Minimum triangle size=15m^2.
- Low resolution: Max triangle size= 200m^2, Minimum triangle size=25m^2.

The figure below shows the comparison of results for these scenarios.

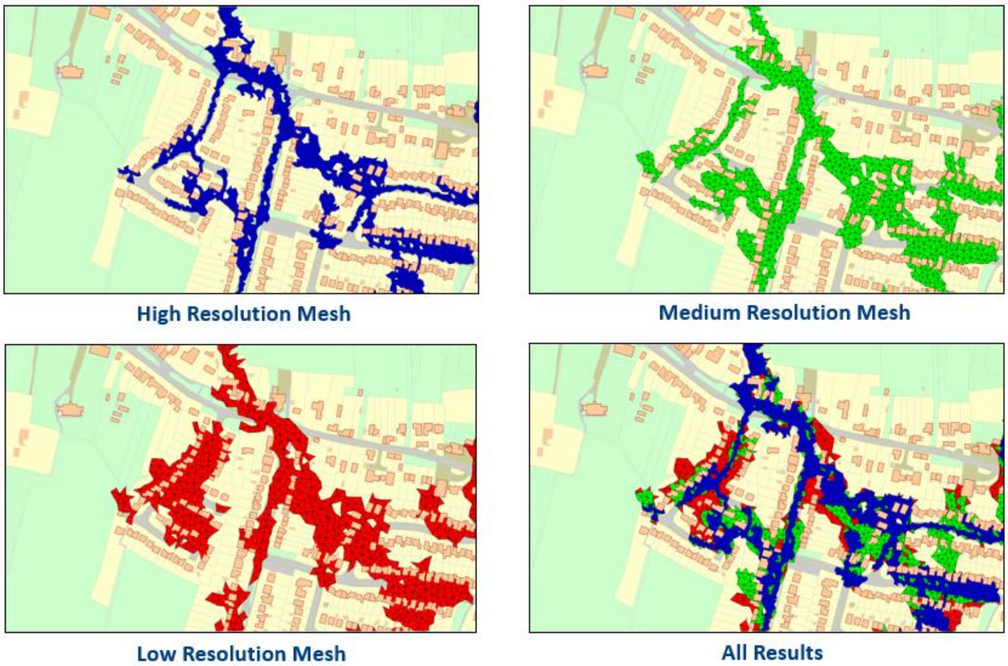

Figure 2: shows a comparison of the modelled overland flows and the impact on predicted risk when different resolutions of mesh parameters are used.

The representation of roads within the 2D mesh was also found to have a large impact on the model results. Whilst DTMs generally have some representation of roads, this is smoothed when the mesh is created, and the lower the resolution of DTM the lower the impact of roads on the conveyance of flows.

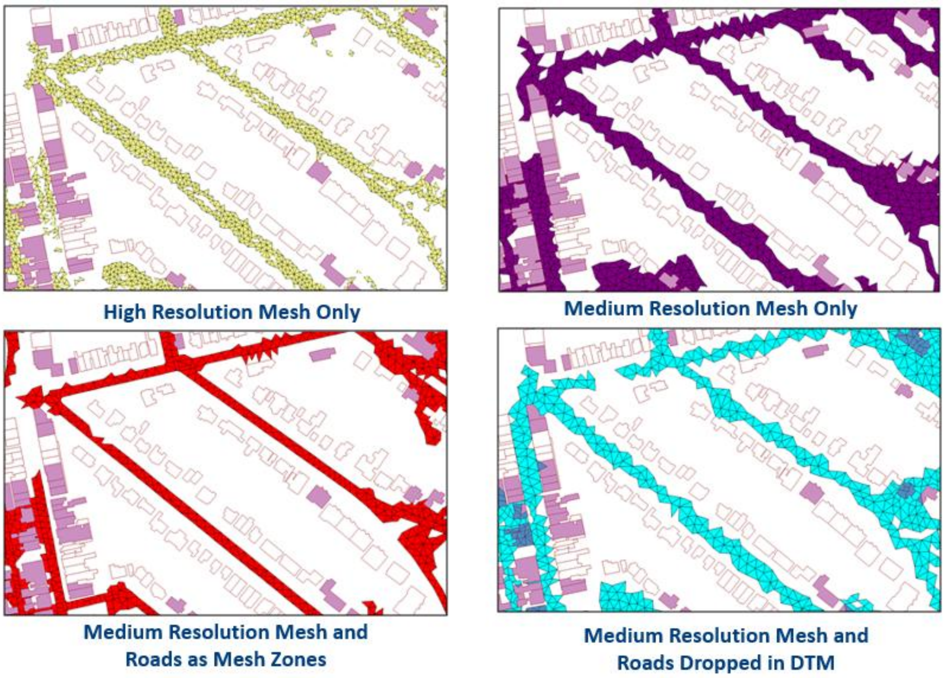

Figure 3: shows a comparison of the modelled overland flows and the impact on predicted risk when different methods are used to represent roads.

The figure above shows the comparison of results for a variety of scenarios that were tested. With just the mesh itself, and no additional representation of roads, flow conveyance along roads is occurring however a much higher consequence is predicted with the medium resolution mesh than the high resolution as flows from the sewer flooding touch on a higher number of properties. With roads added as mesh zones and the mesh lowered by 100mm, the flow conveyance is generally kept strictly to the road and higher confidence to the predicted consequence is given, with properties only flooding when depths are enough to breach the kerb. However, problems were faced with adding roads as mesh zones. Due to the complex nature of road polygons, issues with the stability of the model occur when trying to create a mesh. On a larger (region-wide) scale this would have a massive impact on the stability of the model and therefore large increases in simulation times. Manipulation of the DTM to drop the roads by 100mm prior to import into ICM and meshed to a medium resolution was found to produce results more like the high-resolution mesh without the increase in simulation times associated with the higher resolution parameters.

For the final approach, it was decided that the medium resolution parameters were to be used to produce the mesh and the DTM manipulated prior to import to drop all roads by 100mm. This was considered to produce the most reasonable confidence in results whilst optimising the length of simulation times.

Further testing included comparison of flood types (‘2D’ or ‘2D Gully’) and the representation of buildings (voids, porous polygons, DTM manipulation). The final approach applied all manholes as flood type ‘2D’ to avoid the necessity of adding a head discharge curve and creating unnecessary complexity. Buildings were added to the model as porous polygons to allow a wall height to be applied and allow flooding to occur inside of a building. Additional model complexity such as walls, hedges, infiltration zones and roughness zones would further increase the confidence in model results but to identify these on a region wide scale was too time consuming and complex.

Flood Risk results for the Baseline, Creep, Climate Change rainfall, Growth and Worst Case scenarios were created for 5, 10, 15 and 25 year design horizons using a variety of return periods and storm durations to assess the 'likelihood' of flooding. For each simulation, the 2D mesh results were exported and assessed.

2.2 Cost Modelling

The 2D modelling of overland flows from sewer flooding is only half of the challenge. To assess the 'consequence' side of flood risk, a Flood Risk Analysis Tool was developed to quantify the associated costs of sewer flooding and pollution from overland flows. The tool was used to identify the relationship between the depth of flow on the 2D mesh and the associated cost based on the building/land type where the flooding occurs.

Cost impacts of flooding and pollution were aligned with the AWS Business Index Matrices (BIM) cost model. Additional assessment also allowed the Multi-Coloured Manual (MCM) cost model to be utilised to compare the risk scores generated. Whilst this allowed some level of consistency between stakeholders, several challenges were found when aligning costs from a water company perspective and creating a consistency of approach. For example, whilst costs for cleaning sewer flooding from roads are a standard requirement for water companies, the MCM is more aligned to large scale river flooding and the full inundation of roads. Therefore, no account for jetting or general clean-up is detailed in the MCM and only the relaying of roads at much higher predicted flood depths could be used. On comparison of the total costs between the BIM and MCM cost models it was found that the MCM total costs were generally much lower than the BIM total costs.

Buildings/land types for a catchment were categorised based on region wide datasets. Polygons, taken from mapping data, were sorted and divided into receptor categories; highway, domestic property, non-domestic property, domestic curtilage, non-domestic curtilage, amenity areas, open areas, agricultural land and pollution areas. Further categorisation of receptors was performed to allow application of costs. For example, highway receptors were broken down into Motorways, A-roads, B-roads, and Unclassified roads. The main challenge of this process centred around the identification of internal/external flooding properties. Whilst identification of domestic/non-domestic properties and curtilages was reasonably straight forward, further calculations were then required to assign the curtilages to the relevant properties. Where internal flooding of a property occurred, external flooding of its associated curtilage was ignored to avoid the duplication of flooding events.

The tool was used to assign an annualised cost to each receptor for each scenario based on the depth of flooding predicted at the receptor location for each return period and duration. Total flood risk costs for the catchment were calculated along with a breakdown of costs for each receptor type and a series of flood maps to allow visualisation of impacted areas. Analysis of the results allowed the predicted worsening impact of creep, climate change and growth to be seen for each Design Horizon as shown in the figure below:

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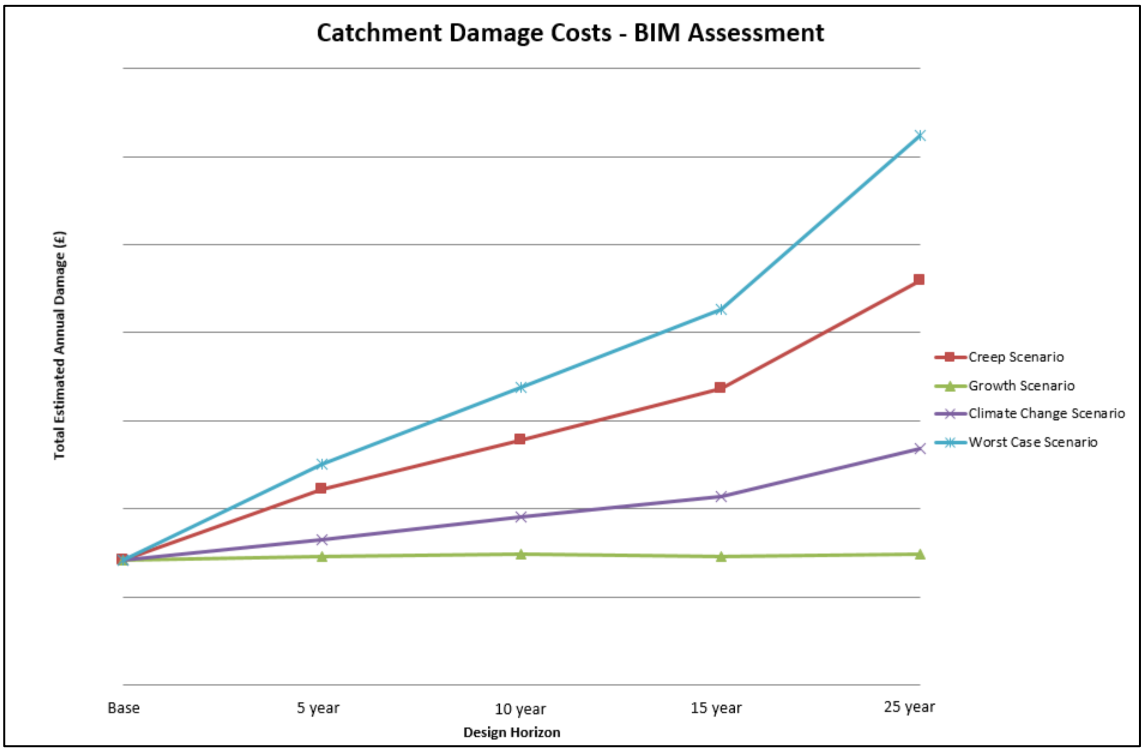

Figure 4 shows the predicted worsening in Total Estimated Annual Damage for an example catchment for each scenario and Design Horizon assessed.

In addition to the total cost impact of flooding for the catchment, high level interventions were produced to remove the predicted worsening impacts of flooding. Based on the number of new internal and external flooding locations and the increase in predicted flood volume, costings for SuDS, Traditional Storage and Property Level Mitigation options were calculated to produce a cost and risk profile for the catchment, as shown in the figure below:

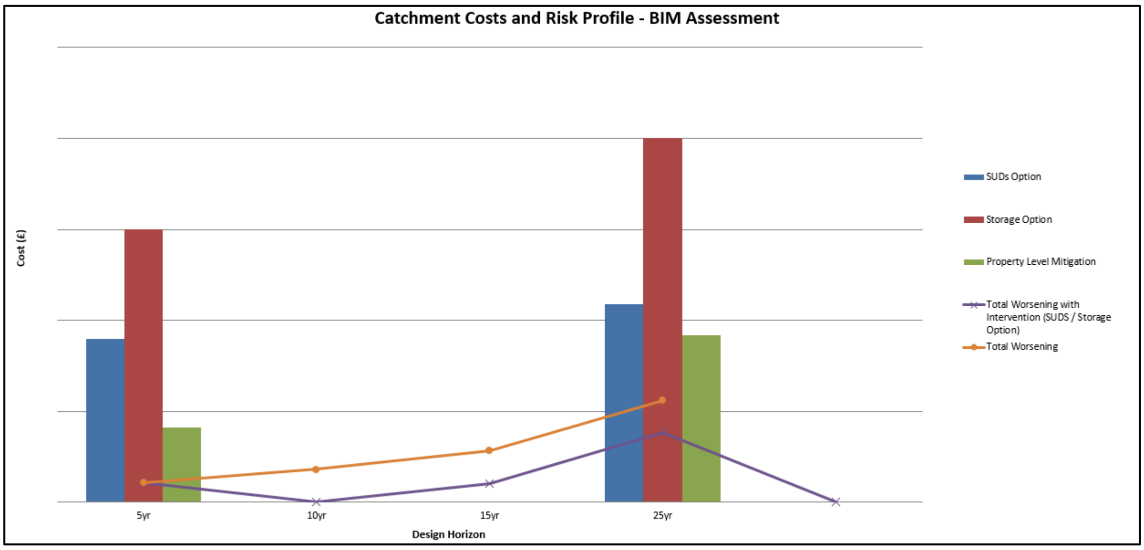

Figure 5 shows the total worsening of costs within the catchment with Planned Interventions for removal of 10 year and 25 year worsening undertaken after 5 years and 25 years. Total costs for SuDS, Storage and Property Level Mitigation Options also shown.

2.3 Extrapolation

Following the completion of the flood risk assessment on the 40 catchments, results were extrapolated to the remaining catchments within the AWS region. This was performed based on several extrapolation criteria as shown in the figure below:

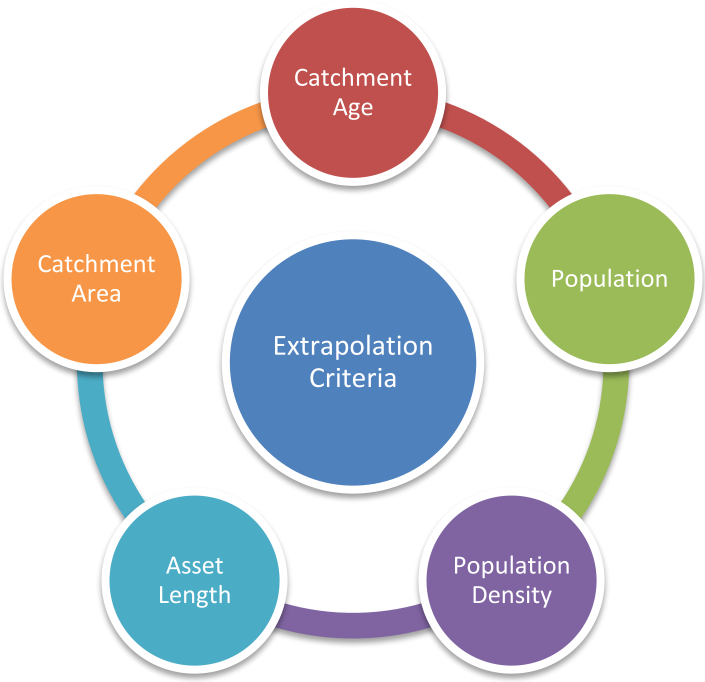

Figure 6: shows the initial catchment properties that were used as extrapolation criteria to produce the flood risk results for the remaining catchments where no assessment has been made.

Using the 40 catchments for which the flood risk assessment was undertaken, catchments were split into three categories based on catchment population and assessed separately:

- Small: 0 – 7,000 population
- Medium: 7,000 – 30,000 population
- Large: 30,000+ population

Trends between the total flood risk cost for those catchments where assessments were undertaken and the extrapolation criteria above were identified. A formula for the trend taken from the associated graph was then used to extrapolate a cost for the remaining catchments in that category. The R^2 value of the trend-line was also calculated and used to weight the individual extrapolation criteria. Subsequently those with a superior trend received a higher weighting to calculate a total flood risk cost for the catchment.

During the extrapolation assessment, a number of issues were found regarding the use of Catchment Age and Population Density as extrapolation criteria, with poor trends being produced. Catchment Age was subsequently dropped from the entire assessment and for smaller catchments, Population Density was omitted from the extrapolation calculations.

A review of the quality of extrapolation was made by comparing calculated values against extrapolated values for the catchment. Generally, a reasonable match was considered to have been achieved. However, issues arose with the extrapolated results for very small catchments. As the 40 test catchments were generally the larger, higher profile catchments due to model availability, results for these were not representative of the smaller catchments and less confidence is given to the results in these areas. The figure below shows a reasonable match between the calculated and extrapolated results:

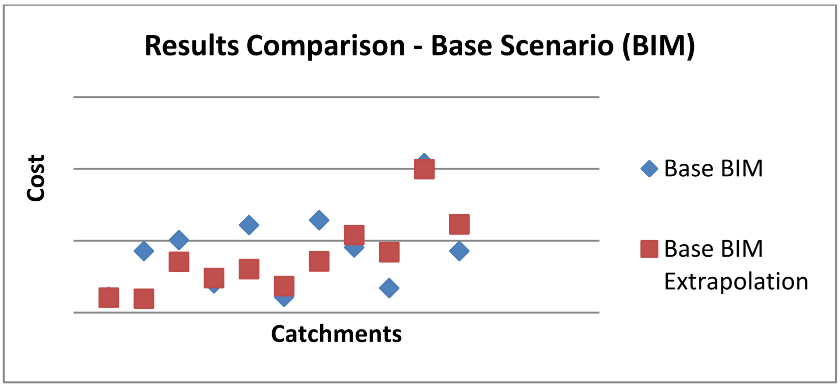

Figure 7 shows a comparison of extrapolated total flood risk costs and the total flood risk costs from the actual flood risk assessment for each catchment.

As with any sample extrapolation, more confidence can be given to the extrapolated results when a larger sample size is used. To improve the extrapolation in this case additional assessments are required to be undertaken, including a wider variety of catchments such as very small catchments and added back into the extrapolation. Only assessments on high confidence models should be added to the extrapolation as entering lower confidence models, such as unverified models, or areas with poor DTM resolution, has the potential to reduce the confidence in the extrapolation results. Another way to improve the extrapolation results is to build in additional criteria to the extrapolation. Properties such as soil type and contributing area percentages (which are not currently available on a region wide scale) would potentially improve the extrapolation projections.

3. Understanding the Results

With all results compiled, analysis can be performed to create that understanding of region wide flood risk that was desired.

On a catchment scale, extrapolated results can only be considered indicative and can only be compared with each other. On those catchments where an assessment has been undertaken a deeper understanding of flood risk can be achieved, holistically and at individual locations to gain a better understanding of future challenges for the catchment.

On a region wide scale, due to the standardised approach of the assessment and the calculation of flood risk costs for each catchment, comparison of results between the different scenarios (creep, climate change, growth and worst case) for the 5, 10, 15 and 25 year design horizon allows us to gain a better understanding of future challenges and the prioritisation of interventions based on the needs of the water company. Taking the full set of results, catchments have been ranked based on their total flood risk, allowing AWS to prioritise catchments for the PR19 process.

To gain that deeper understanding of catchment scale flood risk, an assessment is required to be performed on the modelled catchment. With the IUD programme creating 100% model coverage, alignment of the flood risk assessments with the production of MDM1 models will allow for that deeper understanding of region wide risk.