# Interreg IIIB NWE project 'Urban Water' - IUD Modelling in Renfrewshire.

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**Abstract:** This paper demonstrates an approach to strategic spatial planning using hydraulic modelling to identify flood risk and potential improvement options. A wealth of clear-cut information is presented to planners in a GIS format to ensure that planning and development can be guided to improve urban water management.

Renfrewshire Council has recognised that flooding problems in their urban areas are best addressed through a catchment planning approach and is developing their approach through the Interreg IIIB North West European project “Urban Water”. The project involves co-operation with projects in the Netherlands, France and Germany as well as local Universities to promote sharing of good practice.

The primary aim of the study was to identify sustainable solutions to reduce flood risk and improve water quality. Options for improvement could only be identified with a detailed understanding of the flood regime developed through hydraulic models of the sewer, watercourse and overland flow. Hydraulic models of the pipe and watercourse network were constructed in InfoWorks CS and Hec-Ras. This identified flood locations and volumes and a 2D hydraulic raster based routing model was used to determine the overland flow routes over a ground model. Modelling of overland flow of water unable to enter sewers or sewer flood water is increasingly required for the assessment of urban flood risk. Normal consideration of extreme events has assumed that overland flow is contained within roads and can be modelled in 1D however this is not always representative or applicable. This pilot has found that the use of simple 2D models linked to more complex sewer models provides a good representation of extreme urban flooding and can be used to plan solutions and restrict development in effected areas. This study highlighted that small catchments in urban areas that are unmapped by the SEPA hazard maps place a much greater number of people at risk. In Johnstone 40 properties lie within the SEPA hazard map, the detailed modelling in the urban areas indicated that over 1000 properties may be at risk. If this is replicated in all urban areas it suggests that resources should be directed toward assessing integrated urban drainage systems and overland flow as the best way of reducing overall flood risk.

The paper compares the flood map produced from the IUD InfoWorks CS model with a faster 2D rainfall routing model. The study showed that the faster screening technique is appropriate for a first stage in assessing flood risk from all sources. Which has lead Renfrewshire Council to produce surface water flood maps for the rest of their local authority area.

The project is also recommending a number of sustainable management options to improve flood management. These include investigating the disconnection of surface water runoff from combined sewer systems, catchment management to reduce siltation and culvert blockage, retrofitting SUD systems and deculverting. Overall the proposals will reduce flooding, improve water quality and the environment in a confined urban catchment.

Conclusions

- Good spatial planning is required to improve surface water management. Information on problems and possible solutions need to be available to planners and developers at a strategic level to encourage sustainable development.
- Catchment scale urban modelling techniques can identify areas requiring more detailed modelling to make effective use of limited local authority resources.
- The use of inappropriate modelling techniques can result in very different analysis and conclusions.
- A consistent National approach to policy, modelling and spatial planning is required; guidelines produced by Renfrewshire can be tested and rolled out to all of Scotland.

## INTRODUCTION

The main objectives of Renfrewshire Council's strand of the Urban Water project are to:

- Reduce the development constraints currently in place owing to poor drainage and flooding issues by introducing relevant regulations to improve urban water infrastructure within the Development Plan.
- Identify options for reducing flood risk in key areas.
- Establish coherent and readily understandable guidelines for developers and planners.
- Collate and present the data collected and parameters calculated throughout the project in a GIS format. The GIS database is to be subsequently maintained by the council as a working tool.
- Provide training and build on in-house expertise already available in Renfrewshire Council

This new approach is being developed by studying issues and constraints contained within pilot areas. The first pilot catchment is Johnstone, a town of approximately 25 $km^2$ to the west of Paisley in Renfrewshire. This paper is based upon the findings of the analysis of this pilot catchment. The pilot catchment of Johnstone was selected as a suitable study area as it has a history of frequent flooding from urban watercourses, combined and surface water drainage and flood risk pose development constraints. The modelling highlighted areas at risk, as recommended by the Pitt Review, and the identification of areas requiring additional work to alleviate the flood risk.

An InfoWorks CS model of the combined network was supplied by Scottish Water. This model was used for the study and improved by adding the surface water sewer system which had been constructed in the newer developed areas and the small watercourse network that ran through the town. The addition of the watercourse modelling allowed an analysis of sewer flooding from the drainage system and fluvial flooding from the watercourse to be determined as well as the interaction between the two.

Standard approaches to determine the inflows to the model were used for the rural and urban areas of the catchments flowing into the system. Whilst sewer systems are typically designed to withstand the 30 year return period flood, the aim of the project was to predict flood inundation for return periods up to the 200 and 1000 year floods.

The methodology for modelling the above ground overland flow is an un-coupled representation of flood risk in that the above ground flow cannot re-enter the sewer network. The approach assumes that all floodwater that surcharges from the manholes flows away and is lost from the system. This is appropriate as the entire system is likely to be surcharged at the sort of return periods that were the goal of the research. Further studies in Renfrewshire have indicated that this is a valid assumption except where road gullies connect to culverts with significantly larger capacities, as these roads can still drain during extreme events (Dow, 2006).

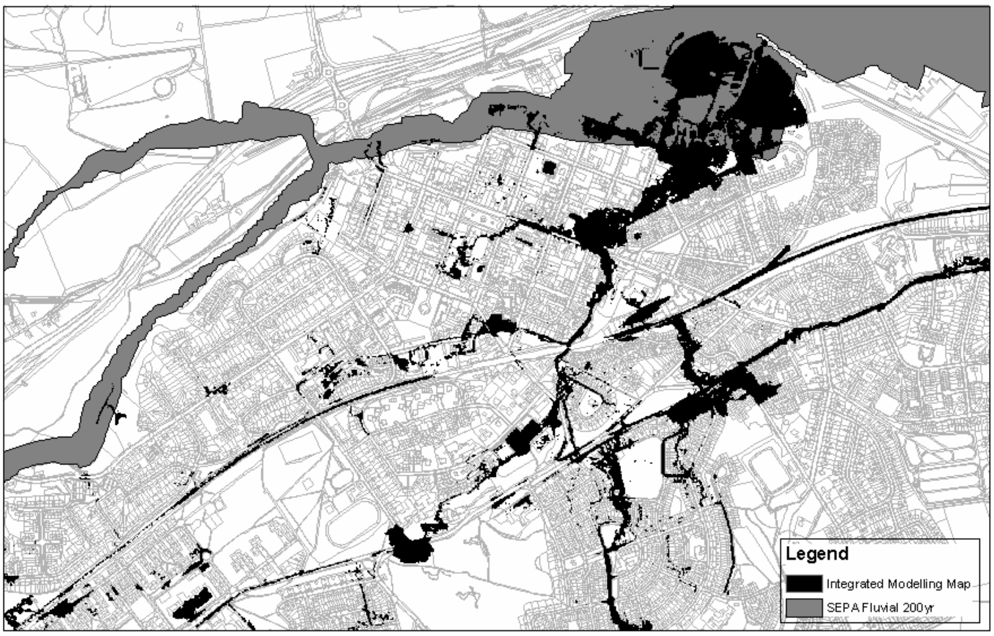
A 2D raster based modelling methodology was used to model the overland flow from each individual surcharging manhole. JBA Consulting's JFLOW was used as it allows rapid prediction of inundation extents where flow is topographically driven and is a suitable methodology for the representation of urban flood inundation (Bradbrook *et al.*, 2006) (Hunter *et al.*, 2008). JFLOW can also easily incorporate flood volumes from the Infoworks CS model.

Building an integrated model, or coupling existing models is data intensive and ground-truthing of flow paths is critical and potentially time consuming. Therefore, this approach is useful for detailed assessments of high consequence flood risk zones within urban areas where this level of detail is necessary. This is therefore not an approach that can be scaled up for screening purposes at a national scale. Despite this, this level of modelling and hazard mapping will be required to understand the urban flood regime and will be required for the development of improvement options. It is therefore likely that detailed modelling of this type is carried out following an initial screening analysis over larger areas.

The results of this inundation mapping have been compared with the Indicative River and Coastal Flood Map (Scotland). Whilst the mapping clearly indicated areas at risk outside the fluvial and tidal boundary, the most significant finding is the number of properties at risk within each of the flood outlines. In the Johnstone area 43 properties lie within the SEPA flood outlines, whilst the detailed inundation maps from the integrated model suggests that in excess of 1429 properties may be at risk.

If this is replicated in all urban areas, it suggests that resources need to be directed towards urban flood risk and that a need for a rapid screening tool is essential.

**Figure 1 Comparison of SEPA and Integrated Modelling Flood Maps for Johnstone**






There is great value in the modeller walking through the catchment to get an appreciation of the topography and watercourse network. Historical flood data is invaluable. Even if the system has been altered a model should be calibrated to the historic rainfall event. If there are flooding areas in the model which did not flood historically, it is likely that the system has not been modelled correctly. Discovering inconsistencies such as these is the best way to find errors in the model.

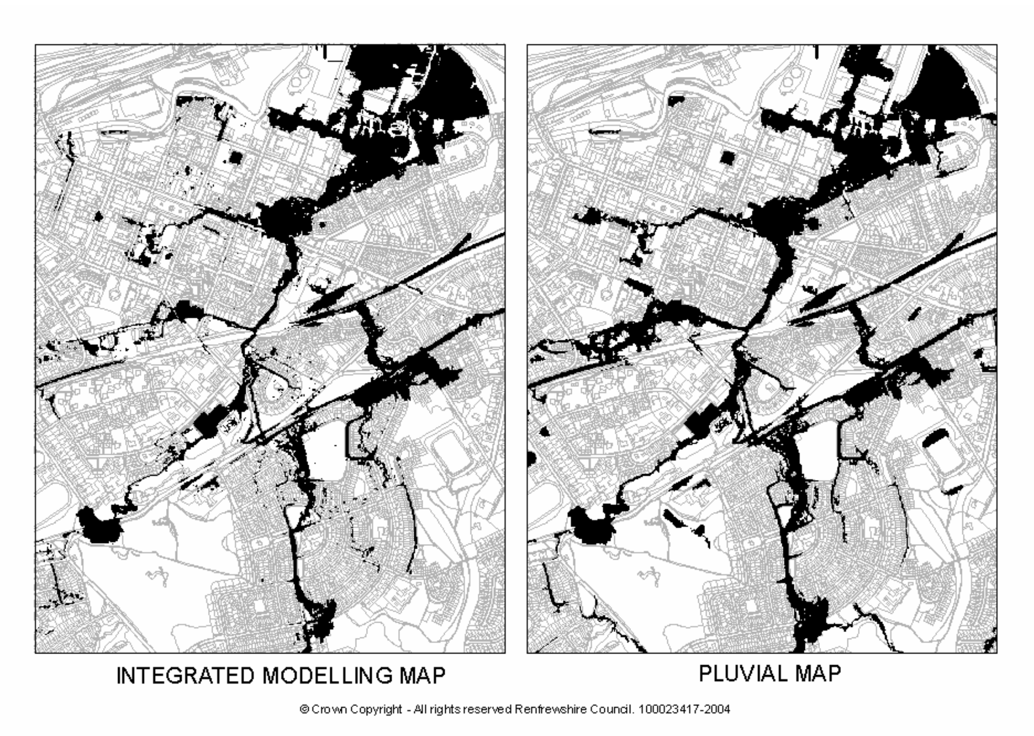
**Rainfall mapping**

Following recent developments of JFLOW a new methodology to urban flood risk assessment has been developed based on a blanket rainfall approach. This assumes direct rainfall (based on a rainfall hyetograph) onto all cells within the DEM. The rainfall input can be adjusted to account for losses to the below ground system. This allows the spread of water over the topographic survey to be modelled as the water settles following the simulated storm. This approach offers a rapid flood inundation mapping technique for urban areas and has the potential to be used as a screening tool.

This type of modelling contrasts against the integrated approach in that the loss to the sewer system is a set amount for the whole model and sewer flood relief points are not identified. In some aspects, this may be relevant as the sewers are likely to be full and surcharging for the return periods with which we are modelling (200 year). However a crude approach to take into account the losses to the sewer system is to assume that the sewer system can cope with a certain return period event (e.g. 30 year). The approach used for Renfrewshire was to remove the 30 year storm depth from the hyetograph rainfall input for the 200 year flood maps. This was determined from multiple trials and comparisons against the detailed integrated modelling approach which found that the results compared favourably as the capacity of the culverted watercourse determined the above ground flood volumes.

As noted for the detailed integrated modelling the degree of surface features and road layouts plays an important part in determining the flow paths through urban areas. The preferred approach used for Renfrewshire is to use a filtered LiDAR DEM with road networks stamped on to the surface. Furthermore, the screening of results to correctly represent flow paths and the removal of unrealistic barriers to flow is essential for this approach. This process has been trialled on the Johnstone area of Renfrewshire and is in the process of being rolled out for all areas of Renfrewshire. The preferred approach is to undertake a two stage process. The first stage being an initial run using a course grid to screen for potential unrealistic flow barriers such as culverts and underpasses. The second stage is to modify the DEM in these locations and re-run the analysis at a finer resolution to provide indicative flood inundation maps for urban areas.

**Figure 2: Comparison of Rainfall and Integrated Modelling Flood Maps**



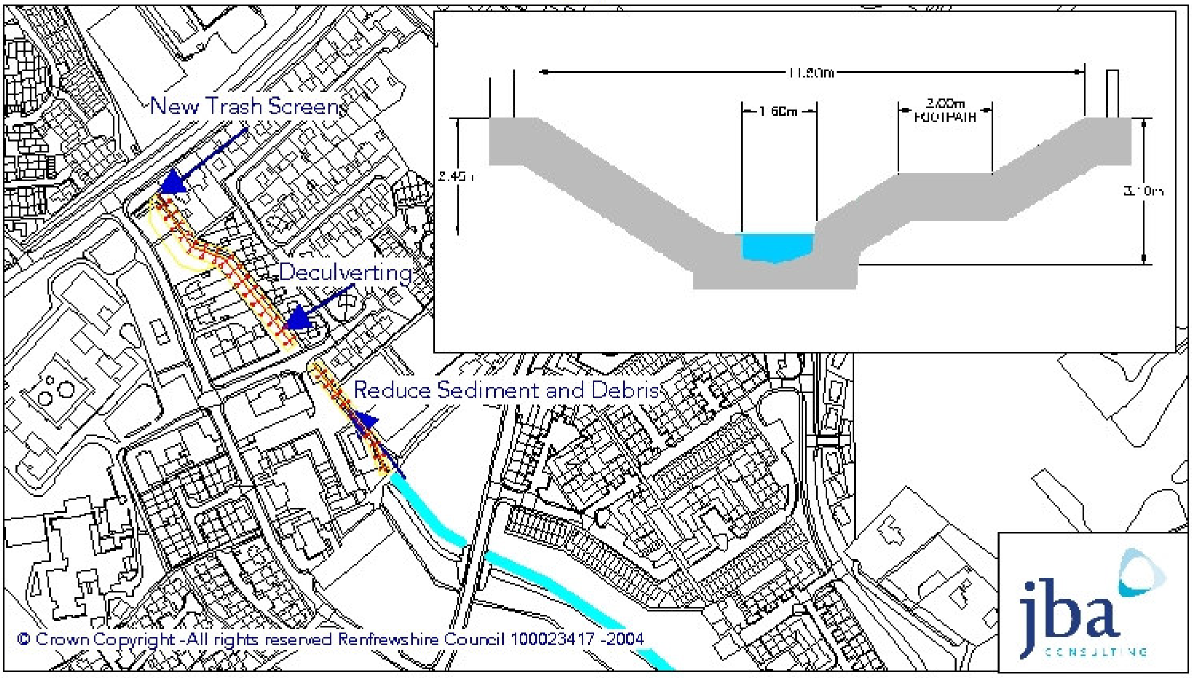

The methodology therefore allows a targeted approach for flood risk inundation mapping in urban areas that can be used for initial screening of high risk zones from surface water flooding.

Modelling of overland flow of sewer flood water is becoming increasingly required for the assessment of urban flood risk. More research is required to test new methods for integrated modelling. A key limitation in overland flow modelling is the lack of accurate DEMs, but improvements are continually being made with further advances in photometry methods and urban surveying techniques. Extreme flooding does not always stay within the road network and therefore cannot be modelled in 1D. 2D modelling needs to be carried out to identify the flow paths that can be modelled in 1D.

**SURFACE WATER NETWORK IMPROVEMENTS**

The models were used to identify the potential improvements in the surface water network that will help to reduce flooding. These improvements are modelled to gain an understanding of the benefit of the improvements. Figure 3 below gives an example of an improvement option of deculverting Spateston Burn.

**Figure 1: Improvement Example**




Other flood improvement options identified during the study include:

- Enhancing urban fringe storage to relieve pressure on the culverted network
- Upsizing and removal of culverted sections which were constraining the flow
- Constructing small sections of wall and embankment to keep water within channel or road networks
- Constructing underground and overground flood storage within the urban area.
- Disconnection of surface water from combined sewers

Designing solutions based on whole catchment analysis of storms critical to the watercourses ensures that all systems are designed to integrate with each other. If attenuation for individual developments is designed separately, the attenuation may result in urban runoff peaking later and coinciding with the rural runoff peak, which would exacerbate flooding. Sewer systems are often analysed in isolation. Integrating the sewer system with the watercourse network allows for the analysis of sewer tailwater levels. Flooding can be caused by sewer systems being prevented from discharging due to high river levels, which is difficult to account for in separate simulations.

**Catchment Management Improvements**

Spateston Burn has an ongoing problem with large volumes of gravel and sediment blocking trash screens upstream of a sensitive length of culvert. The river corridor survey highlighted areas where animal access, gabion failure and river bank instability was leading to increased loading of sediments in the watercourse. Figure 4 gives two examples of eroding, firstly due to bank instability and secondly due to "poaching" by stock. The installation of fencing and reforming the bank where significant erosion occurs would remove these sources of sediment and remove the need for further rock and sediment traps in the watercourse. It would also reduce the chance of flooding from blocked trash screens, which has been the cause of flooding in the past.

**Figure 2: Bank Erosion on the Spateston Burn**

The approach adopted in this project is to take a holistic view of surface water management to identify improvements in ecology, water quality and visual amenity as well as reducing flood risk. Al these factors will aid the rejuvenation of the town and encourage economic development.

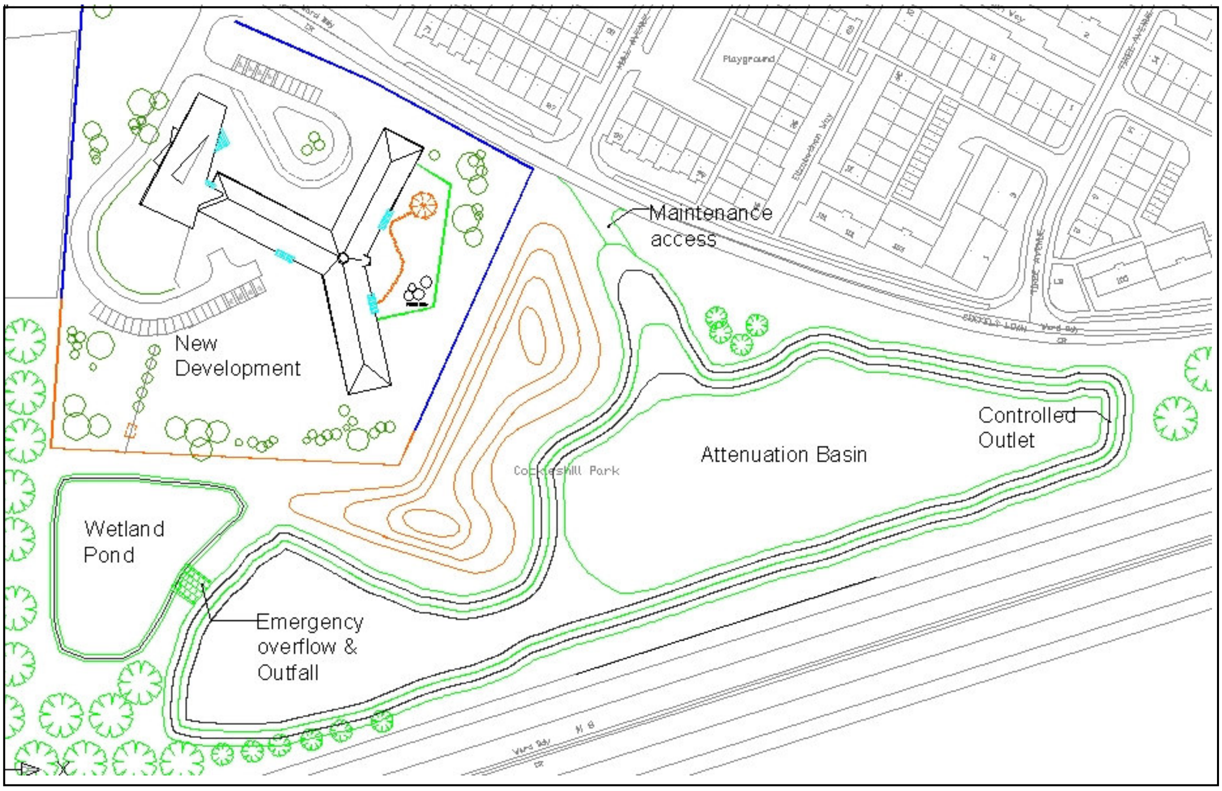
A main output of the project is a Surface Water Management Plan, which would identify the existing problems with the watercourses and the potential improvements. The aim of the report is to improve watercourse and catchment management by introducing new maintenance regimes. The surface water management plan and improvements brought about by redevelopment will ensure that the redevelopment of Johnstone can be guided to improve the urban water system.

**SPATIAL PLANNING**

The opportunities for implementing improvements to the surface water network are often identified at a late stage in the planning process. In many situations flood risk is identified late in the planning process when it is difficult to accommodate flooding or potential improvements. The need to incorporate sustainable flood management options is seen as unsustainable often by both planners and developers. One of the main aims of this project is to clearly identify both areas of flood risk and the potential for improvements, and present this information to the planners in a GIS layer. This will hopefully lead to early negotiations with developers at outline planning stage, or before, and allow for the inclusion of sustainable flood management in the initial development proposal. Improvement options can be provided by the developer as an alternative to providing attenuation storage, which is currently required to attenuate the 25 year post development runoff to the 2 year pre development runoff.

An example is given below, a residential home was being constructed by the local authority adjacent to a culverted watercourse and motorway, the development involved the construction of a noise bund. The existing knowledge of the site and hydraulic models allowed us to provide the details of the levels and volume needed to store the flood water during a design event quickly. Our proposals included additional storage to alleviate an existing flood problem. The volume excavated provided material for a noise bund and the storage maintained existing green space in an area unsuitable for development due to the proximity to the motorway.

**Figure 3: Example of a Development Improvement Opportunity**




The information gathered during hydraulic modelling, ecological studies and examination of potential SUD systems has been presented to Renfrewshire Council Planning section in GIS format to allow for basic information regarding flood risk to be used during the planning process. This will hopefully aid in identifying the sites that will require Flood Risk Assessments or Drainage Impact Assessments at an early stage in the planning process. Some developments are only made aware of the need for a FRA or DIA at a late stage in the planning process, if the development is within a flood risk area the development may not be allowed to proceed. This can be frustrating to the developer as time and money have been spent on the development, with this new approach these situations will hopefully reduce dramatically.

The GIS layers prepared for Renfrewshire Council are:-

- Layer 1 - Watercourses, the line of the watercourses defined included culverted sections.
- Layer 2 - Culverts, the asset data and capacity information
- Layer 3 - Habitat Survey, for river corridors
- Layer 4 - Hotlinked Photograph Layers, to aid recall of structures and maintenance issues
- Layer 5 - Anecdotal Flood Data and Buffer, to aid identification of flood risk areas
- Layer 6 - Road Slope Arrows, potential flow routes and properties at end of flow routes
- Layer 7 - 200 Year Flood Grids from Flooded Manholes/ Watercourses
- Layer 8 - Flooded Outlines from 200 year Pluvial Flooding
- Layer 9 - 200 year Manhole Flood Volumes
- Layer 10 - Road Depth Flood, highlighting routes with access issues
- Layer 11 - Flooded Properties in 200 year Envelope, to aid damage assessment
- Layer 12 - Background Storage Maps, to assess storage required for developers
- Layer 13 - Watercourse Maintenance, locations that need regular inspection

## A NATIONAL APPROACH

This study utilised data from many parties, Renfrewshire Council, Scottish Water, SEPA and local residents to obtain asset data and historical flood information. The study identified that if this data was recorded and stored on a national database it would improve the approach. Standardisation of post event flood data would greatly assist the validation of flooding predicted by models.

Assessing rainfall hazard indicates that the flood hazard maybe significantly greater than an assessment relying on current fluvial and coastal maps. This would seem to be supported by urban flood events in Renfrewshire, Glasgow and Hull, and also recent insurance estimates that 40% of damages are from outwith the flood map. The analysis in Renfrewshire shows that there may be a significant flood risk in certain areas that are currently excluded from national coverage maps, and thus also from flood management and policy procedures. In order to correct this and to incorporate pluvial flood risk consistent datasets, methodologies and records of urban flooding will be essential.

There are existing difficulties with managing the surface water system as it involves many stakeholders; the division of responsibility between Scottish Water and the Renfrewshire Council's is unclear. Sewer flooding up to the 30 year event is the responsibility of Scottish Water where as flooding during a 200 year event is the Local Authority's responsibility. Current guidance address these issues separately and can result in conflicting approaches. There is a need to address all surface water management through one management approach. The Surface Water Management plan and new spatial planning approach as presented in this paper will be developed for Johnstone to meet the needs of many stakeholders, the local authority, Scottish Water and SEPA. It is hoped that the new legislation being developed in Scotland to meet the requirement of the European Floods Directive will bring about this much needed guidance and clarity of bodies responsible for surface water flooding. The implementers of surface water management are likely to be the local authority and the driver is to reduce flood risk in order to allow economic development. Through consultation with the other stakeholders it is hoped that the document and planning approach will allow management of all aspects of the surface water system. The use of the subsequent guidance by many stakeholders will lead to changes and improvements of the management system and planning policy. After consultation and trialling stage it is hoped that the findings of this study and subsequent planning approach will be used as a template for other urban water networks throughout Renfrewshire, and potentially to other local authority areas.

## CONCLUSIONS

- Good spatial planning is the future of surface water management. Information on problems and solutions need to be available to planners and developers at a strategic level to encourage sustainable development.
- Catchment scale urban modelling techniques can identify areas requiring detailed modelling to make effective use of limited local authority resources.
- The use of inappropriate modelling techniques can result in very different analysis and conclusions.
- A consistent National approach to policy, modelling and spatial planning is required; guidelines produced by Renfrewshire can be tested rolled out to all of Scotland.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