

PLUVIAL EXTREME EVENT RISK APPRAISAL TECHNIQUES WITH RECENT APPLICATIONS IN IRELAND AND THE UK

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Abstract

Pluvial' flooding is defined as flooding from rainfall generated overland flow *before* the runoff enters any watercourse or sewer. It is usually associated with high intensity events but can also occur with lower intensity rainfall where ground is saturated, developed or otherwise has low permeability resulting in overland flow and ponding in topographical depressions. Drainage systems and surface watercourses may be completely overwhelmed. Recent examples include the Summer 2007 floods in Ireland and England where pluvial flooding has been a major contributing factor.

Identifying areas potentially at risk from pluvial flooding is a requirement of the Floods Directive, particularly in relation to the Preliminary Flood Risk Assessments which, as a first stage involves, high level screening of a catchment to determine all sources of potential flood risk.

Jacobs have delivered Defra's MSfW RF5 project which has assessed the technical feasibility of 'Flood Warning for Other Forms of Flooding'. As part of this, Jacobs has developed a Pluvial Extreme Event Planning (PEEPs) technique which identifies areas likely to have greater susceptibility to pluvial flooding through an initial rapid screening process using GIS to identify depressions in the topography and critical flowpaths. Site inspection of highlighted areas verifies risk and identifies local issues and potential solutions. This can be followed by more detailed assessment where justified.

The technique has been used to produce 'pluvial flood risk maps' in Belfast, Hull, Sheffield, Carlisle and Kingston-upon-Thames, and results demonstrate a close correlation with observations of pluvial flooding where available. This paper will summarise the approach adopted along with example results for some of the PEEPs assessments undertaken with a particular focus on Ireland.

Introduction

The UK Environment Agency's flood warning service mainly focuses on flooding from the coast and rivers. However, in line with the holistic approach to flood risk management outlined in the Making Space for Water (MSfW) programme, the RF5 *Feasibility study into Expanding Flood Warning to Cover Other Flood Risks* (Jacobs, 2007) has investigated the *technical* feasibility of providing warning services for sources of flooding other than from rivers and the sea. During the project, the impact of some of these 'other' sources of flooding was dramatically seen in the UK in the summer of 2007, where surface water, drainage capacity exceedance and groundwater flooding all contributed to the overall damage. Although the RF5 study was under way well before the Summer 2007 flooding, the outcomes are directly relevant to a number of the key recommendations made in the Pitt Review, Pitt (2007, 2008).

This paper summarises an appraisal of the technical feasibility of providing warning services for sources of flooding other than from rivers and the sea and focuses on potential forms of surface water flood warning service. Surface water flooding is often termed *pluvial* flooding and can be defined as flooding which results from rainfall generated overland flow *before* the runoff enters any watercourse, drainage system or sewer. Surface water flooding is often termed *pluvial* flooding and can be defined as flooding which results from rainfall generated overland flow *before* the runoff enters any watercourse, drainage system or sewer. The RF5 study involved a number of case study applications.

The paper also describes, as a further example, the subsequent application of the screening process in East Belfast to identify areas susceptible to surface water pluvial flooding following widespread flooding in June 2007.

It is envisaged that high level screening of the potential for pluvial flooding could provide sufficient information to enable a preliminary assessment of the level of pluvial flood hazard to be made over a wide area. As such, this could help to inform Preliminary Flood Risk Assessments under the Floods Directive and the development of a resource efficient strategy for subsequent mapping possibly using more detailed techniques.



Combined pluvial and fluvial flooding in East Belfast in June 2007.

Review of ‘Other Sources of Flooding’

Following a review of all non-fluvial and non-coastal sources of flooding perceived as significant by the MSfW *Flooding from Other Sources* project (HA4a; JBA, 2006), Jacobs (2007) recommended that provision of a warning service should be prioritised as follows:

Priority A: warning system urgently required

- surface water (pluvial) flooding.
- urban sewer capacity and surface water drain capacity exceedance.
- groundwater response to prolonged extreme rainfall, high in-bank river levels and rebound in major conurbations.

Priority B: warning system less urgent

- urban infrastructure blockage or failure.
- dambreak.
- tsunami.
- canal breach.

Priority C: warning not urgent but to be kept under review

- small and ‘lost’ watercourses and culverts.
- old watercourse routes.
- mud/debris flow.
- water supply infrastructure failure.
- land drainage system infrastructure failure.

This assessment was based on criteria which included the frequency of occurrence, potential impact, likely practicality of warning and opportunity to provide better warning information. Following this initial assessment, the technical feasibility of providing forecasts and, hence, a warning service for each of the Priority A and B sources is summarised in Table 1. Each source of flooding has been ranked on a capability scale against criteria including forecasting, lead time and dissemination. Current feasibility is expressed as currently feasible (I), feasible in the near future (II) or unlikely to be feasible for some time (III).

Table 1 shows that of the priority A and B sources, it is currently technically feasible to consider providing some form of warning service for pluvial flooding and the following three groundwater sources: extreme rainfall in Chalk catchments; high but in-bank river levels in Superficial aquifers; and rebound due to the cessation of industrial abstractions in major conurbations.

Providing a forecast and warning service for pluvial flooding is considered technically feasible, because:

- rainfall radar coverage is good, but could still be further improved through funding of existing plans;

- high resolution forecast models have been proven in development but are still to be implemented operationally;
- identification of areas ‘at risk’ is beginning; and
- apart from isolated initiatives, there is currently no widely-accepted example of operational ‘best practice’ to follow.

Table 1. Feasibility of a forecast and warning system for the priority A and B forms of flooding

Type of Flooding	Sub-category	Current Feasibility
Pluvial	Pluvial	I
Sewerage and Drainage System Derived	Urban Sewer Capacity Exceedance	II
	Urban Surface Water Drain Capacity Exceedance	II
	Urban Infrastructure Blockage or Failure	III
Groundwater	Response to Extreme rainfall	I
	Response to High In-bank River Levels	I
	Rebound in major conurbations	I
Catastrophic	Dambreak	II
	Tsunami	II
	Canal Breach	III

Providing a forecast and warning service for the three forms of groundwater flooding is discussed fully in the RF5 report, Jacobs (2007a) and in a recent paper which summarises this work Jacobs (2008a).

Context for Pluvial Flood Warning Service

Providing a warning service recognises that at some point a rainfall event will occur that will exceed any surface water management arrangements and provides an option to limit the resulting damage. The impacts of pluvial flooding may be most severe in urban areas where rainfall exceeds the capacity of the drainage system, such as in the June 2007 flooding in Hull. In the UK, Defra (2005) recognised the complexity of flood risk in urban areas and identified the need for an improved and integrated approach to managing the risk. Through the fifteen Integrated Urban Drainage pilot studies, new approaches to reducing the future impact of urban flooding (including pluvial) have been tested. These new approaches include modelling, surface water management plans and Sustainable Urban Drainage Systems. Therefore, while not strictly a management option, a warning service for pluvial flooding should be considered in the context of these, and other ongoing investigations.

Through initial demonstrations of technical feasibility, the RF5 project has proposed a potential forecast and warning system which could provide organisations preparing for and responding to pluvial flooding with more warning than is currently available. It was suggested that a form of service could comprise the following two main elements which are explored in more detail below:

- Extreme Rainfall Alerts providing targeted forecasts of severe storms; and
- The preparation of Pluvial Extreme Event Plans (PEEPs) such that actions prioritised in the PEEPs could be initiated on receipt of an alert to maximise effective use of the available lead time.

From a technical feasibility perspective it is suggested that, due to the limited lead time likely to be available, alerts of severe rainfall which may cause pluvial flooding are issued directly by the UK Met Office to all responding organisations. This should provide adequate lead time to make preparations, e.g. checking that culverts/screens at key locations are clear, ensuring adequate emergency staff are available and deployed at strategic locations etc.

Further information on techniques which are evolving to provide targeted Extreme Rainfall Alerts is provided in a recent paper, Jacobs (2008a) which summarises work undertaken for this element of the RF5 project. Pluvial flooding is often caused by short duration intense rainfall, although it can be caused by more prolonged 'moderate' rainfall (e.g. June 2007 flooding in Hull) sometimes with embedded high intensity rainfall cells. The high resolution 1.5km Nation Weather Prediction model will enable the UK Met Office to provide an early warning of 6 – 9 hours lead time, updated every 3 hours, based on an accurate forecast for scales of around 1000km² with update warnings at 1 – 2 hours lead time, updated every hour, based on an accurate forecast for scales of around 100km². Spectacular improvements in forecasting definition (intensity and location) are obtained with the 1.5km model when compared with the 12km and 4km models currently in use.

Pluvial Extreme Event Plans (PEEPs)

As well as examining the feasibility of processes whereby the UK Met Office could provide an Extreme Rainfall Alert service, the RF5 study also reviewed rapid GIS screening techniques to enable areas which might be susceptible to pluvial flooding to be identified. Such mapping could be used in conjunction with Extreme Rainfall Alerts to maximise the available lead time for emergency preparedness and response and help to target resources more effectively. The rapid screening forms a key element in the preparation of Pluvial Extreme Event Plans (PEEPs) which involve the four steps illustrated in Figure 1. The Contour Polygon Screening Technique trialed as part of the RF5 study provided consistently good results in clearly identifying potential pluvial hazard areas for subsequent inspection.

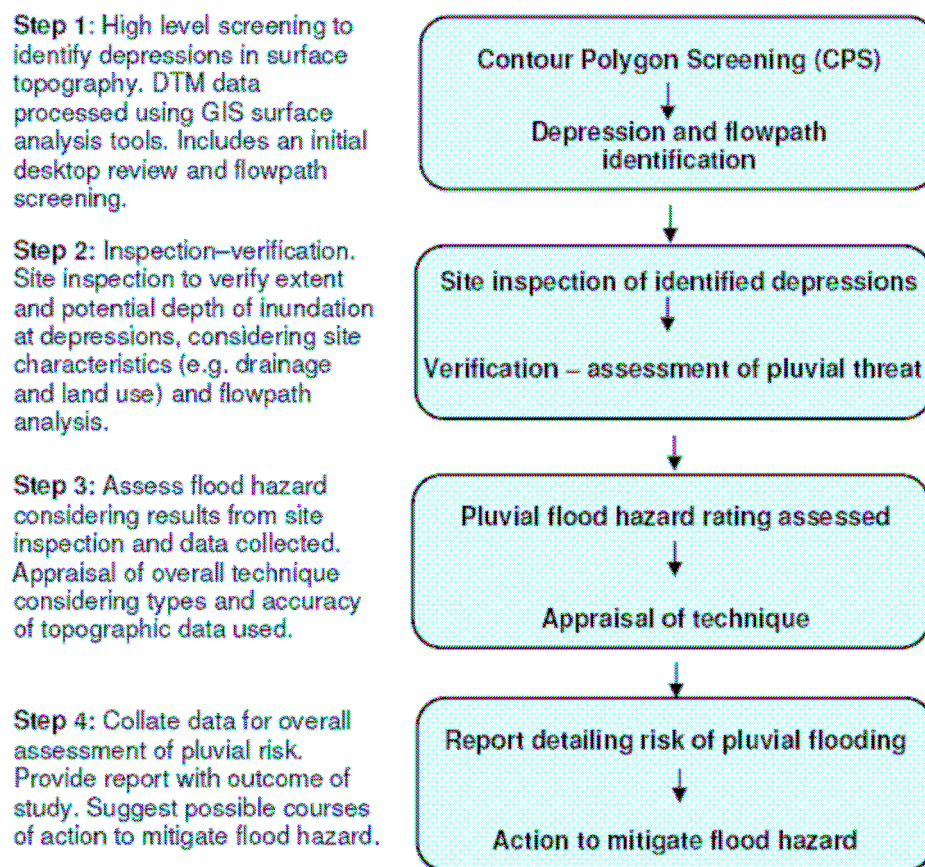


Figure 1. Flowchart illustrating four key tasks in preparing a Pluvial Extreme Event Plan assessment for an area.

It is envisaged that PEEPs would form part of a **tiered approach** to pluvial mapping whereby a *Refinement and Review* stage would enable subsequent more detailed assessment of hydraulics to be undertaken in areas where this is justified. Plans would be kept under continuous review to incorporate refinements, new techniques or observations from real events.

It is also anticipated that PEEPs maps of areas most susceptible to pluvial flooding could be developed and used in conjunction with similar existing maps and plans (e.g. Surface Water Management Plans), including those for other sources of flooding.

The feasibility of undertaking the first two elements in the PEEPs process was initially demonstrated during 2007 in four case study locations: Kingston-upon-Thames, Carlisle, Hull and Sheffield using both LIDAR and IfSAR (Interferometric Synthetic Aperture Radar) digital terrain datasets and a range of contour intervals from 1m down to 0.25m. IfSAR has a reported vertical accuracy of approximately +/- 1.0m and LIDAR approximately +/- 0.15m.

Following a review of available techniques to identify significant topographic depressions and significant flowpaths for surface runoff, two techniques were trialed in the four locations. The clearest identification of risk areas as verified by site inspection was obtained through the Contour Polygon Screening technique (CPS). Techniques to calculate the depths of depressions as an indicator of possible flood hazard as well as the presence of surface flowpaths were evaluated.

Considering only topography to identify areas susceptible to pluvial flooding ignores any role that subsurface (or surface) drainage may play in alleviating (or not) possible flooding. However, as demonstrated by the June 2007 flooding in Hull, drainage systems are almost always overwhelmed during pluvial flooding such that their consideration is of secondary importance. Thus, it could be assumed during pluvial flooding that the drainage systems have inadequate capacity, are blocked or otherwise fail (e.g. pumping stations) and, therefore, only warrant consideration (for any positive impact they may have) at the more detailed Inspection and Refinement and Review stages in the PEEPs methodology.

Table 2 summarises the RF5 study verification of the screening to identify depressions, where 100% indicates that, from the random selection of depressions identified on the maps, the site inspection confirmed that the depressions as indicated by the screening maps exist and are significant.

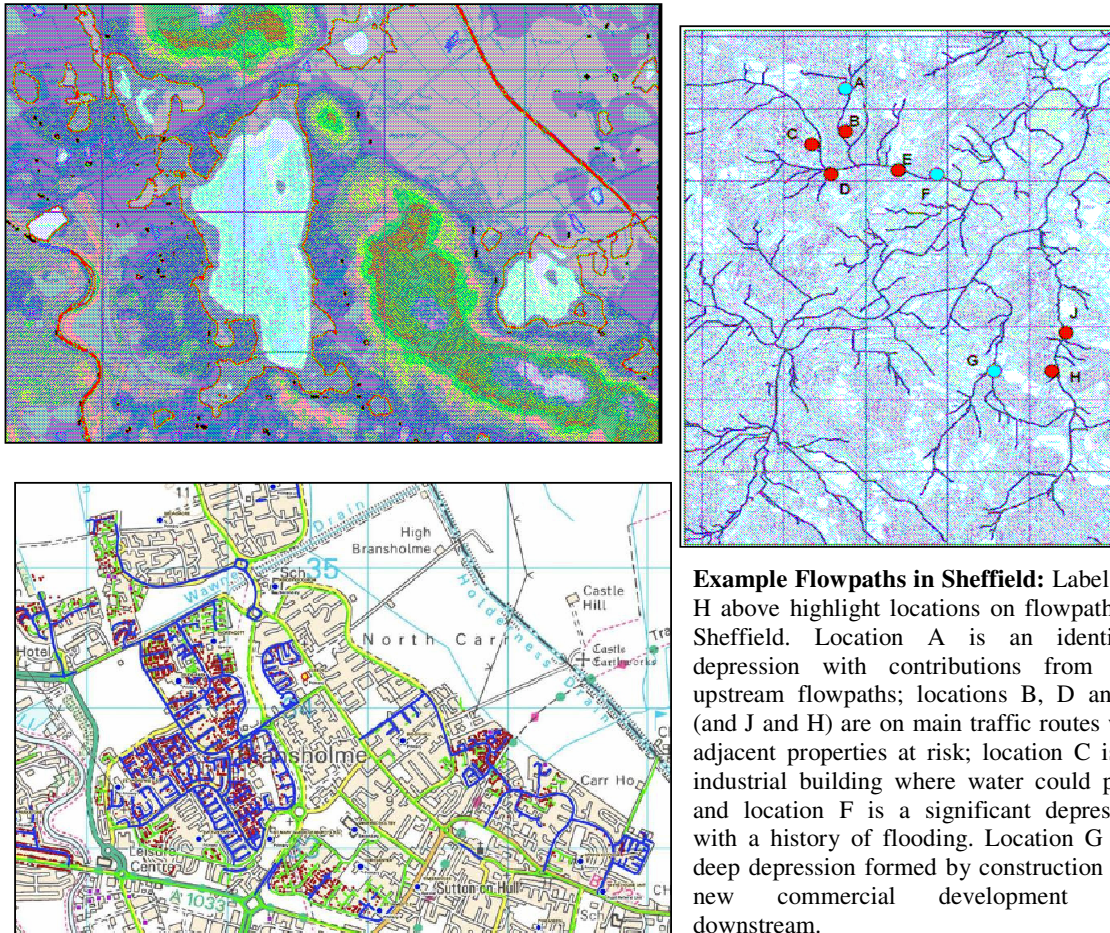
Table 2. Summary of rapid GIS screening and subsequent on-site inspection results for the four RF5 case study areas

Study Location	IfSAR data contoured at:		LiDAR data contoured at:		
	1m	0.5m	1m	0.5m	0.25m
Hogsmill/Kingston	46%	54%	92%	100%	-
Carlisle	75%	90%	100%	100%	-
Sheffield	-	75%	-	100%	-
Hull	-	82%	-	-	81%

These initial trials showed that, firstly, a combination of catchment-wide rapid screening using the CPS with IfSAR data, coupled with application of this technique with LiDAR data in urbanised town/city centres, could prove to be a cost effective approach for regional screening of areas most susceptible to pluvial flood risk. Depth screening enables filtering out of shallow depressions which will usually present a low hazard (Figure 2). Secondly, in areas with steeply sloping topography such as Sheffield, identifying depressions in conjunction with surface flowpaths is considered to be particularly useful in identifying areas susceptible to pluvial flooding (Figure 2). Thirdly, the PEEPs

approach involving follow-up site inspection of identified significant depressions and consideration of potential hazards and mitigation measures has been demonstrated as practical and feasible to undertake.

At Carlisle records were also available of pluvial flooding which had occurred in conjunction with the major fluvial flooding in January 2005. As was found at Hull, good correlation was obtained between pluvial mapping using the CPS technique and these observations.



Example Flowpaths in Sheffield: Labels A-H above highlight locations on flowpaths in Sheffield. Location A is an identified depression with contributions from two upstream flowpaths; locations B, D and E (and J and H) are on main traffic routes with adjacent properties at risk; location C is an industrial building where water could pond and location F is a significant depression with a history of flooding. Location G is a deep depression formed by construction of a new commercial development area downstream.

Figure 2: Example maps showing (top left) topographic depressions identified from IfSAR data in Hull and (bottom left) recorded occurrences of flooding in the same area of Hull (darker lines; taken from Coulthard et al., 2007), and (right) surface flowpaths identified from IfSAR data in Sheffield.

Pluvial Hazard and Risk Assessment Techniques

Pluvial flooding is usually associated with high intensity rainfall events (typically $>30\text{mm/h}$) but can also occur with lower intensity rainfall or melting snow where the ground is saturated, frozen, developed or otherwise has low permeability. High intensity rainfall cells can also occur within much longer duration rainfall events. Thus it is quite possible for pluvial flooding to occur in combination with fluvial flooding. Pluvial flooding can also occur in conjunction with flooding from surcharged sewerage and drainage systems and indeed such flooding can contribute to surface flooding and ponding and also contaminate surface floodwater with foul sewage.

Pluvial flooding results in overland flow, which can be of high velocity where flowpaths are steep, and ponding in depressions in the topography which can be up to several metres deep. Although pluvial flooding can be of relatively short duration, high velocities or deep ponding can pose a risk to life. Pluvial flooding can affect areas which have not been mapped as being at risk of flooding (primarily

fluvial flood risk areas) and hence those impacted may be completely unprepared and unaware of a potential flood risk.

During pluvial flooding, urban underground sewerage/drainage systems and surface watercourses may be completely overwhelmed. Nevertheless the rate at which ponding and surface water dissipates will usually depend on the capacity of local watercourses and subsurface drainage and sewerage systems to drain down areas affected.

The interaction between pluvial, fluvial and sewer flooding is complex. Nevertheless, for a high level review, simplifying assumptions can be made which enable a preliminary assessment of pluvial flood hazard to be undertaken which can then be used to target more detailed assessment where appropriate.

The GIS-based PEEPs approach assumes that areas impacted by pluvial flooding are either depressions in the topography where surface water ponds or surface water flowpaths. The depth of ponding, which can vary from <0.5m up to several metres, together with the location of flowpaths, provides a broad indication of hazard.

The hazard associated with the flowpath alone can be associated with the velocity, where gradients are moderate to steep, or simply the volume of flow. A flowpath which intersects a depression is assumed to increase the level of hazard associated with the depression. A situation which can arise in heavily urbanised areas is where a flowpath flows adjacent to or in to an entrance to an underground car park, a goods entrance to a commercial premises or an underground station. The CPS technique with LIDAR data can often identify such entrances where there is a clear, albeit small, depression. Even if there is no depression, an adjacent flowpath could still result in flooding of an underground installation. Such situations may be identified during the site inspection of significant depressions and flowpaths (the second stage in the PEEPs approach).

For a preliminary high level review, the identification of areas of 'High' pluvial hazard can initially be based on the assumption that average depression depth gives an initial broad indication of the likely severity of pluvial flood hazard. Depths of the depression scan be categorised into four depth ranges:

- (i) 0.2m - 0.5m indicating **low** pluvial hazard
- (ii) 0.5m - 1.0m indicating **moderate** pluvial hazard
- (iii) 1.0m - 2.0m indicating **high** pluvial hazard
- (iv) >2.0 m indicating **severe** pluvial hazard

Depths less than 0.2m would not normally be considered significant in terms of pluvial flood hazard.

However the following aspects are also relevant:

- Presence of a **flowpath** that transects the depression that may drain an upstream catchment area.
- **Land-use and sensitivity** of the area to flooding: whether there is significant infrastructure, or other buildings that would be particularly vulnerable to pluvial flooding in the vicinity.
- **Drainage** outlet: how the depression would drain in the event of a significant rainfall event. Is there potential for blockage of this outlet that could exacerbate the pluvial flooding.

These elements can be assessed during the site inspection phase (Step 2) and from subsequent more detailed review of mapping and other available information (Step 3).

For an initial high level overview of a particular district, a preliminary assessment of overall pluvial hazard can be based on the total volume of depressions for all depth ranges divided by the total unit area of the district being evaluated. This is defined as the 'Hazard Index' (HI). This can be assessed for both urban and rural areas. A high Hazard Index is considered to be of lesser significance in terms of potential damage to infrastructure within predominantly rural areas although it may still be significant in terms of impact on environmentally sensitive areas. For example, in an urban area a district might be regarded as having a 'High' hazard rating in relative terms, if the HI is >0.25; 'Moderate' if the HI is 0.1-0.25 and 'Low' if the HI is <0.1.

For more detailed evaluation of pluvial hazard which takes into account possible impact and hence might be considered as an initial assessment of pluvial flood *risk*, a matrix-based technique can be

applied which firstly takes into account the presence or otherwise of a flowpath in determining a 'severity of flooding' rating and then sensitivity of the land use assessed as:

- **Low** : parkland, farmland etc
- **Medium** : commercial, industrial etc
- **High** : residential, significant infrastructure, emergency services, power sub-stations, underground transportation, water supply, hospitals etc

A hazard rating for flowpaths can also be assessed taking into account the steepness of the flowpath and the upstream contributing area..

Pluvial Mapping in East Belfast

On the 12th June 2007, large parts of Northern Ireland experienced severe storms, of high rainfall intensity, but relatively short duration. As well as in Belfast, intense rainfall caused flooding in Newtownards, Comber, Omagh and Magherafelt. However, the worst of the flooding occurred in East Belfast where the Met Office instrumentation (radar plus gauges) recorded 48.3mm of rain falling between 12:30hrs and 13:30hrs. This rainfall was estimated to have around a 0.3% to 0.2% annual chance of occurrence.



This resulted in both fluvial flash flooding and pluvial flooding which caused major disruption throughout Belfast with over 400 properties affected by flooding (Jacobs 2008)

Many of the areas in East Belfast known to have flooded on the 12th June were outside the designated fluvial flood outline. Application of the PEEPs process independently over the catchment correlated well against the actual areas flooded on 12th June outside the fluvial flood outline - confirming the pluvial flood risk. Figure 3 compares the 12th June flood outline with the PEEPs derived areas susceptible to pluvial flooding.

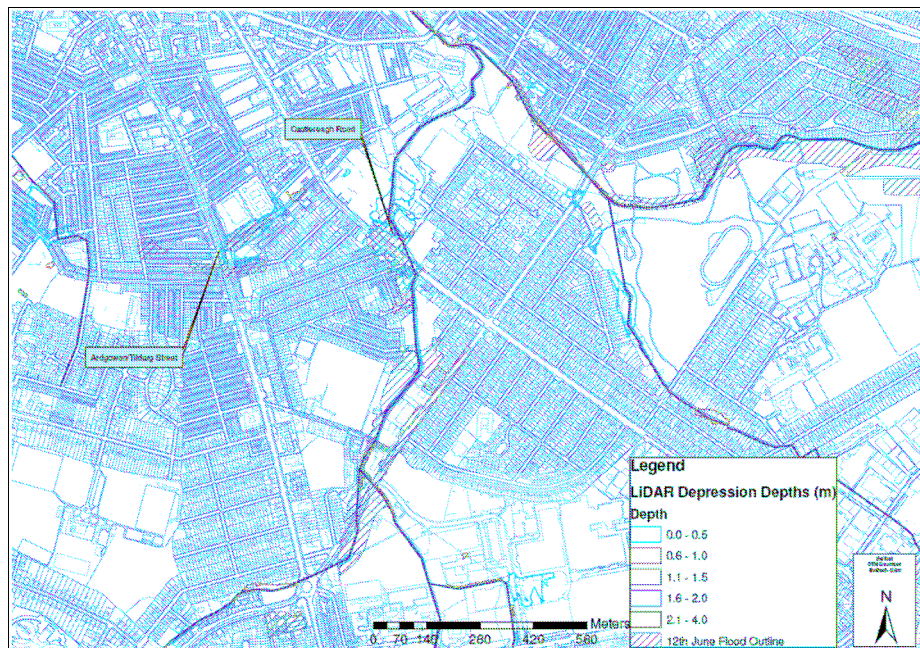


Figure 3: PEEPs flood outline compared with 12th June actual flood outline.

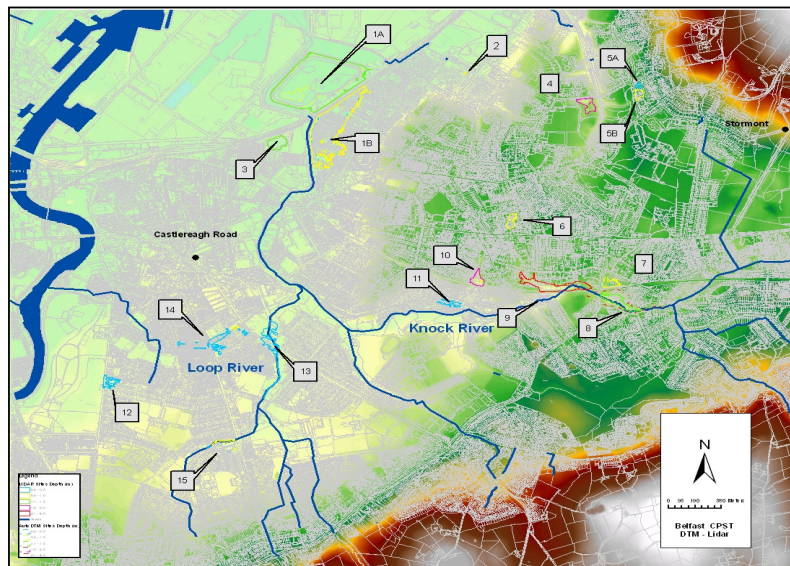


Figure 4: Pluvial flood risk areas in East Belfast inspected as part of the PEEPs process.

Similar to the results summarised in Table 2, a site inspection of 17 locations identified as depressions from the LiDAR data of East Belfast (Figure 4), confirmed that all 17 existed posed a moderate to severe hazard. In addition, in 89% of locations, the depth of the depression was correctly calculated by the GIS analysis. Furthermore, there was close correlation between locations identified using the CPS technique and areas which flooded from surface water on 12 June 2007. An analysis of identified flowpaths highlighted a number which passed through or in close proximity to identified depressions which could exacerbate the risk in these locations.

Site inspection confirmed the severity of the level of hazard and enabled a preliminary assessment to be made of possible solutions. Some depressions were found to have a combined fluvial and pluvial hazard i.e. a watercourse may be present with an associated fluvial hazard but the drainage outlet (often a culvert) was such that a localised high intensity rainfall even could potentially increase the hazard beyond that associated with the watercourse alone. In a number of cases it was found that man-made features had created the depression and pluvial hazard – Figure 5 illustrates one example where a disused railway embankment and blocked or partially blocked culverts had created the pluvial hazard. Clearance/improvement of the culverts would alleviate the risk.

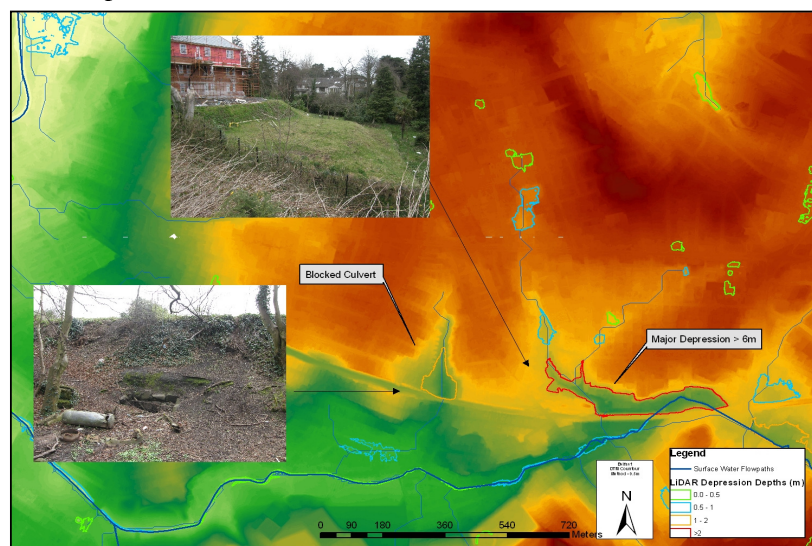


Figure 5: Example of major depressions in East Belfast associated with disused railway embankment.

Conclusions

The PEEPs process coupled with the CPS rapid screening technique has been demonstrated to be an effective high level approach which can provide a preliminary indication of the level of pluvial flood hazard over a wide area. As such, this can help to inform Preliminary Flood Risk Assessments under the Floods Directive and the development of a resource efficient strategy for subsequent mapping.

It is recognised that computing power is rapidly evolving such that it will become feasible in the near future to run more sophisticated modeling techniques to identify areas at risk of pluvial flooding within run times that are sufficiently fast to be of practical use. These techniques which represent the routing of rainfall across the topography, and so can be termed 'wet' techniques, may provide improved definition of flow direction, velocity and depth within susceptible areas. Demonstration here of technical feasibility of the use of simpler 'high level' approaches considering only topography (so-called 'dry' techniques) could be viewed as setting a baseline from which results could be progressively refined.

High level 'dry' screening enables a risk based **tiered approach** to be adopted such that resources can be effectively targeted on areas that merit subsequent more detailed assessment possibly using surface flow modeling or integrated urban flood modeling. It also provides a preliminary overview of potential pluvial hazard and has the advantage of gaining an early understanding of locally significant issues through the site inspections which provide valuable verification of the mapping. Other factors, including land use and potential flood impacts, can then be taken into account to make an initial assessment of potential pluvial flood risk.

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References

- Coulthard, T., Frostick, L., Hardcastle, H., Jones, K., Rogers, D. and Scott, M. 2007 The June 2007 floods in Hull. *Interim Report by the Independent Review Body*. August 2007.
- Jacobs 2007a, Feasibility Study into Expanding Flood Warning to Cover Other Flood Risks (reference RF5) Technical Feasibility Report. November 2007.
- Jacobs 2007b Groundwater Flooding Records Collation, Monitoring and Risk Assessment (reference HA5) Consolidated Report. December 2007.
- Jacobs 2008a Potential Warning Services for Groundwater and Pluvial Flooding, July 2008.
- Jacobs 2008b East Belfast Pluvial Extreme Event Planning. May 2008.
- JBA 2006 Flooding from Other Sources (reference HA4a). Final Report, October 2006.
- Pitt (2007) Learning lessons from the 2007 floods: an independent review by Sir Michael Pitt. Interim Report. Cabinet Office. December 2007.
- Pitt (2008) Learning lessons from the 2007 floods. Cabinet Office. June 2008.