Modelling Overland Flow – the future?

Incorporating a case study on Wonastow Brook

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1. Introduction

With the onset of the AMP 4 period imminent and sewer flooding high on the list of priorities the necessity to model and replicate overland flow has come to the fore. Recent events in the UK have highlighted the importance of understanding overland flow and with flooding issues making national UK news headlines, water companies are under increasing pressure to mitigate sewer flooding.

It is now possible to incorporate geo-referenced elevation data in computer models of drainage networks and use this to assess overland flow of floodwater. This advance enables the likely effect of the overland flows to be assessed, for example whether the floodwater will result in property flooding or whether it will return to the formal drainage network downstream.

Figure 1 - Aftermath of flooding in Boscastle, Cornwall. Although a river flooding problem it demonstrates the potential impacts of flooding in urban areas. (http://newswww.bbc.net.uk)

This paper highlights a number of considerations that need to be addressed when modelling overland flow. The Wonastow Brook Flood Alleviation Scheme in Monmouthshire looked at overland flow and flooding from a small urban water course. The study highlighted the importance of replicating overland flood paths and incorporating them into a model to predict flooding levels at properties.

The Foresight 'Future Flooding' Report, published in April 2004, highlighted the need for a better understanding and capability of modelling overland flow:

> *"The risk of flooding in towns and cities, as well as possibly being our greatest challenge in the future, is also the area of greatest uncertainty. If we want to plan ahead effectively for our cities, we need to develop much better modelling capabilities to predict flooding and manage flood routes in intra-urban areas."*

The aim of the project was to produce a challenging and long-term vision for the future of flood and coastal defence for the UK. Some of the outcomes of this report have been incorporated into the Department for Environment and Rural Affairs (DEFRA) consultation paper "Making Space for Water". Both of these papers look at the importance of sustainable solutions to urban hydraulic modelling by using a more holistic approach.

In the past, computing processing power has been the main limitation to modelling overland flow. With advances in computer technology and software, modelling will become more prevalent to understand flooding issues and causes so that appropriate solutions are developed.

Figure 2 - Flooding in London caused by sewer incapacity. (http://newswww.bbc.net.uk)

2. Sources of Data and Methodology

2.1 Data Sources

Geo-referenced elevation data is available in a number of forms (as detailed below), either creating a Digital Terrain Model (DTM) or a Digital Elevation Model (DEM). The DTM provides the best form of data for representing the ground surface; it is also the most common form of elevation model. A DEM provides all elevation data recorded including representations of trees and buildings along with adjacent ground elevation. This form of data is useful in predicting where diversions may occur due to barriers rather than just relying upon the contours for predicting flood paths.

- *Sewer Records*, geo-referenced cover levels from the water companies asset databases. These can provide simplified elevation models when thematically mapped in GIS software packages.
- *Land Survey*, the most accurate form of topographical data and also one of the most laborious. An example of this can be seen in Figure 3.
- *Ordinance Survey Contour Data,* held in grid form currently available in a data set called 'Profile'.
- *Photogrammetry,* the automatic generation of a DTM from existing stereo photography.
- *Synthetic Aperture Radar*, a process which uses an electromagnetic imaging sensor mounted on an aircraft or satellite. Can be used to create both a DEM and a DTM.
- *Light Distance and Ranging (LIDAR),* involving an aerial mounted laser scanner which emits pulses which are returned to the aircraft upon refection from the surface it hits. Again this data can be converted from a DEM to a DTM.

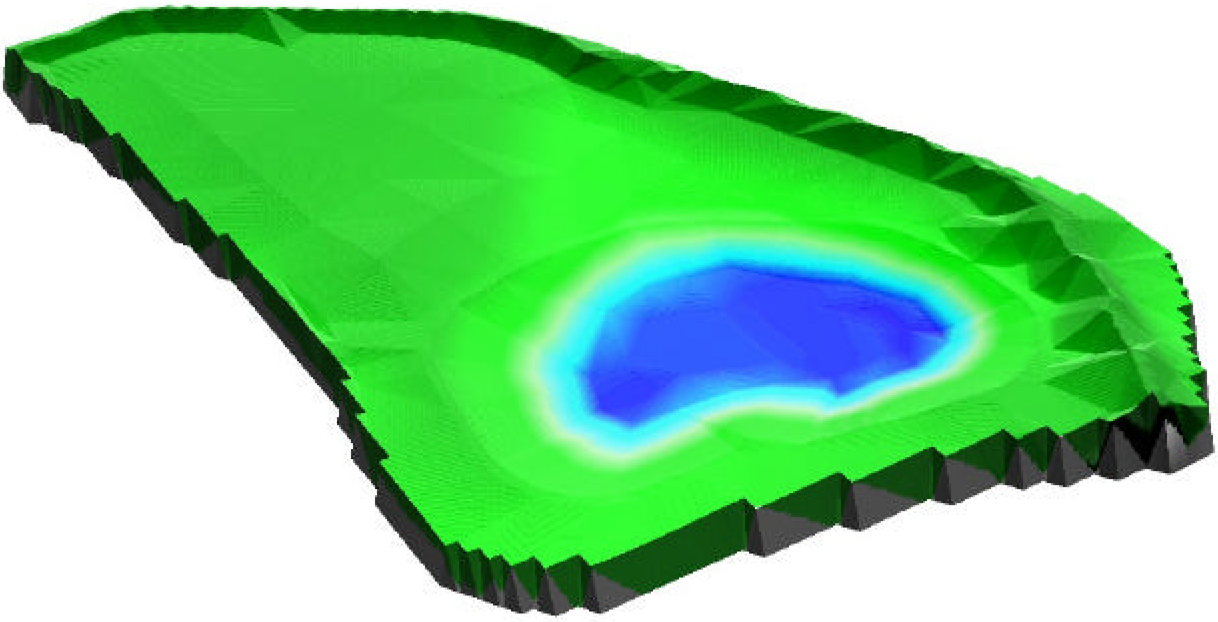

Figure 3 - 3D Thematic of the Rockfield Storage Pond, Monmouth. Map is based upon land survey data undertaken as part of the Wonastow Brook Flood Alleviation Scheme.

There are several different data sources ranging in accuracy from +/- 10mm to +/- 2.5m. The choice of which data to proceed with will be highly dependent upon time/budget constraints and the level of accuracy required by the client and/or study.

2.2 Software Availability and Application

There are a number of methods which can improve the speed (and possible accuracy) of determining flood paths. The most basic and time consuming method involves determining flood paths based upon a thematic map generated from manhole cover levels, combined with engineering judgement following site surveys.

Add-ons for GIS packages can go someway to determining flood paths; however these can be rather crude and will only work if one can import the DTM data into the GIS package. Other packages such as spatial analysis software have potential to aid us in the future.

Three dimensional modelling of overland flood paths is not a new concept; Micro Drainage's package WinDes has had the ability for some time. It is possible to overlay Ordnance Survey background maps and DTMs so that the package can then generate the flow paths. Figure 4 shows an example of this. It should however be noted that this is a design package and not a drainage area planning tool.

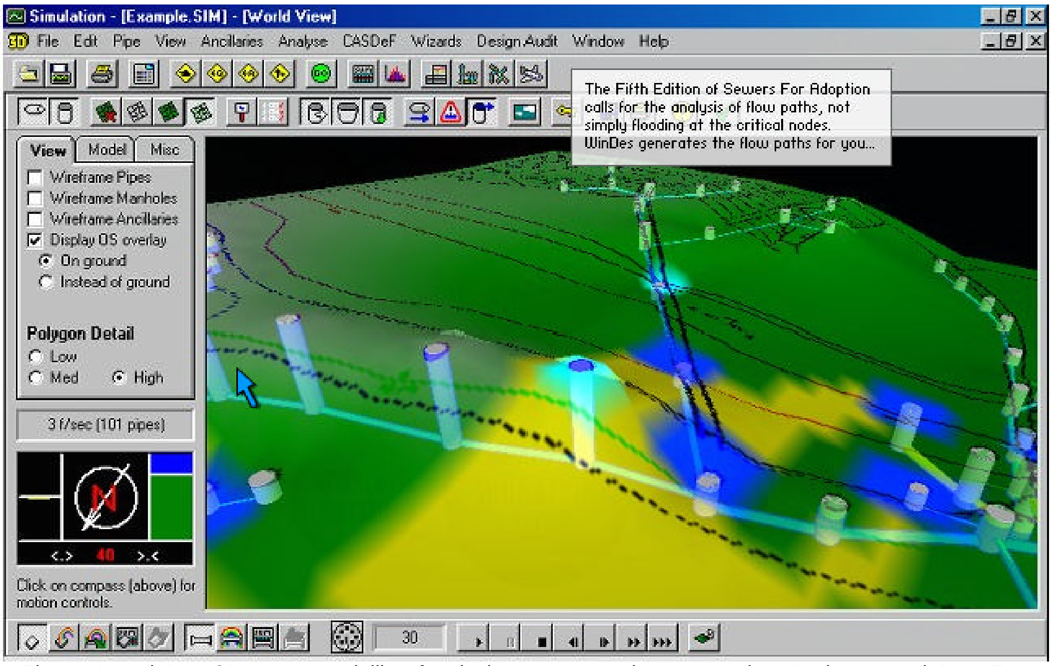

Figure 4 - WinDes 3D sewer modelling for design purposes, (source – Micro Drainage's WinDes 'Future Engineering' CD).

2.3 Modelling the Flood Paths

The UK's industry standard DAP modelling package, InfoWorks is now capable of modelling the overland flow channels. Once the flood paths themselves have been determined, there are two methods that can be used to replicate the overland flood channels. These are:

- Open box channels set to an average width and height, where invert levels are set to cover level of the up and downstream manhole.
- Building specific cross sections along a stretch which is known to flood, again, inverts would need to be set to the cover level of the up and downstream nodes.

Both of these methods have benefits and limitations in their application. The use of standard open box channels is a relatively straightforward method to employ but does not take into account any camber/cross sectional profile change that might be associated with the road or flow path. The data input associated with creating defined shapes/'river' links can be very time consuming but will take into account the true cross sectional area of any highway/flow path. Hence the new overland flow channels in InfoWorks v6.0 will be viewed and examined with interest.

There are a few considerations that need to be made when applying these methods. These include, but are not necessarily limited to, the following three items:

A – Additional storage (default physical details)
The additional storage included within the manhole shaft and chamber when set to the default flag can alter massively when adding a nominal six metre wide overland flow channel. If the manhole chamber and shaft parameters are set to the default flag in InfoWorks then they will alter once a new link is applied thus affecting the amount of storage within the chamber and shaft, as shown below:

Prior to the addition of a channel to represent the flood path a nominal manhole with default dimensions offers approximately **3m^3** of storage where the chamber and shaft plan **is 1.5m^2**. As shown in Figure 5.

After the addition of a 6m wide 0.5m high open channel for the above ground flood path the default dimensions change resulting in **88m^3** of storage (18m^3 above cover level) with the chamber and shaft plan areas becoming **35.9m^2**. As shown in Figure 6.

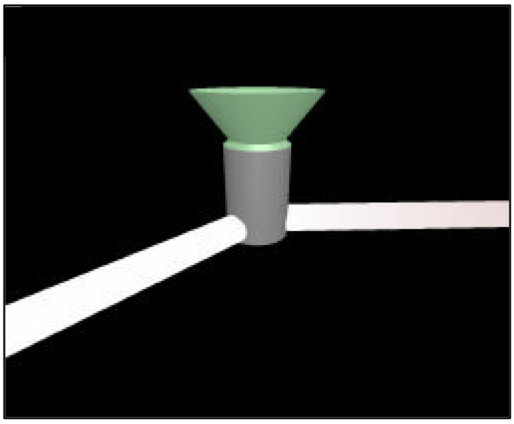

Figure 5 – Manhole with no over land flood channel applied. The shaft and chamber plan area are both 1.5m^2.†

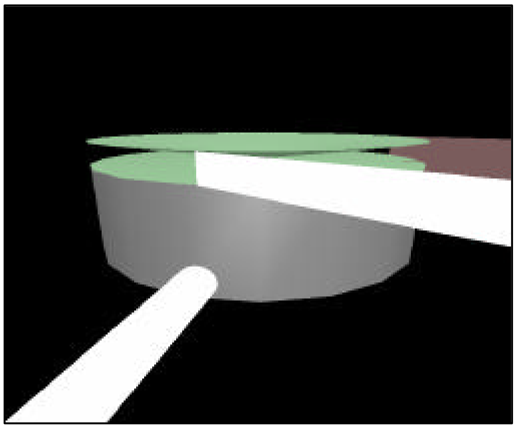

Figure 6 – Manhole with an overland flood channel where the invert level is set to the cover level of the manhole. The shaft and chamber plan both increase to 35.9m^2.†

†Note: this is the same manhole at approximately the same scale with a 450mm incoming and outgoing conduit.

B – Additional storage (numerical correction)
Numerical correction for baseflow and Preissmann Slot, when applied after the addition of overland flow channels, is different to that of the same model without such links included (if the Default flag is applied). This could lead to the over or under-prediction of storage within a manhole.

The very nature of overland flow channels (open links rather than closed pipes) means that Preissmann Slot is ineffective. The link should never become pressurised under surcharge conditions because it is an open channel. There is therefore, no need to undertake numerical correction for open links as there is no need to add or reduce storage in the manhole which is located subsurface. The numerical correction should either be undertaken prior to the addition of overland flow channels, or, default flags on manhole dimensions should be changed prior to the addition of overland flow links.

C – Flood cone
Manholes with an overland flood channel attached do not need a flood cone to which they can store waters as all flood flows should be stored in the channels or should flow to another part of the catchment as is the nature of modelling overland flow. However if no flood cone is applied then software assumes the manhole is stored so flows will not exit the manhole.

The first two points are addressed by building the below ground model first and then applying the overland flow channels appropriately so that default flags are changed as required. The third item presents questions: do we actually need a flood cone on overland flow paths? Will we actually need to quantify flood volumes anymore, or are we more interested in flood depths - in which case do we need to get overland flood paths and property dimensions correct? Should we be setting flood cones to the minimum possible values, whilst making sure the height of the overland flow channel is sufficient enough so as not to allow flood water to exceed them.

Wonastow Brook in Monmouthshire provides one example of how it has been possible to accurately model overland flow in an urban area using open channels where flood depths were more important than flood volumes.

3. Case Study - Wonastow Brook Flood Alleviation Scheme

3.1 Background

Atkins Water was commissioned by Monmouthshire County Council in March 2003 to undertake a 'Project Appraisal' of options which would reduce flooding from Wonastow Brook. Wonastow Brook, a tributary of the River Monnow in Monmouth is known to have flooded on three occasions in the last 17 years. The most severe of these events was during February 2002 when approximately 30 properties were inundated with flood water from the Brook.

Wonastow Brook, a minor tributary of the river Monnow drains and area of 2.7km^2 to the west of its confluence. The upper and middle reaches of the brook drain a predominantly rural catchment. The lower reaches, near its confluence with the River Monnow, are predominantly urbanised with a number of culverted sections.

The Brook is currently served by two flood relief mechanisms. The first is located adjacent to the confluence with the River Monnow and consists of a flood attenuation pond (The Rockfield Storage Pond); the second consists of an ancient monument forming a flood relief channel, the Clawdd Du Ditch, which also discharges to the River.

The urbanised nature of Wonastow Brook, with its numerous culverted sections, meant that it was not practical to use traditional river modelling packages such as HEC-RAS, Mike 11, ISIS or InfoWorks RS (as it uses ISIS as the hydraulic engine). The hydraulic model was constructed using Wallingford's InfoWorks CS software because of its ability to run both open and closed system links and for generating urban runoff.

View looking down Wonastow Road after one of the flooding events.

3.2 Flooding

December 2000 – flood depths were recorded by the Environment Agency (EA) and were in the order of 17.1m to 17.2m AOD. It is understood that approximately 20 properties were inundated with flood water. The cause was believed to be as a direct result of flood locked conditions resulting from downstream levels in the River Monnow.

February 2002 – two events occurred during this month; one on the 2nd and on the 4th. Again, flood depths recorded by the EA were in the region of 17.2m AOD. The flooding during these two events was more severe than the December 2000 event resulting in approximately 30 properties being inundated with flood waters. The mechanism of flooding was understood to be as a result of the downstream River Monnow levels.

3.3 Rainfall Data

Rainfall data was obtained for three events, one in December 2000 and two in February 2002, from two locations. These rainfall profiles were then combined with the FEH catchment descriptors to develop the flow hydrographs for each of the events. The calibration events had an annual occurrence probability of less than one year.

3.4 Methodology

The Wonastow Brook Flood Alleviation Scheme Model is a detailed urban runoff model which features a representation of Wonastow Brook, Clawdd Du Ditch, the Rockfield Storage Pond and a representation of surface water sewers draining to the brook. The surface water system serves approximately 400 properties within the catchment. Both Wonastow Brook and Clawdd Du Ditch are in part open channel and part culverted.

Hydraulic analysis was undertaken for both free flow and flood locked conditions to identify the level of flood risk from Wonastow Brook.

A number of flood alleviation options were developed based upon the results of this study.

3.5 Model Construction

The model was constructed using InfoWorks CS (v.4.02 – current version available at the time); Table 1 details the model statistics. There was no network simplification undertaken; surface water sewers were included where their location was known from paper plans.

Nodes (nr.)	Contributing Area (ha)	River Links (m)	Culverted Links (m)	Outfalls (No.)	Weirs (No.)	Flap Valves (No.)	Bar Screens (No.)
110	40.91	1,084	326	2	1	3	2

Table 1 - Model Statistics

A topographic survey, undertaken by Monmouthshire County Council, included channel cross sections (incorporating Wonastow Road) and a number of spot heights to gauge property flooding levels. This information was entered into the model by applying the channel profiles to the link type *'river'* in InfoWorks. A site walkover determined a number of flow paths, most notably the link between the Clawdd Du Ditch and Wonastow Brook.

The final model consisted of the following three main components and the known surface water drainage network:

Wonastow Brook – approximately 720m of the brook have been included in the hydraulic model of which 530m is open channel, the remaining being culverted. There is a weir in the model representing the conveyance path into the Clawdd Du Ditch (three gully pots).

Clawdd Du Ditch – the ditch, an ancient historic monument, is approximately 690m long of which 136m are culverted. There is a flap valve at the confluence with the River Monnow.

Rockfield Storage Pond - a flood alleviation pond located close to the confluence of the Wonastow brook and the River Monnow.

3.6 The Mechanism of Flooding

There are a number of culverted stretches along the urbanised section of Wonastow Brook. In high flow conditions some of these culverts are known to act as restrictions thus causing flood waters to back up and spill onto Wonastow Road which in turn conveys flows and acts as storage. One of the challenges to the study was to replicate this accurately.

Surveyed cross sections were taken at possible key restrictions such as culverted sections and changes in channel profile, etc. Each change in profile/entrance or exit from a culverted section was represented by a node. Where Wonastow Road runs adjacent to the open channel it has been incorporated into the channel profile as if it were part of the cross-section. Where the road runs adjacent to a culverted section, an 'above ground' overland flow link was included running parallel to the culverted section. Invert levels of the overland flow links adjacent to culverted sections were set to the 'spill height' of the channel. This allowed for waters to spill at key restrictions and continue flowing down the road and either be held in storage, become re-entrained in the brook channel, or flow through a series of gully pots to the Clawdd Du Ditch.

Clawdd Du Ditch effectively acts as a storage pond when levels in the River Monnow are high. It receives flow at three locations, two of which are from surface water drains serving the highways and properties to the south east of the ditch. The third main inflow point to the ditch only occurs during high flow conditions in Wonastow Brook when storm flows are conveyed down Wonastow Road and through a series of three gullies into the ditch.

The Rockfield Storage Pond provides some attenuation of flow from the brook. It was important to model the pond accurately as this could have an effect upon the levels of flood waters outside the affected properties.

As it was more important to model flood levels accurately rather than flood volumes, the roads were included as 'river' links to define their shapes rather than using simplified open top box links. Additional links were included in the model to represent Drybridge Street where the worst of the flooding occurred. Some of the open links included in the model simply provided storage of flood waters (the Dry Bridge Street Links) and did not convey any flows.

3.7 Calibration

Inflow hydrographs were applied to the upstream node in the model. Initial simulations concluded that the hydrographs for the calibration events were insufficient to initiate the observed flooding along Wonastow Brook during the three incidents. During the calibration simulations it was identified that flooding was a direct consequence of 'flood locked' conditions at the outfall from the Wonastow Brook and Clawdd Du Ditch to the River Monnow.

The downstream boundary conditions were derived using recorded information at a level recorder located on Monnow Gate Bridge downstream of both the Wonastow Brook outfall and the Clawdd Du Ditch outfall. Sensitivity analysis was undertaken to take into account the afflux imposed by Monnow Gate Bridge, typically 0.33m as the level recorder was located on the downstream side of the bridge.

Table 2 indicates that the predicted flood levels generally match those observed in the calibration events.

Event	Calibration Level	Location	Flood Level 1(1)	Flood Level 2(2)
14 December 2000	17.1-17.2	Drybridge St	17.219	17.245
2 February 2002	17.2	Drybridge St	17.029	17.246
4 February 2002	17.2	Drybridge St	17.142	17.429

Table 2 – Calibration Levels

Note 1: Downstream boundary set at recorded stage at Monnow Gate Bridge.
Note 2: Downstream boundary has been adjusted to take account of afflux at Monnow Gate Bridge.

3.8 Optioneering

A number of options have been developed to keep flooding below property threshold levels. It was stated by the client, Monmouthshire County Council, that excessive flows could spill onto Wonastow Road as long as flood waters were kept below the property threshold levels.

A number of options were considered including:

- Increasing the size of the Rockfield storage pond. This was discounted because the longer duration design flood levels still exceed the flooding threshold for the properties.
- Diversion of flows from Wonastow Road to the Clawdd Du Ditch. There were complications with this in that the ditch is an ancient monument. Also, with this the longer duration design event flood levels still exceed the flooding threshold for the properties.
- Individual property protection for all properties.
- A pumping arrangement aimed at keeping flood levels below the property flooding threshold.

The final solution is subject to detailed design but will consist of Individual Property Protection (IPP) on the isolated properties along Wonastow Road and a pumping station arrangement.

4 The Future

Following the DEFRA paper “Making Space for Water”, we may be moving towards a new form of integration of drainage management in urban areas. The consultation document states;

> *“Flood risk, especially in built up areas, can be managed most effectively if there is an understanding of the way the floods arise and have an impact on the various drainage systems. Such an understanding should enable better use to be made of above ground pathways and storage for extreme events”.*

Clearly there is pressure to consider the use of highways as floodwater detention and conveyance channels for higher return period events. So solutions such as the one developed for Wonastow Brook in 2003, which actually uses the adjacent road as a conveyance method and storage for flood waters, could become more commonplace. However, while this is acceptable for surface water runoff, there will be added complications when it is storm sewage being considered.

It seems likely that during AMP4 there will be an increased effort to resolve property flooding problems with urban flood routing could become more relevant. We should also make sure that we do not overlook the potential interactions between conventional piped drainage and urban watercourses. There are potential benefits in the development of a fully integrated sewer, river and coastal modelling package. The scope of most drainage areas plans may need to pay more attention to modelling ALL the surface water system as standard practice.

The release of software such as InfoWorks CS v.6, expected early December 2004, may just be starting to bridge the gap between what needs to be carried out and what we can economically justify undertaking. It will have the additional functionality of:

- Producing an elaborate 3D representation of a selected network element.
- Inferring node cover levels from using Digital Terrain Models/Digital Elevation Models.
- The overland flow tool which includes; a new variant of manhole ‘gully’ and wizards for automatically generating overland flow links based upon existing underground links, road networks, digital terrain models or other criteria.

With these added functionalities it should be more straightforward to include overland flood routes, allowing for a more accurate representation of above ground flows during high return period storm events. However, the modeller must be aware of the software and data constraints and question information and concepts appropriately.

Could it be that in ten or 20 years time we will be using an integrated sewer, river and coastal modelling package incorporating some of the following:

- Flood Estimation Handbook rainfall will have been superseded. Real time satellite radar rainfall data will import directly into the new software package.
- Ground levels will be incorporated into models directly from LiDAR (or other?) data sets to a high level of accuracy, which can be imported directly into the latest software.
- Floating sonar/GPS systems will record river cross sections quickly and accurately. This data can be imported into the software and will generate accurate cross-sections for every meter of river/stream bed and geo-reference them automatically. This will reduce model build time and costs.
- Above ground flood paths will be automatically calculated from a combination of DTMs and background maps. Ordinance Survey maps are used to work out the most probable route and flood paths are built accordingly.
- Exports from the software will be compatible with the Environment Agency's flood hazard maps allowing detailed assessment to be undertaken.
- The UK Climate Impact Programme 2020 (UKCIP20) future scenarios will be accurately represented in design storms for optioneering purposes.
- All surface water runoff systems will be modelled, irrespective of "ownership".

When we are celebrating the WaPUG 40th birthday, will we be able to look back at the next set of industry developments and advances with pride?

5. Conclusions

Advances in availability of geo-referenced elevation data means that the composite modelling of underground drainage with overland flow routing is now a readily available technique in drainage area planning.

There are a number of important issues to consider when modelling the overland flow channels, such as the changes in manhole dimensions, numerical correction and the possible implications in storage related to these. These issues need to be addressed on a case by case basis.

In future, wastewater planners are likely to need to look at urban drainage modelling in a more holistic manner. The boundaries between river models and urban drainage studies will continue to diminish, reflecting more clearly the overall performance of the entire system. Similarly, the scope of what is traditionally considered to be a conduit for flood flows is set to be redefined.

For extreme events, if wastewater planners can use the techniques described above to determine which roads can satisfactorily act as flood conduits and which ones cannot, then this will allow the finite funds for future flood alleviation spending to be targeted at the sites at greatest risk. Similarly, at sites where property or human life is at risk, the analysis tools available allow us to consider precisely what capital works are required to the below ground or above ground conduits, in order to reduce the risks in the most cost-effective manner.

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