GIS based Sewer Network Capacity Modelling.

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A GIS based decision support system has been developed to support strategic planning for new developments within Thames Water Utilities Ltd. (TW) infrastructure flooding growth investment area. The work is borne out of activates undertaken during the companies Price Review 2014 (PR14) to identify and justify catchment studies. This new GIS based tool defines the state of the waste water sewage capacity network through a storage utilisation index for a 1 in 2 year rainfall event of a duration of 2 hours.

In contrast to previous works, this tool attempts to serve the entire TW area, whilst also incorporating factors of climate change, urban creep and population growth. In addition to these predictive parameters other factors include; physical asset data, rainfall depth, modelled infiltration, household populations and Ordnance survey master map (OSMM) topography, which were all used in a pipe volume capacity model to yield the dimensionless index.

Due to differences in catchment compositions across the TW area specifically that of London compared to regional sub catchments the TW area was sectioned into smaller parts when applying the model. Hence, pipe volume capacity models were modified for inner London, outer London and provincial areas. These subareas predominantly affected the model component rain loading into sewers as well as incorporating the differences in foul and combined sewer network assets.

The initial GIS result is a 2016 base map that gives a broad, but importantly companywide overview of the capacity of the waste water sewer network for TW sub-catchments (SDAC). The model shows that the current state of the network generally performs well under a 1 in 2 year rainfall event (120 minute duration), but does indicate issues of insufficient capacity in and out of London.

The pipe volume capacity model is defined by the following formula:

Storage Utilisation Index = Sewage Volume Generated in SDAC / Available Network Storage Volume in SDAC

SDACs are the sub catchments within the TW boundary.

For the purpose of this model, the network storage volume is defined by the TW's gravity sewer system. The majority of this network is represented by foul and combined purpose sewers; therefore, these were used to define the available network storage as the total volume or pipe full storage capacity.

The sewage volume generated was calculated using the following equation:

Sewage Volume Generated = Rain Loading + Property Loading + Infiltration Model + Population Growth + Urban Creep + Climate Change

Population growth, urban creep and climate change factors were only included in the predictive versions of the model, 2020, 2025 and 2040.

Rain loading was the total volume of rain calculated to enter the sewer networks generated by a 1 in 2 year rainfall event for a 2 hour period. It was calculated for foul and combined systems separately. The Modified Rational method was used to determine estimates of available rainfall, where depth was used instead of discharge to give volumes instead of peak discharge. The impermeable area used was extracted the OSMM topography layer. Road and Building features were clipped by buffers around the selected sewer network.

Based on hydraulic model averages of a few selected case study areas, different percentages of rain loading along the length of the sewers were attributed to foul or combined systems. A difference was also identified and therefore propagated for foul sewers that fell within inner London, outer London and the provincial areas. For combined sewers, 85% of the potential rainfall generated for each SDAC was applied for rain loading along the sewer lengths. For foul sewers, 34% was applied to inner London, 10% to outer London and 3% for the provincial SDACs.

The property loading factor is the volume of waste water generated by the household population that enters the sewer network. The Experian population data for each SDAC, provided to TW, was used instead of an average of 2.6 people per household across the entire region.

Infiltration at sewage treatment works (STWs) were extracted from a 2013 SOLAR download. The unaccounted flow values were used as the 'summer' or base infiltration in m^3 per day. Infiltration was then factored as proportional to sewer pipe length within the SDACs that constitute the STW catchments. Averages were used for STW not present in the SOLAR dataset, where STWs were defined by the total sewer length and assigned a suitable infiltration average.

As stated before, the factors of population growth, urban creep and climate change were applied to predictive versions of the models. Population growth utilised modelled Experian population data and applied this to calculate new values for property loading. An urban creep model was adopted from '*Estimation of Urban Creep Rates over the Thames Water area, Thames Water, Johannes Andersen, November* 2012', which identified ground cover change in aerial photography from 2001 and 2011. It provided an annual percentage increase in impermeable area. These percentage increases were applied to the newly extracted impermeable areas and calculated for the predictive years in the models.

Climate change values were extrapolated from '*Thames UKCP09 Rainfall Intensity Assessment, Final Report, Thames water, Atkins, June 2012'*. It provided values for changes in rainfall intensity by the 2080s for 11 areas within the study. The output for the highest emissions and the 50^{th} percentile rainfall depth was used. These initial values were percentage increases in rainfall intensities from 2012 to 2080, thus, each value was divided by 68 for a single year percentage increase. This was then used to calculate increases in rainfall intensity for 2020, 2025 and 2040. As these results were only for the 11 studied areas, spatial analysis was carried out to assign rates on all other SDACs based on their proximity to the given areas.

Thematic maps representing model indices values were produced. The 2016 base model result gives a broad overview of the capacity of the waste water sewer network. The outcomes from the predictive models also appear to successfully incorporate factors of urban creep, climate change and population growth. However, it must be emphasised that the models are based on a 1 in 2 year rainfall event and will perform and appear differently for different rainfall events.

All of the models show areas where the model indices exceed pipe volume capacity, with as expected, the 2040 model showing the greatest effect from the predictive factors. Furthermore, the tool allows us to go beyond the current model forecasts by facilitating the ability to input new or revised population figures to generate updated utilisation indexes.

However, broad generalisations and assumptions were made in order to facilitate a working model across the entire region. For a better match to the reality of network performance, it is possible to continually refine the process at smaller scales, achieving closer alignment to TW's wastewater catchment hydraulic models. A major improvement to the model would be to calculate pipe capacity as pipe flow rather than a volume. The current method assumes a uniform filling of the pipes across SDACs. Having a pipe flow capacity would take the topography of the SDAC into consideration and allow for a more realistic filling of the sewer pipes.

This would mean that parameter loading into the sewers need to also be calculated as flow rather than volume. Rather than a rainfall volume for a 1 in 2 year event, rainfall intensity can be used. Additionally, where wastewater catchments have corresponding hydraulic models, these can be used to establish a flow rate of the runoff and domestic flows generated from rainfall, population and infiltration. Multiple runs of models would also allow us to establish different outcomes for different rainfall events.

Additionally, the Experian Population figures assume that the entire population discharges waste water into the gravity sewer network; it does not take into consideration that portions of the population may be discharging to sceptic tanks and therefore not contributing to pipe flow. Sceptic tank data could be used to remove excessive population loading into sewers, this would improve the model, predominantly for rural areas.

Essentially this work has compounded our understanding that climate change, urban creep and population growth represent an ever increasing strain on the TW's sewer network that needs to be mitigated if flood risks are to be managed in the future.